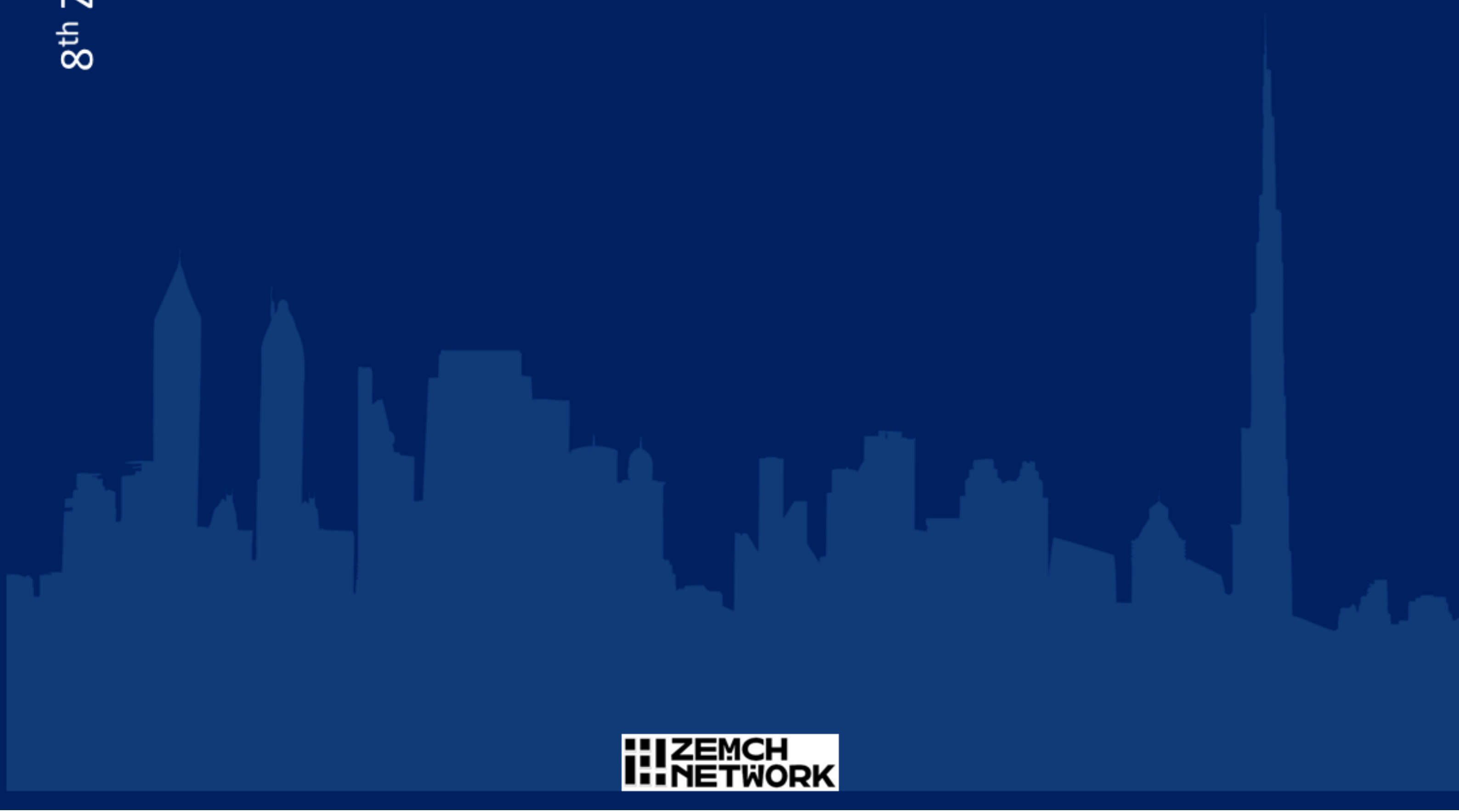
ZEMCH 2021 International Conference Proceedings

Dubai, United Arab Emirates
26 – 28 October 2021

8th Zero Energy Mass Custom Home International Conference



ZEMCH NETWORK

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Forewords

On behalf of the local organizing committee and the United Arab Emirates University, the host institution, it is indeed an honor and privilege to share with you the full proceedings of the "ZEMCH 2021" International Conference, held in Dubai, UAE from October 26th to 28th, 2021.

ZEMCH stands for "Zero Energy Mass Custom Home", a commitment to the development of a socially, economically, environmentally and humanly sustainable built environment. ZEMCH pursues its objectives through international industry-academia collaborative study tours, international conferences and workshops supported by a solid network of over 900 global partners from academia, industry and government, based in over 45 countries. Since 2012, ZEMCH has organized international conferences and events across the globe. Past conferences have taken place in Europe, the United States, South America, Asia and Australia. This was the first time that the ZEMCH conference was held in the Middle East, a region of fast growth and urbanization under an extreme climate, making this an urgent and intriguing journey towards a sustainable built environment and global climate resilience.

This exceptional networking conference with renowned expert speakers, academicians, researchers, industry representatives, policymakers and general stakeholders, was designed to foster discussions on a diverse range of topics. These included topics related to social, environmental and economic sustainability, mass customization and personalization, as well as renewable energy and technology. Other topics of equal relevance were housing and prefabrication, building performance evaluation and simulation, user behavior and human-centered design and, green economy and policies.

The one hundred papers presented at the ZEMCH 2021 International Conference span over a wide spectrum of topics evolving around the design, production, operation and marketing approaches to the ZEMCH delivery and operation, with showcases of some exemplary attempts in different climates around the globe. We believe ZEMCH 2021 was an inspiration to both in-person and online delegates and attendees from a wide array of interests to initiate collaborations within and across disciplines in the pursuit of a truly sustainable and healthy society.

All papers included in this proceeding have been peer-reviewed. The editors and the local organizing committee extend their heartfelt thanks to all authors, reviewers and the scientific committee for their effort and commitment in the difficult health situation engendered by the global pandemics.

We cordially invite you to collaborate with the ZEMCH Network, and actively contribute in shaping the future of our built environment.

Sincerely yours,

Kheira Anissa Tabet Aoul
Conference Chair
(on behalf of the local organizing committee)
ZEMCH 2021 International Conference

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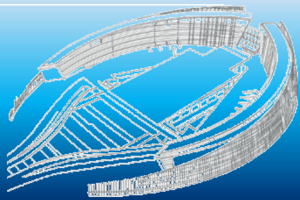
Session 1:

Energy Efficiency in Buildings



A Comparative Study of the Energy Flexibility Activation Strategies for Zones with Hydronic Radiant Systems

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Abstract: Radiant floor heating (RFH) systems offer significant potential for studying and developing energy flexibility strategies for buildings and their interaction with smart grids. Efficient design and operation of RFHs require several critical decisions on design and control variables to maintain comfortable thermal conditions in the space and floor surface temperatures within the recommended range. This paper presents comparison of different control strategies to activate energy flexibility for zones with RFH systems. The focus of this paper is on the zones with radiant floor heating systems for which the hydronic pipes are located deep in the concrete and therefore, there is a significant thermal lag. A perimeter zone test-room equipped with a hydronic radiant floor system in an environmental chamber is used as a case study. Considering a typical cloudy and cold winter day, three different control strategies were studied based on controlling the zone air temperature, floor surface temperature and the operative temperature. Then considering higher than usual price signals from the grid, the energy flexibility is quantified and compared with each other for all the different control strategies. The advantages of each control strategy are discussed.

Keywords: Energy Flexibility, Radiant Floor Heating, Low-Order Models

1. Introduction

The increasing global energy demand, the foreseen reduction of available fossil fuels and the increasing evidence of global warming during the last decades have generated a high interest in renewable energy sources and integration of renewable energy sources into the power grid is increasing rapidly worldwide. However, renewable energy sources, such as wind and solar power, have an intrinsic variability that can seriously affect the stability of the energy system if they account for a high percentage of the total generation. The flexibility of building energy demand profiles is commonly suggested as part of the solution to alleviate some of the upcoming challenges in the future demand-response energy systems [1]. Knowledge of energy flexibility that buildings can provide is important for the design of future smart energy systems, smart grids and buildings. The knowledge is however, not only important for utilities but also for companies when developing business cases for products and services supporting the roll out of smart energy networks. Furthermore, it is important for policy makers and government entities involved in the shaping of future energy systems.

Radiant floor heating (RFH) systems are receiving considerable attention due to the multiple advantages they offer such as improved thermal comfort in buildings. Zones with radiant floor system that has significant thermal mass provide a great opportunity for energy flexibility and load/power shifting. Hydronic radiant heating can utilize low temperature renewable energy heat sources and provide significant flexibility to smart grids by storing energy and shifting heating demand. The operation of these systems can be optimized by applying predictive control and further the energy costs can be reduced by optimizing their interaction with smart grids by utilizing the flexibility in their demand profiles.

Energy flexibility can be defined as "the ability to deviate from the reference electric load profile or baseline power consumption, or the business-as-usual scenario" [2]. Flexibility could be expressed as energy kWh (or power kW), the energy/power that can be shifted, increased or decreased in reaction to an external signal (price signal for example) without scarifying the indoor comfort over a certain time span. This article is focused on zones with hydronic floor heating systems to evaluate and compare the potential energy flexibility considering three different control strategies in the zone.

2. Building Energy Flexibility Index

A quantitative assessment of the energy flexibility provided by structural thermal energy storage is essential to large scale deployment of thermal mass as in an active demand response (ADR) context. The available storage capacity expresses the amount of energy that can be added to the structure's thermal energy storage (STES) during a specific ADR event. Thus, the heat that can be stored within a dwelling not only depends upon the thermal properties of the building fabric, but also on the properties and actual use of the heating and ventilation systems [3]. Four performance indicators or characteristics for ADR are defined and quantification methods for the ADR potential of structural thermal storage are presented by Reynders et al. [4] that are mainly focused on the energy that is reduced/increased over a certain period. The indicators are briefly described here: available structural energy storage capacity (C_{ADR}) is defined as the amount of heat that can be added to the structural mass of a building for an active demand response (ADR) event without jeopardizing indoor thermal comfort in a specific time-frame (that is heating above the upper threshold comfort temperature) which can be quantified as:

$$C_{ADR} = \int_{0}^{l_{ADR}} (Q_{ADR} - Q_{Ref})\,dt \tag{1}$$

C_{ADR} is quantified by the integral of the difference between the heating power during this ADR event (Q_{ADR}|W|) and the heating power in normal reference operation (Q_{Ref}|W|), represented by the gray area in Figure 1.

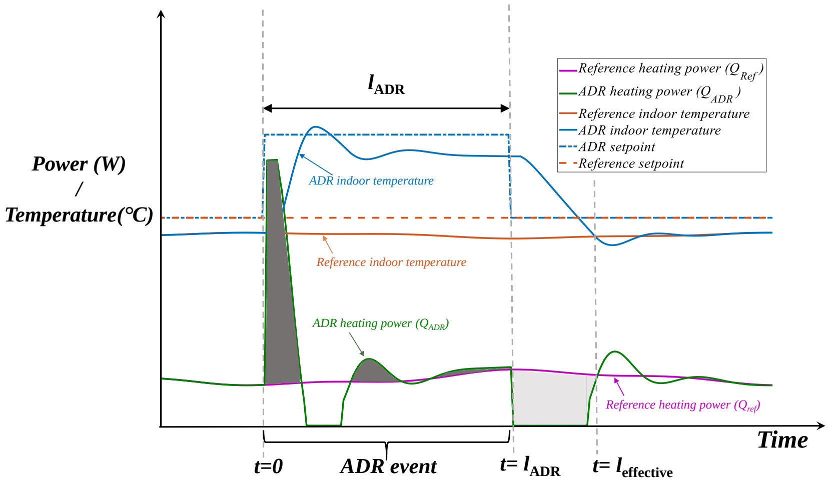

Figure 1. Conceptual representation of the measures used to quantify the available storage capacity and the storage efficiency [5]

The parameter C_{ADR} that is used in this article calculates the building energy flexibility during a desired period which is the ADR event. The other three parameters include: storage efficiency(η_{ADR}), stage of charge (*SOC*) and power shifting capacity (Q_{σ}) for which the descriptions can be found at [4].

3. Modelling approach

The modeling approach used for this study is based on the low-order lumped-parameter thermal network models which have been shown to be practical for control studies and especially model predictive control [6,7]. In this approach the thermal mass under consideration (radiant floor concrete slab) is discretized into a number of control volumes. Each of the discretized control volumes is represented by a node and considered to be isothermal. Each of the nodes, has a lumped thermal capacitance connected to it and thermal conductances connecting it to adjacent nodes. Considering the time interval p and time step Δt, the general form of the explicit finite-difference model for the nodes with a lumped thermal capacitance can be stated as:

$$T_{\mathrm{i,p+1}} = T_{\mathrm{i,p}} + \frac{\Delta t}{C_{\mathrm{i}}}\left(Q_{\mathrm{i}} + \sum_{\mathrm{j}} \frac{T_{\mathrm{j,p}} - T_{\mathrm{i,p}}}{R_{\mathrm{i,j}}}\right) \quad (2)$$

where $T_{i,p}$ represents the temperature of node "i" at time step "p", $T_{j,p}$ represents temperature of node "j" at time step "p", C_i is the thermal capacitance of node "i", $R_{i,j}$ is the thermal resistance between nodes i and j and Q_i is the heat source at node i.

A model with fewer parameters facilitates setting up the initial conditions which is a key parameter for control studies [6]. When the details of the construction are not known, a low order grey box modelling approach is practical and can be developed and calibrated by means of real time data from the building. The models must be accurate enough to provide reliable information but also flexible enough for quick and computationally efficient decision-making [8,9], especially in reaction to electric grid's short notices on the change of the price signals.

An important part of a model for zones with radiant floor heating system is the radiative and convective heat transfer which are inherently nonlinear processes. However, the respective heat transfer coefficients are usually linearized so that the system energy balance equations can be solved with linear algebra techniques and represented with a linear thermal network. In the case of radiant floor heating, this linearization generally introduces less error for the for long-wave radiation heat transfer (h_r) than the convection heat exchange between the radiant floor surface and room air (h_{cf}) [10]. For example, in the case of radiant floor heating where usually the floor is hotter than the air and the heat flow is upward h_{cf} is in the order of 3 W/(m^{2}K) while for a cold floor and warmer air it is in the order of 1 W/(m^{2}K). Therefore, usually certain amount of calibration for the convection heat exchange between the radiant floor and room air is required for a model especially when considering the low order models.

A well calibrated low-order model can accurately capture the most important thermal dynamics of a zone with a radiant floor heating system. This modeling technique was validated through experiments in a test facility called solar simulator/environmental chamber. The details of the experiments performed, and the model validation can be found at [11].

The validated low-order modelling approach is used in the following section for a similar office in a multi-story building to study different control strategies based on floor surface temperature, zone air temperature and operative temperature. The quantified energy flexibility for each case is compared to each other. The office room considered has an external façade with 50% WWR and double-glazed low-e windows. The exterior walls have the R-value of RSI 4.5. Figure 2 thermal network model of the room.

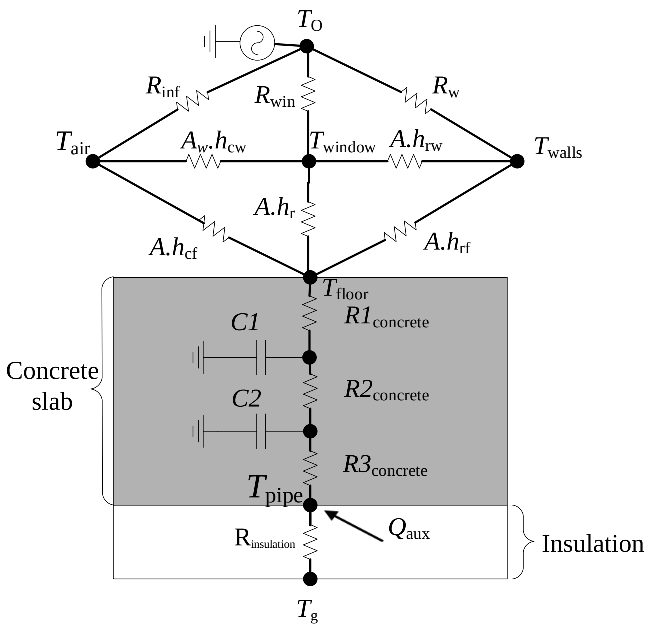

Figure 2. Thermal network model of the room

4. Modeling results

This section presents the simulation results of controlling different temperatures in the zone and their respective energy flexibility. The outdoor condition is considered as a typical cloudy cold winter day in Montreal as shown in Figure 3:

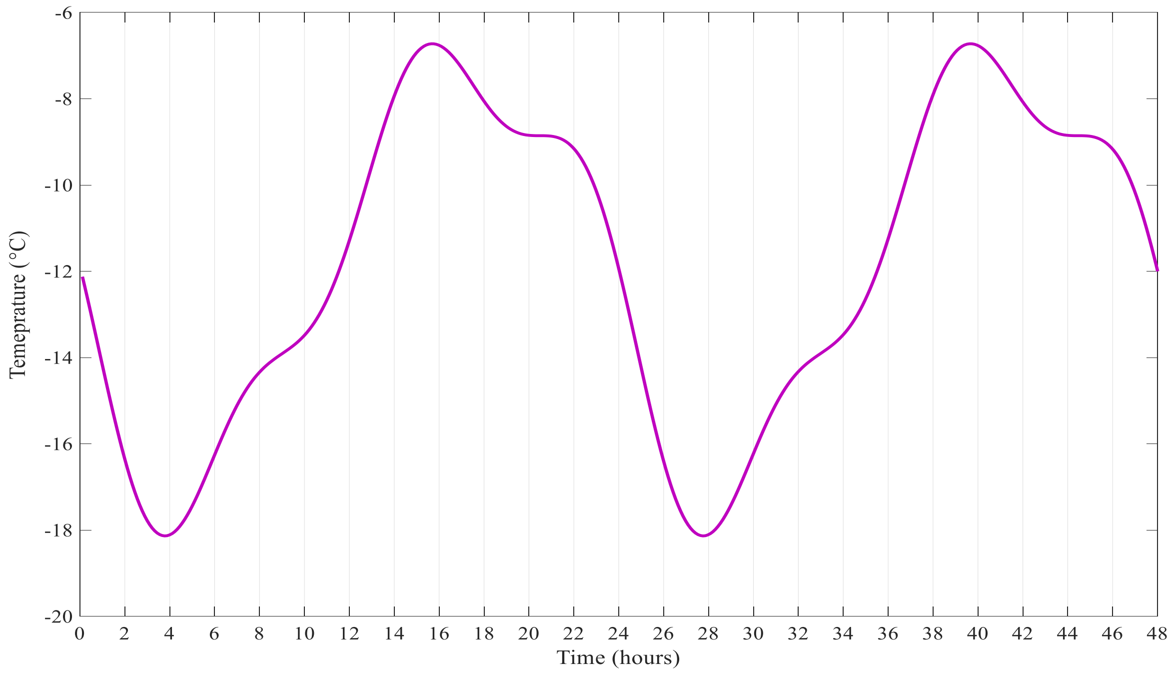

Figure 3. Outdoor temperature profile

Figure 4 shows the result for the floor surface temperature control (proportional) for the reference setpoint of 26°C. it can be observed how the heating load changes during this 48-hour period.

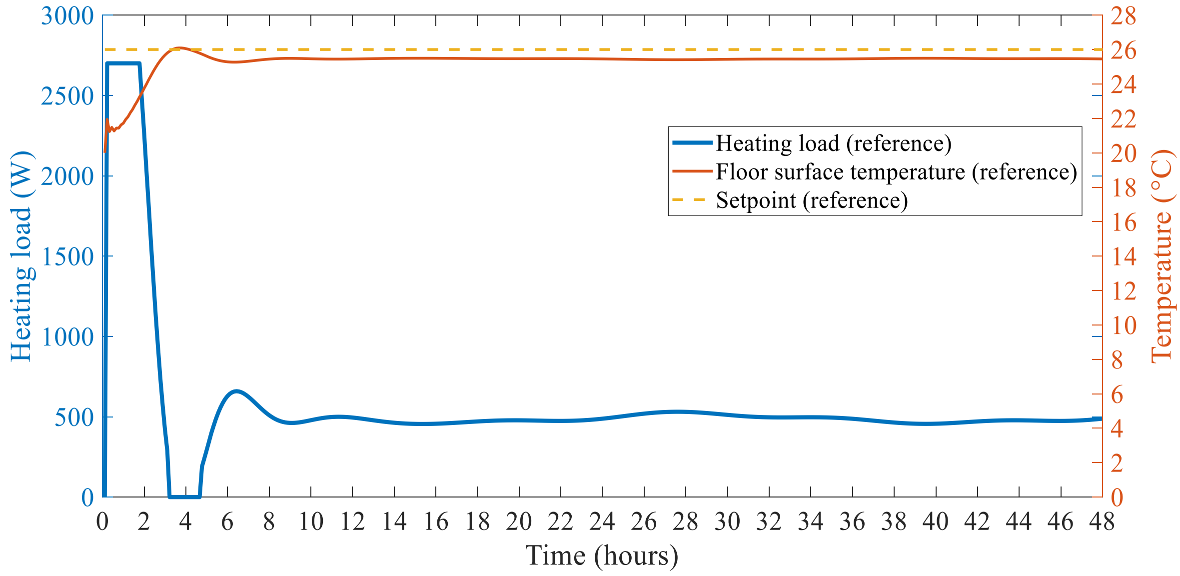

Figure 4. Reference case for floor surface temperature control

Now let's assume that a higher than usual price signal from the grid is observed on the first day during the evening peak demand period which is around 4 to 8 pm. If we lower the surface temperature setpoint by 2°C (from 26°C to 24°C) during that period, the following change in the heating load is observed:

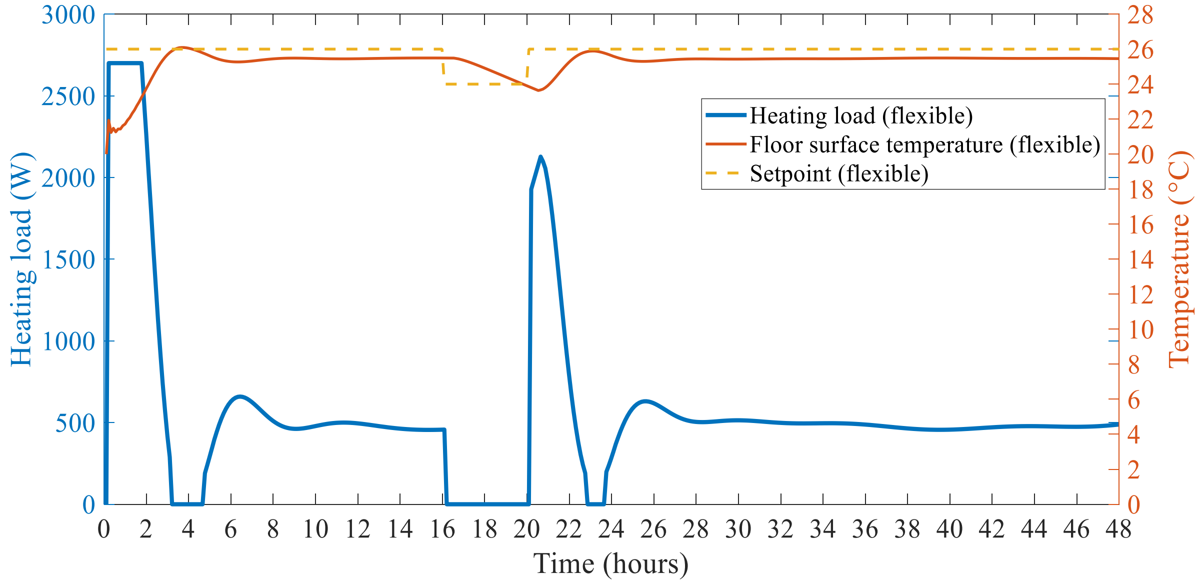

Figure 5. Downward flexible case for floor surface temperature control

For this 4-hours period, the downward flexibility, $C_{ADR,D}$ is calculated from equation (1) and is equal to 198 Wh/m². Also with this control strategy, the zone air and operative temperatures stay within the comfort range as observed in Figure 6.

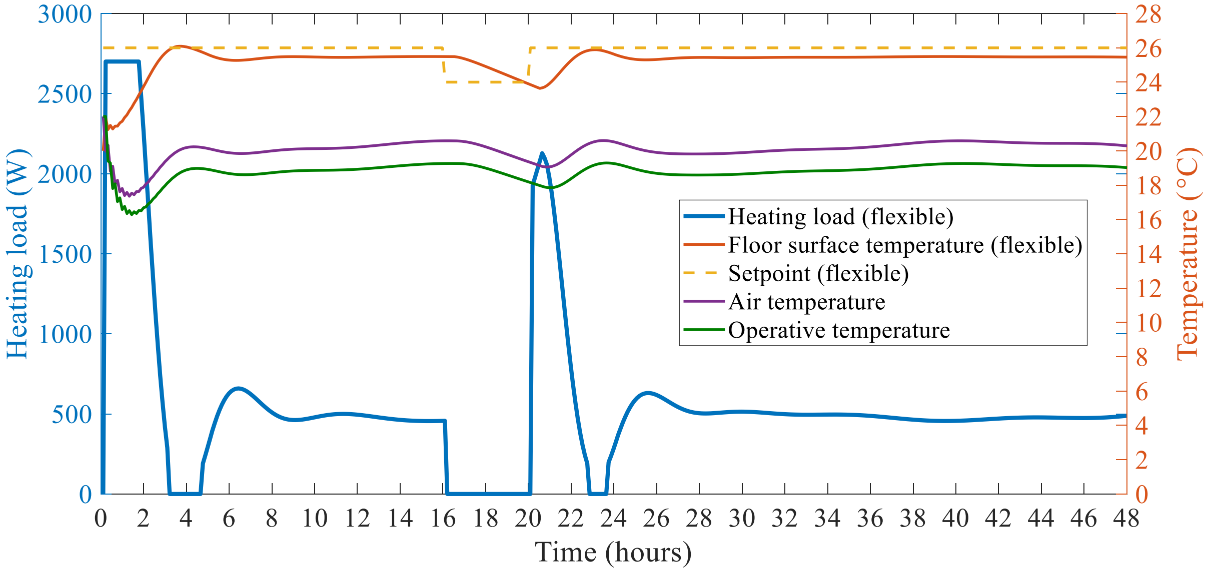

Figure 6. Zone air and operative temperatures profiles with surface temperature control strategy

Now for the upward flexibility, if we preheat the slab by increasing the setpoint to 28°C at night for 3 hours just before the morning peak demand period which is between 6 to 9am (hours 30-33 in the graph), then the heating load and energy consumption will be zero during the peak demand period as observed in Figure. The upward flexibility for this 3-hours period is calculated as $C_{ADR,U}$=222 Wh/m².

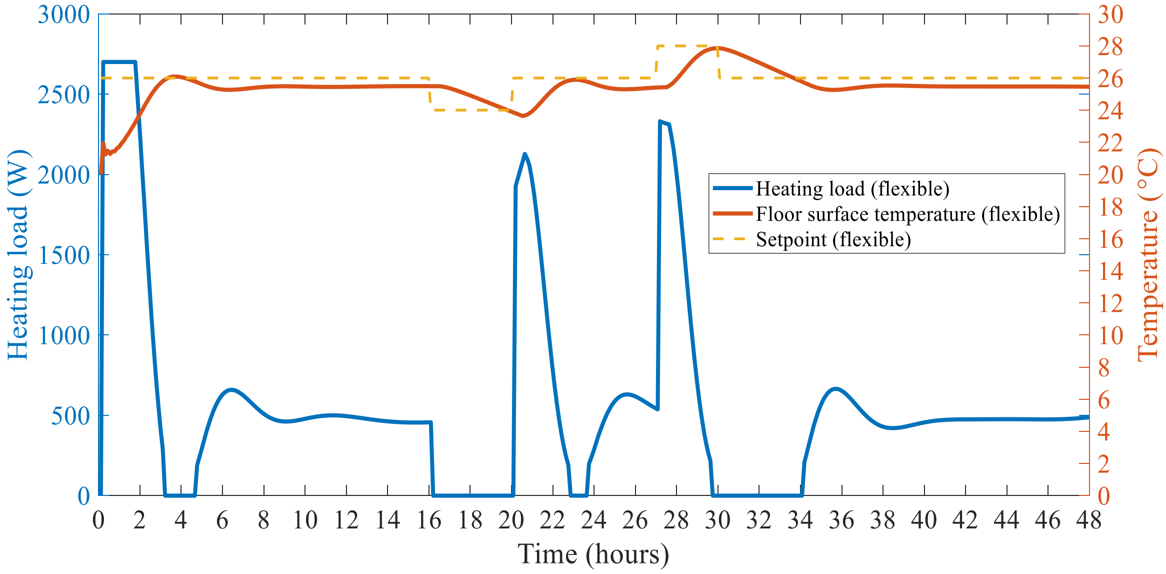

Figure 7. Upward flexible case for floor surface temperature control

Now, if we consider the same control for the zone air temperature with the reference setpoint of 22°C, the heating load profile for the reference case is shown in Figure 8:

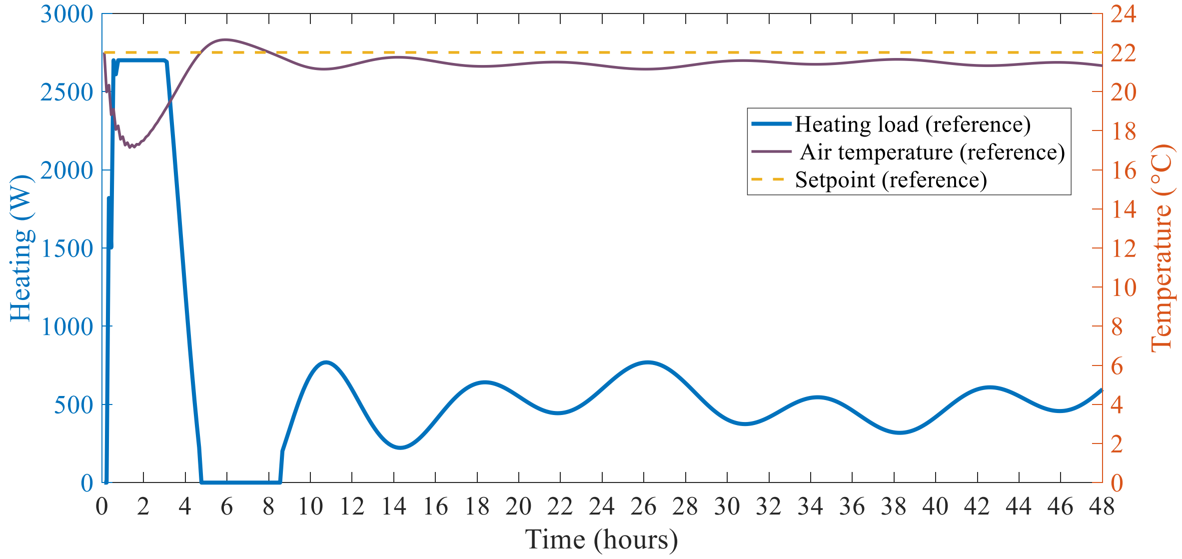

Figure 8. Refence case for air temperature control

And if the air temperature setpoint is decreased 2°C (to 20°C) during the high price period, then the heating load is observed in Figure 9.

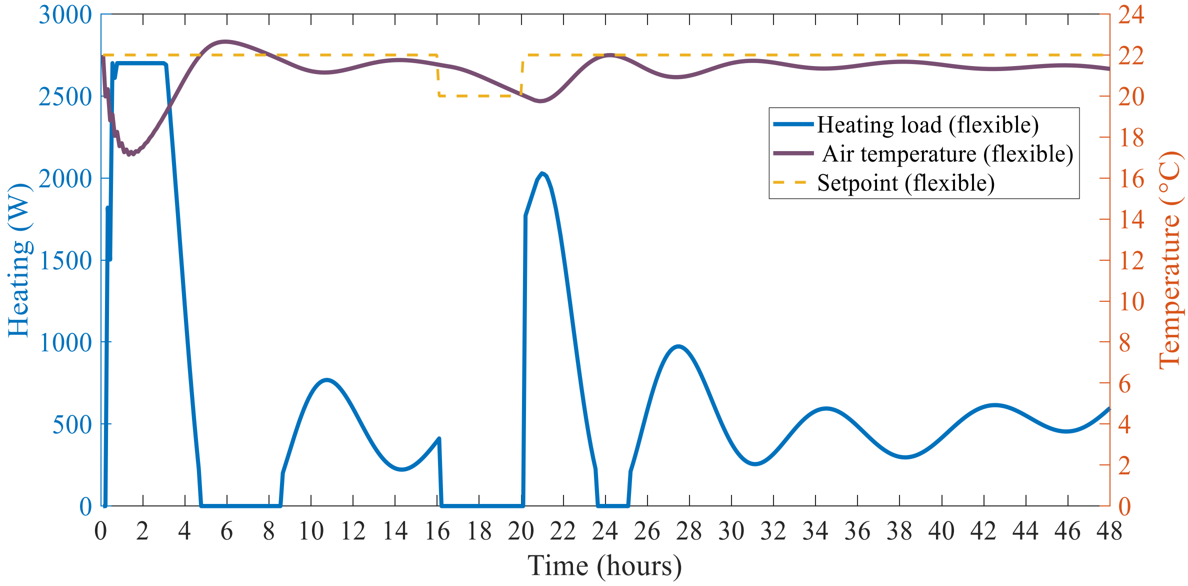

Figure 9. Downward flexible case for air temperature control

In this case, $C_{ADR,D}$ for the 4-hour period is equal to 247 Wh/m². Now considering the preheating before the morning peak period (6-9am), the heating profile is shown in Figure 10. The upward flexibility is calculated as $C_{ADR,U}$=313 Wh/m².

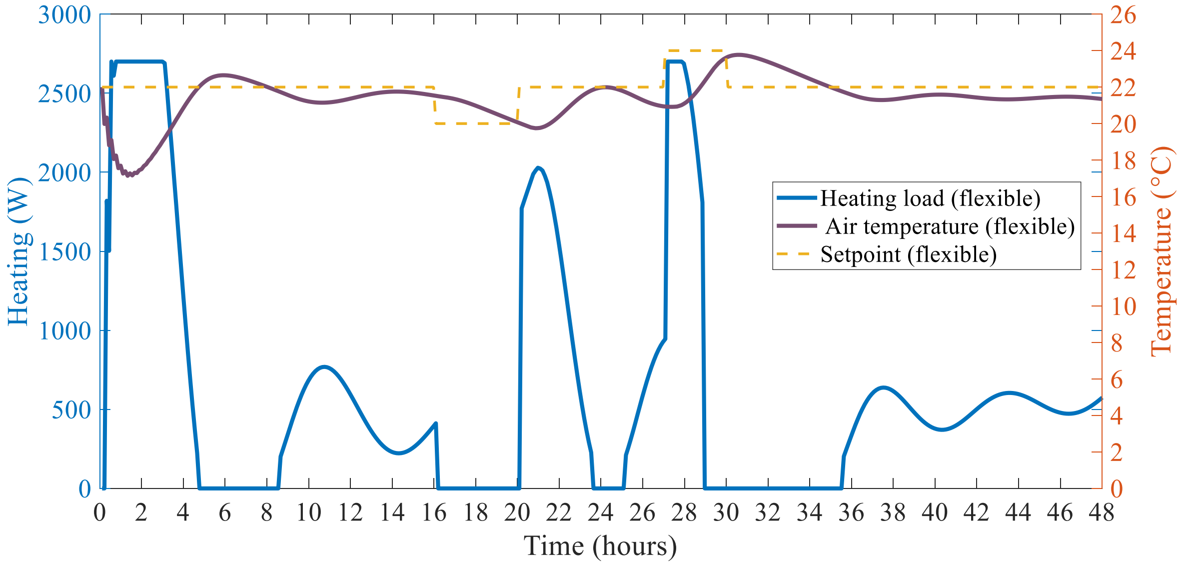

Figure 10. Upward flexible case for air temperature control

It is observed that this control strategy based on zone air temperature, also results in longer hours of zero heating load after the upward flexibility event compared to the floor surface temperature control.

The operative temperature of a zone is defined as [12]:

$$T_{op} = \frac{T_{air} + T_{mr}}{2} \tag{3}$$

where T_{mr} is the mean radiant temperature and T_{air} is the zone air temperature.

Now for the operative temperature control, Figure 11 shows the heating load profile for the reference setpoint of 22°C.

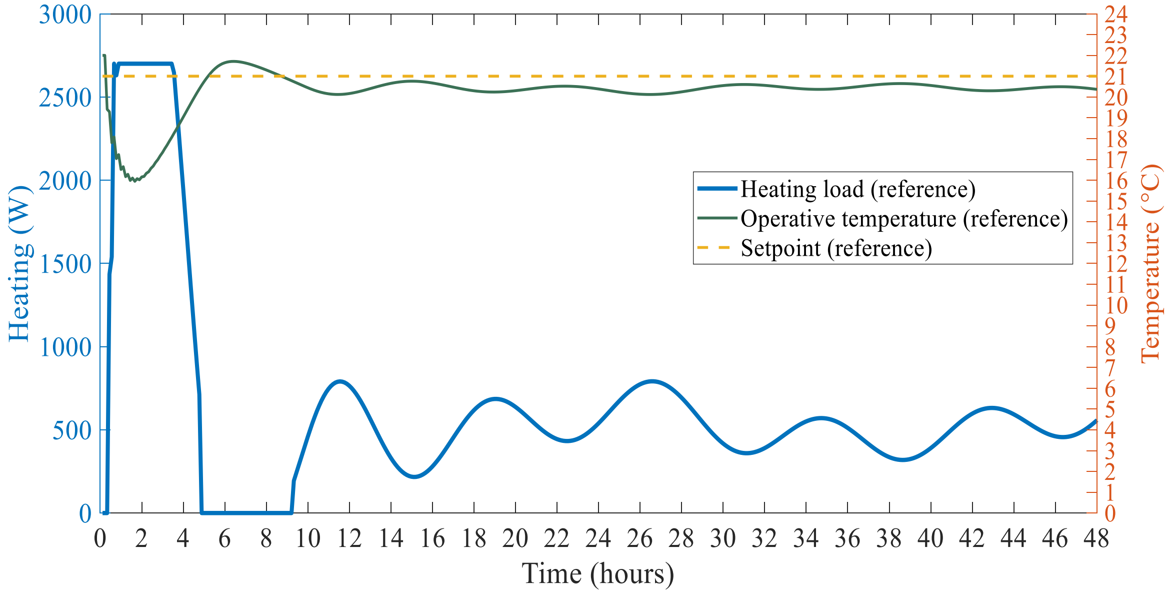

Figure 11. Reference case for the operative temperature control

And for the upward and downward flexible case, the heating load is shown in Figure 12.

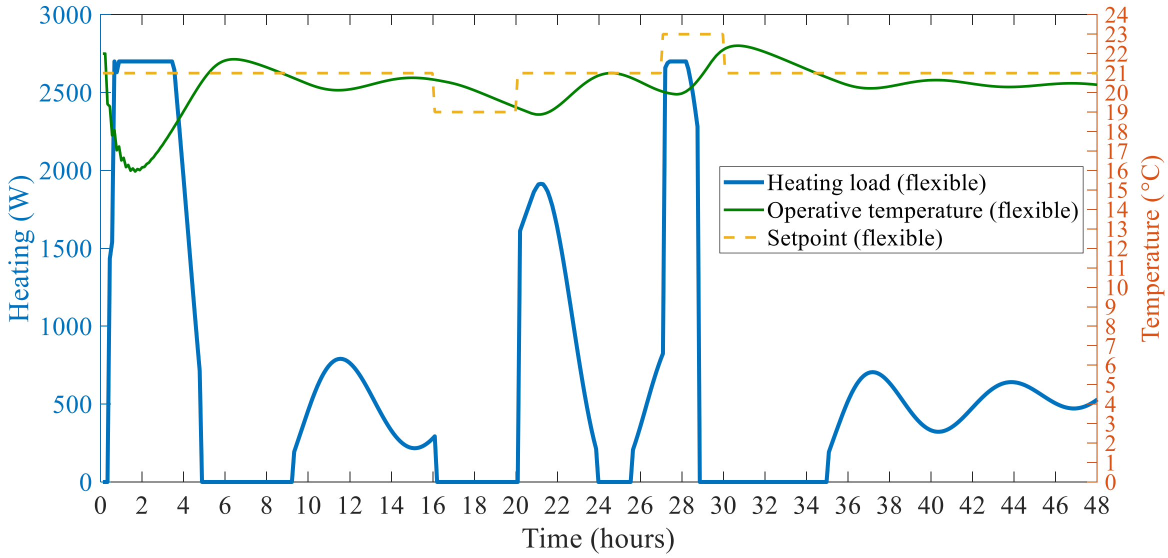

Figure 12. Downward and upward flexible case for the operative temperature control

For the downward flexible case, $C_{ADR,D}$ =240 Wh/m² and for the upward flexible case, $C_{ADR,U}$=294 Wh/m². Table 1 sums up the results for different cases and control strategies.

Table 1. Comparison of different control strategies.

	Control strategies		
	Floor surface temp	Air temp	Operative temp
Downward Flexibility ($C_{ADR,D}$)	198 Wh/m²	247 Wh/m²	240 Wh/m²
Upward Flexibility ($C_{ADR,U}$)	222 Wh/m²	313 Wh/m²	294 Wh/m²

Comparing the three cases, it is observed that for the same reduction or increase of 2°C in the corresponding setpoint, the air temperature control gives higher C_{ADR} and therefore higher energy flexibility (both upward and downward) compared to floor surface and operative temperatures control.

4.1 Effect of increasing the WWR

The effect of increasing the window area of the extrior façade on the energy flexibility is investigated. The WWR is increased from 50% to 75%. Figure 13 shows the comparison of the two variations for the reference case of air temperature control.

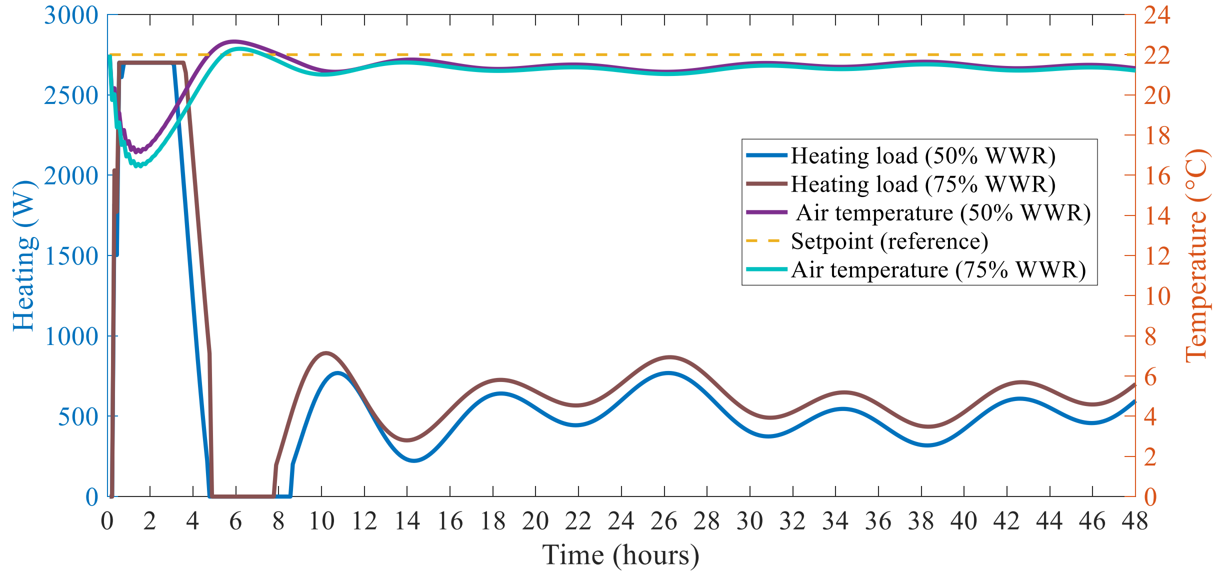

Figure 13. Comparison of air temperature control reference case for two WWRs

As expected, there is a noticeable increase in the heating load. Now considering the flexible setpoint, heating load for the 75% WWR is observed in Figure 14.

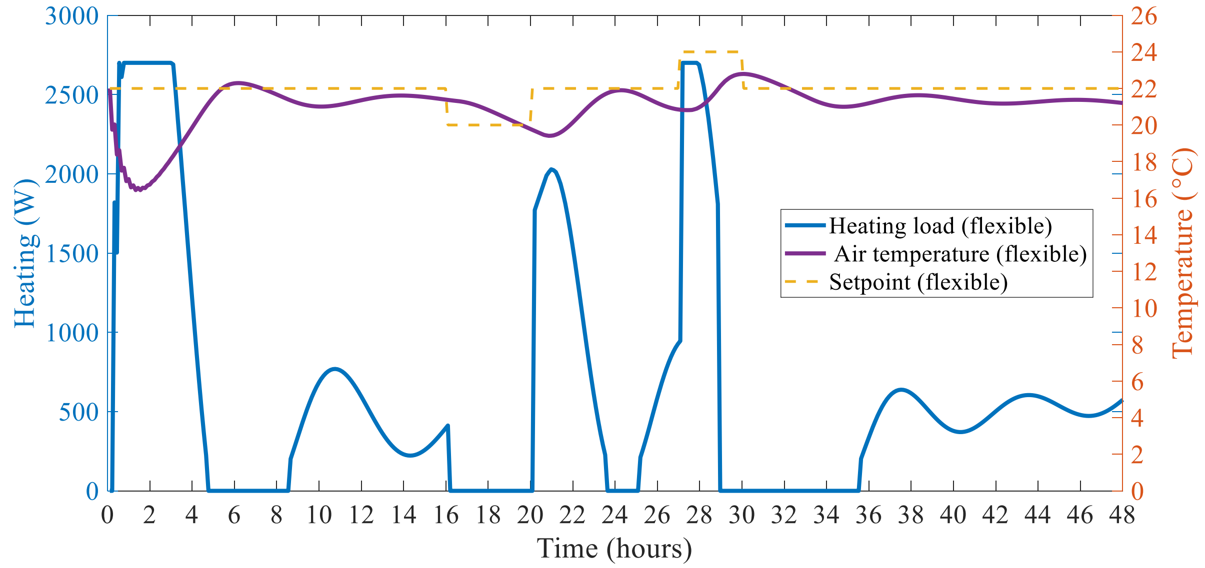

Figure 14. Downward and upward flexibility for the air temperature control and 75% WWR

The downward and upward energy flexibilities for this case are: $C_{ADR,D}$=289 Wh/m^2 and $C_{ADR,U}$=182 Wh/m^2. Therefore, significant decrease in the energy flexibility is observed.

5. Conclusion

This paper presented a comparative analysis of energy flexibility for different control strategies for zones with radiant floor heating systems with significant thermal mass. It was observed that with every control strategy, a noticeable amount of energy flexibility is achieved by decreasing or increasing the control temperature setpoint during or before the high price signal period. It is observed that the control strategy based on air temperature results in a higher energy flexibility compared to the floor surface temperature or operative temperature control. This is an important consideration in the design of control strategies for the zones with radiant floor system where higher energy flexibility is a major objective.

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Conflicts of Interest: The authors declare no conflict of interest.

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Life Cycle Energy Analysis of a House in UAE

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Abstract: In the United Arab Emirates (UAE) about 70% of total energy produced is consumed by building sector, and this compares with the global average of about 40%. Energy usage in buildings has often been discussed from the standpoint of operational energy, mainly used for purposes of heating or cooling. In recent times the discussion on building energy consumption has also raised the need for investigating the energy embodied in the construction of buildings and manufacturing of their constituent materials and components. This reorientation of energy consciousness in the construction industry is of critical importance in efforts to reduce the environmental impacts of the built environment. In United Arab Emirates, significant efforts have been made in recent times to reduce the operational energy consumption; however, embodied energy consumption is nearly unaddressed. The challenge this paper addresses is the need to review not only the operational (OPE) energy of a building but also its initial (IEE) and recurrent embodied energy (REE). The aim of this paper, therefore, is to calculate the energy consumption of a residential building over its life in UAE, and to identify the significance of embodied energy. A case study residential building in the UAE was selected as a representative example of government-built homes for UAE citizens for the purpose of this investigation. Using an input-output hybrid approach to calculate the energy required at the time of its construction and REE value calculated over a period of 50 years, the study compares the IEE, OPE and REE for the case study to extrapolate comparative data. Results from this study suggest the importance of including the initial and recurrent embodied energy of buildings in building life cycle energy analyses, which in this case represented 18% and 17% of the life cycle energy of the building. The anticipated merit of this study to building professionals is an appreciation and holistic consideration of the life cycle embodied energy of building design towards promoting a reduction in total building energy consumption.

Keywords: Life Cycle Embodied Energy, Initial Embodied Energy, Recurrent Embodied Energy, Comparative Analysis, Case Study, United Arab Emirates

1. Introduction

The built environment and building industry account for over 40% of global energy consumption, 36% of all CO2 emissions [1,2], and 28% of Greenhouse gas emissions [3]. The United States Energy Information Administration (EIA) has predicted that global energy demand will increase by 50% by 2050 [4]. Buildings in the United Arab Emirates (UAE) consume about 70% the electricity produced in the country, with almost 70% used for cooling [5,6]. Reflecting on per capita energy consumption, the weighted average for GCC countries is seven times higher than the global average [7].

In recent years, the discourse on building energy consumption has sought a more intricate assessment of the critical aspect of embodied energy, in the view of total building energy consumption which has not been studied as much as operational energy. While several studies have focused on reducing the operational energy, there is a need to adopt a more holistic approach to assess the impact of energy consumption across the building life cycle [8]. The comparative lack of research on embodied energy relative to operational energy calls for a comprehensive life cycle consideration [9]. The call for embodied energy has been presented as a key component towards sustainable global energy transition [10]. Studies report that embodied energy may account for 2-38% for conventional buildings [11] but for low energy buildings this may be as high as 50% [11,12] or even recently, as high as 60% [13]. In another study, Rauf and Crawford (2013) showed by using a comprehensive embodied energy calculation method that it can be greater than the life cycle operational energy and may account for 60% of the total life cycle energy over a 50 year period building lifespan [14].

As the world shifts towards low-energy buildings, some researchers argue that although less operating energy may be being achieved through high performing buildings, more building material is being used in this process [12] leading to a rise in the embodied energy [15]. Unfortunately, the practicality of calculating embodied energy/CO^2 emissions of the envelope building elements in the United Arab Emirates (UAE) is difficult due to the absence of certain critical data [16,17]. This gap calls for further investigation which is particularly relevant in the context because the tendency is to simply shift focus on developing high-performing and low operational energy buildings. The current study is focused on UAE residential buildings where there are far less studies on embodied energy impact on life cycle building energy consumption. This paper aims to fill the knowledge gap about the embodied energy consumption of residential buildings in UAE. This paper reports part of the findings so far as a preliminary report on the on-going investigation. This paper focuses on the calculation of the total life cycle energy demand, the initial embodied energy, the recurrent embodied energy, and operational energy for a case study building in the UAE over a 50-year building lifespan.

2. Life Cycle Energy Analysis

The approach used to quantify the energy demand of a building across its lifespan is known as life cycle energy analysis (LCEA) which has recently been investigated in various residential and non-residential contexts [8,18,19]. The LCEA can be described as a simplified but more focused version of the life cycle assessment (LCA), concentrating only on the energy dimension across the building life cycle [20]. It includes both embodied energy and operational energy [21], and closely relates to the environmental aspects of building impact [22]. The LCEA is thus, the sum of embodied energy and operational energy of a building. The reliability of the calculated results is influenced by completeness and accuracy of the case study building data and, of the calculation method used for the analysis [20].

In research and practice, the methods used to evaluate operational energy are well established. However, approaches to quantify the buildings' embodied energy are still being developed and not well-understood [23]. To substantiate this claim, a recent review reported that the reduction of operational energy in buildings can cause an increase in a building's total life cycle energy use due to direct and comparative increase in its embodied energy [20]. In specific terms, LCEA focuses on the evaluation of energy inputs from different phases of the building life cycle and various processes related to manufacture, construction, operation, maintenance and demolition phases of the building [8,20], as shown in Figure 1.

Figure 1: Life cycle stages of a building (Adapted from [24])

2.1 Embodied Energy Of Buildings

Embodied energy is generally described as the energy used directly onsite and offsite during construction and related processes, as well as indirectly in relation to use of materials and equipment. While initial embodied energy (IEE) is used in construction, recurrent embodied energy (REE) refers to energy consumed in recurring maintenance, and replacement or repair of building components [25]. The total embodied energy is a summation of three components: initial, recurrent and demolition embodied energies [10,15,23,26].

There is insufficient understanding about the significance and method of recurrent embodied energy calculation [23]. One recent review noted that only 30% of studies in this area clearly explain the calculation approach [25]. The review further notes that proper evaluation of REE and IEE, as well as conversion into primary or source energy terms is necessary. In addition, the calculation method, material database, and system boundary have to be clear, consistent and valid [20,25,27]. A previous study indicates that life cycle embodied energy can be as high as 60%, and thus, significantly more than the life cycle operational energy [14]. Other studies report that EE makes up 35% of the primary energy for advanced retrofit homes [28], and 67% for NZEB compared to 32% for a conventional construction [29]. These studies suggest that embodied energy for high performing buildings may be more due to the use of more materials, when compared with standard construction [12,15].

2.2 Embodied energy assessment methods

In literature, there are specific approaches to conduct the calculation of embodied energy. Commonly used methods are the process analysis, input-output analysis, and hybrid analysis [8,25,30]. As there are significant differences noted in calculated values across each of these analysis methods [31], the call for a global standard has been made [25]. This section highlights some of those variations.

Process analysis

The procedure for this approach uses data from various processes, products and locations to evaluate environmental flows and effects based on definite information which define the embodied energy of a product [8,31], and approximate energy aspects [32]. This approach has also recently been used to track the sustainability of manufacturing practices [33]. For its limitation, researchers have argued that some data is excluded from manufacturer's databases used such as the source of these calculations, creating an incomplete definition of the system boundary [8,25,31,34]. Consequently, missing or lack of detailed data of some of the production processes as well as the attendant complexities which inherent in upstream supply chains can impinge the reliability and specificity of this approach [8,25]. Some researchers have suggested that this approach can be used in life cycle assessments to differentiate 'sub-processes' and associated environmental factors for impact valuation. However, Fan et al. [35] asserts that process analysis is a time-consuming approach, made up of countless steps, leading to selection of only major inputs; and thus, it is subject to truncation errors plus uncertainties in defining its system boundaries [34,36].

Input-output analysis

This approach uses a form of "dual tracking system" to trace and aggregate both energy and monetary flows/transactions within an entire supply chain [31,32] making it systematically complete [23]. By comparing and collating entire national economy data on energy between sectors, Baird et al. asserts that this is a significant advantage of this approach but also suggests that this may lead to a proverbial "black box". This is due to the mismatch of dissimilar products within individual sectors [32]. In a recent review, Malik et al argued that this approach provides an alternative technique to LCA as it enumerates various supply chain impacts and avoids tedious data collection [37]. Other authors, have however stated that though the approach is comprehensive, the "black box" limitation has three negative effects relating to the data and the results [14,25,38]. These are uncertain homogeneity, proportionality, and inadequate considerations of the economies of scale.

Consequently, Dixit argues that the IO model may lead to double counting of energy inputs, making the results questionable and unreliable [25].

Hybrid analysis

The unique constitution of this approach is that it seeks to adapt the advantage of previous analysis methods into one calculation approach [39], in a way that addresses their limitations [40]. This approach is the most comprehensive technique in computing life cycle inventories [31,41]. This assertion argues that it allows for the combination of bottom-up industrial process data and top-down macroeconomic input-output data. There are two variations of this approach, either a process-based hybrid analysis (PBHA), or an input-output-based hybrid analysis (IOBHA). In general, the process-based hybrid analysis as an approach, focuses on the quantification of individual products delivered in addition to energy intensities extrapolated using the input-output analysis [34,42]. This second component is mathematically computed for each material by adding process data results of the energy required to produce it, to "the difference between the total energy intensity of the input-output path of the basic material, and then multiplying it by the total price of the basic material" [42].

On the other hand, the input-output-based hybrid analysis is used to solve the limitation of the process analysis/process-based hybrid analysis [43]. Recently, it was suggested that though this approach applies an integrated system boundary its input-output data is liable to be outdated or miss new product data [30]. Other authors [41,44], have asserted that the lack of a database may limit the accuracy of an embodied energy calculation even in an input-output hybrid analysis. However, other authors [8,31], argue that embodied energy calculations using this approach combines several steps such as energy data aggregated from process analysis, with system boundary completeness improved by hybrid material energy intensity figures and input-output data. In addition, the approach makes use of integrated process and input-output data at the material level to create a define hybrid material energy coefficients" [31].

3. Research method

In order to quantify the total life cycle energy demand, the initial embodied energy, and the recurrent embodied energy were calculated for a case study of 5-bedroom villa in the UAE. The period of analysis chosen for this study was 50 years based on the assumption that a building in the UAE will be used for this period. It is also assumed that at the end of this period, the building would be at the end of its useful life and ready for demolition. Based on referenced literature in Section 2, the selected approach for calculating the embodied energy for the current investigation was the input-output hybrid approach. Also, secondary data from previous studies was used to approximate the operational energy of the building and the calculation of the life cycle energy of the building.

There are few comparatively related investigations with a robust material database reference in the UAE on embodied energy which define the system boundaries, embodied energy coefficients and intensities needed for this investigation. Due to the absence of a comprehensive energy intensity data for different building materials and components used in construction industry in UAE, the EPIC database compiled by University of Melbourne, Australia [45], was used in this study to calculate embodied energy.

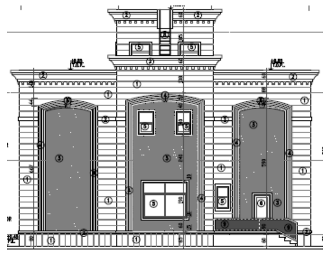
3.1 Case study building

A two-storey 5-bedroom villa located in Al Ain with a total floor area of 532m^2 was used as the case study for this analysis (Fig.2). The house is constructed using conventional materials and construction systems including a concrete slab floor, hollow block walls, and plaster. Wall finishes include ceramic tiles, oil and acrylic paint, the ceiling was made of plasterboard and floors covered with ceramic tiles. The windows are double-glazed and aluminum-framed, and doors and their frames were made of teak wood. A full material schedule was received from the firm that designed the building and was used for the EE calculations. A few assumptions were made to clarify the parameters for calculations, these included:

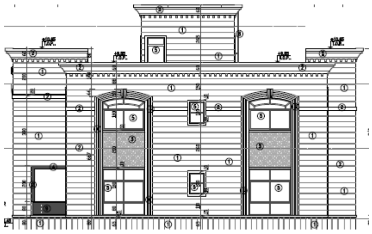
3. The building was constructed with no specific green rating system requirements.
4. Standard dimensions were used for component specifications where the material schedule did not give explicit information. For example, the thickness of doors and glazing.
5. The replacement period/service life of the materials used in the EE calculations are based on Rauf (2015), and general construction and residency experience in the UAE.

Elevations

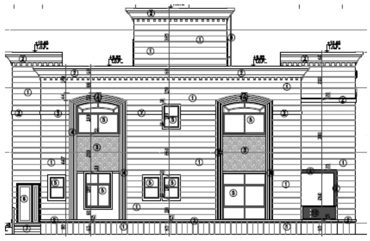
Front view



Back view



Right view



Left view

Figure 2: Case study building

3.2 Initial Embodied Energy

Using the IOBHA approach, the embodied energy of the case study building was calculated by multiplying the delivered quantities of each material by the embodied energy coefficient of the respective material which was obtained from the EPIC database. The resultant figure gives the process-based hybrid embodied energy of the house. In the next step, the energy embodied in non-material inputs was calculated to complete the system boundary and the value was added to the process-based hybrid embodied energy EE value. This *remainder* – for non-material inputs, was calculated with the use of a disaggregated energy-based input-output model. A detailed description about the use of input-output-based hybrid analysis to calculate the initial embodied energy of the case study house is available in [8].

3.3 Recurrent embodied energy

To calculate the recurrent embodied energy two values are of critical importance; firstly, the material service life (MSL) i.e. the number of years a specific material would be used before it needs to be replaced by a new one. For this, a literature review was conducted on the service life values for different materials and components. Average service life values from the available literature were used for this study. Assumptions were made where the service life value of any material or component was not available. Secondly, a period of analysis which approximates the lifespan of the building. Based on the average service life of residential buildings in available literature, a building service life of 50 years was used for this study, which the structure will be demolished. These two values will determine how many times a material or component will be replaced over the lifetime of house.

The recurrent embodied energy of the house was calculated as per the initial embodied energy of the house. The delivered material quantities associated with each replacement were multiplied by the respective material embodied energy coefficients. These values included the direct and indirect energy associated with the manufacture of materials. To complete the system boundary, the non-material inputs or remainder associated with materials being replaced, were then calculated as per the initial embodied energy calculation. The energy embodied in each material was then multiplied by the number of replacements for that material over the life of the house and summed to determine the total recurrent embodied energy associated with the house. A detailed description about the use of input-output-based hybrid analysis to calculate the recurrent embodied energy of the case study house is available in [8].

3.4 Operational energy

To compute the total life cycle energy (LCE), the operational energy (OPE) needed for heating, cooling, and running of household appliances was approximated. Electricity consumption was determined based on secondary data available in literature for UAE [46–49]. This electricity consumption data from these sources was aggregated, and average gas consumption for cooking for an average family size suitable for this villa was added to calculate the operational energy requirements.

4. Results and Discussion

In this section three specific results are presented and discussed. Firstly, the life cycle embodied energy (including initial and recurrent embodied energy) results, the operational energy approximations, and the total life cycle energy of the case study building, indicating the IEE, REE and OPE values for 50 years life span. This is followed by a discussion on the importance of these results in the context of the UAE. Secondly, the framework for a comparative analysis with previous studies in other contexts is presented.

5.1 Embodied Energy

The embodied energy calculated using IOBHA for the initial construction of the case study house was found to be 7605.68GJ (14.3GJ/m^2). In terms of initial embodied energy value per square meter, this case study house (14.3GJ/m^2) has relatively high embodied energy when compared to other studies using the same assessment method (11.7GJ/m^2 [50]; 13.GJ/m^2 in a study by [8]). One reason for this relatively high value may be due to the use of more high energy intensity materials, such as use of concrete for roof construction and concrete blocks for walls. When compared to the embodied energy results in the studies using other analysis methods (e.g. 2.86 GJ/m^2 and 5.09 GJ/m^2 for two buildings using process analysis [51]), this study has shown significantly high embodied energy demand. This is due to the much broader and complete system boundary for the input output-based hybrid analysis approach.

The recurrent embodied energy was calculated over the 50 years life span and was found to be 6894 GJ (12.96GJ/m^2). The life cycle embodied energy (LCEE) was thus, 14,908 GJ (28 GJ/m^2). Taking a closer look at LCEE, Figure 4 shows that the recurrent embodied energy made up 48% of the LCEE, while the initial embodied energy was 52% of the LCEE after 50 years. This suggests that REE would play a greater role as the building life extends and thus, the IEE would become comparatively less. As suggested in literature [8,14,25], multiple factors such as the material service life and building service life will play a significant role in defining the differences with respect to time.

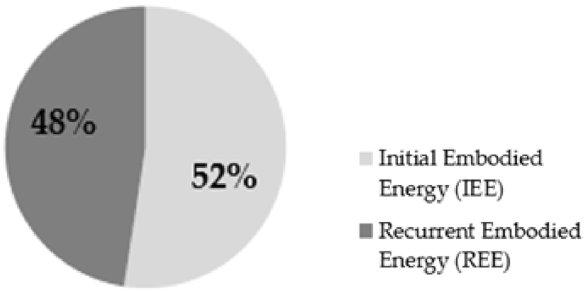


Figure 3: Proportion of initial and recurrent embodied energy for the case study building

5.2 Operational Energy

Based on secondary data found in literature [46–49], the average operational energy for villas in the UAE was calculated and found to be 273.36kWh/m²/yr. Annual energy consumption for the case study villa, with the total area of 532m² is thus, 145432.84kWh/yr. which is equivalent to 523.56 GJ/yr (0.9841GJ/m²/yr). For the 50-year period, this value rises to 26177.91GJ (49.2GJ/m²). Operational energy was found to constitute 64% of the life cycle energy of the house over a period of 50 years. This shows the importance of the operational energy in efforts to reduce energy consumption by residential buildings.

5.3 Life Cycle Energy

The life cycle energy computed over 50 years was calculated as a sum of the initial, recurrent, operational and demolition energies. The Demolition Embodied Energy (DEE) was calculated at 1% of the life cycle energy demand [52]. Thus, the LCE calculated was 41,086 GJ (77.3 GJ/m²). Figure 4 shows a comparison of the LCEE and OPE for the case study.

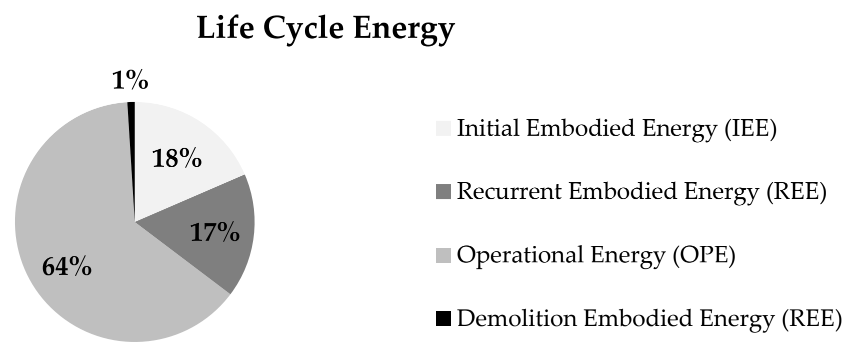


Figure 4: Life cycle energy of the case study building over 50 years

The figure shows that the total embodied energy was 36% of the life cycle energy, of which 18% was initial and 17% was recurrent embodied energy; while operational energy was 64% of the life cycle energy. In general, the results show that the embodied energy, which is often neglected in design and energy research considerations, makes a significant contribution (35%) to the total energy consumed by the building during its lifespan. Results from this study also suggest the importance of including the recurrent embodied energy in building life cycle energy analyses, which various of previous studies ignore in a life cycle analysis [23].

The life cycle embodied energy results present certain other considerations. Firstly, the LCEE is about 57% of the OPE, which a percentage that is too significant to be ignored in the building design, material specification. Operational energy requirement for a building on the other hand is expected to reduce with installation of more energy efficient energy systems and appliances in future. It is also important to note that efforts to reduce the operational energy demand of buildings are also focusing on using more materials to improve the thermal performance of building envelop. As a considerable amount of energy can be used in the manufacture of these building materials, this can result in an increase in embodied energy. This shows the importance of ensuring that energy demands are not inadvertently shifted from one area (i.e. operational) to another (i.e. embodied). The UAE also aims to increase the contribution of clean energy sources in the total capacity mix to 50% by 2050, as compared to 98% of its electricity in 2018 using natural gas-fired generation [53]. This shift towards clean energy will help further reduce the GHG emissions associated with operational energy consumption by a building. As a result, importance of embodied energy will increase further, as mining and manufacturing processes for materials production are expected to rely mainly on fossil fuels for a much longer time.

5.4 Comparative insightand future research

This section compares embodied energy values from different studies to present certain insights. Currently, our review shows that some authors who have evaluated LCEE have arrived at different percentages. Considering the context and building type as subjective variables, the interest in this section is the proportional comparison for each case as a basis for suggesting further research pathway for a detailed review. Table 1 shows a few studies on embodied energy calculations, conducted in different locations, using the same analysis method (input-output based hybrid analysis) with similar building service life.

Table 1: Comparison of LCEE and OPE

Reference	Country/ Region	Building type	Building Life	LCEE	OPEE
Current Study	UAE	Residential	50	36%	64%
[18]	UK	Office	60	10%	90%
[19]	Norway	Residential	60	50.7%	49.3%
[29]	Italy	Office	50	67%	33%
[14]	Australia	Residential	50	59%	41%

In terms of life cycle embodied energy proportion compared to life cycle operational energy, 36% embodied energy is lower than other studies which has used same embodied energy calculation method. Main reason for this relatively low proportion of embodied energy is due to the high operational energy demand to cool the buildings in long summer with extremely high temperatures in UAE. Other reasons include the difference between the scope and location of these studies, selection of materials and their service lives used as compared to this study. Improved access to process-based embodied energy data will help to minimize the errors inherent in current hybrid embodied energy data and assessments. However, authors believe that findings of this study can be applied to the residential buildings of same type in similar climatic conditions.

5.5 Limitations

A significant limitation faced during this study was the absence of UAE energy intensity data for various building materials and components; such complexities associated with EE calculations have been noted in literature [16,17]. To ensure a standardized approach in the estimation and comparison of the current study with existing studies, the EPIC database for materials and building component was used.

Another limitation this study faced was the absence or lack of localized service life data for different materials used in the construction of case study house. Due to the unavailability of such data from UAE, a literature review was conducted to find the service life values of different materials and components around the world. These values were then adjusted to reflect the local conditions and used to calculate the recurrent embodied energy.

In this study, operational energy of the case study building was considered to be unchanged over the life of building. However, in reality, it is expected that operational energy will reduce due to the more energy efficient energy systems and appliances in future as well as a change in energy mix in UAE.

6. Conclusions

This study has focused on the calculation of the life cycle embodied energy for a case study building in the UAE. A comprehensive input-output based hybrid analysis method was used for embodied energy calculations. This study has shown the significance of both the energy required to initially construct a building and the recurrent embodied energy associated with the maintenance and replacement of materials over its life. The total embodied energy calculated was found to be 36%

of the life cycle energy over a building lifespan of 50 years. The initial and recurrent embodied energy were found to constitute 52% and 48% of the life cycle embodied energy. The considerations of the impact on the total life cycle energy of the building from the embodied energy components –initial, recurrent and demolition which the study presents is part of a larger study to evaluate its importance in the UAE context. Further research is on-going to explore other parameters and factors which may influence the current findings in an effort to reduce the life cycle energy demand of the buildings.

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Parametric Study of Building Orientation Effect on Building Energy Consumption

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Abstract: Building orientation is a term mainly used to describe the direction a building faces in relation to seasonal variations in the sun's path. Although several publications and technical documents have discussed the significance of building orientation and related impacts on building energy consumption, very few have estimated the actual electricity cost savings or losses involved. What's more, a detailed parametric study on the subject is scarce in published literature. The main objective of this study was to comprehensively investigate the effect of building orientation on building energy consumption in terms of energy savings or losses towards space heating and cooling. Dynamic building energy analysis was carried out using EnergyPlus based on ASHRAE 90.1-2016 operational schedules for stereotypical office building, considering selected climates in both northern and southern hemispheres. In all, 32 scenarios were investigated. Results showed that building orientation has a significant effect on the ultimate total building energy consumption, translating to building energy losses of about 4600-58000 kWh/yr and increased electricity costs of 1000-7000 USD/yr for the locations considered. Finally, some noteworthy limitations of the study were duly reported.

Keywords: Building orientation; Building energy; Electricity costs; EnergyPlus; Parametric study.

1. Introduction

Energy used in buildings (for space heating, cooling, lighting, etc) represent a significant quota of the overall final energy in many countries. Although topics such as renewable energy generation and integration, sustainable and passive building designs and systems, environmentally friendly and green building materials, artificial intelligence solutions and automated control systems, among others, have become key global subjects being tackled by various research institutions, their proper adoption into everyday buildings remains to be somewhat realized on a monumental scale. For instance, according to the IEA, direct and indirect emissions from electricity and commercial heat used in buildings rose to 10 GtCO2 in 2019, the highest level ever recorded [1]. Factors contributing to this rise included growing energy demand for heating and cooling with rising air-conditioner ownership and extreme weather events. Further, it was reported that enormous emissions reduction potential remained untapped due to the continued use of fossil fuel-based assets, a lack of effective energy-efficiency policies and insufficient investment in sustainable buildings. While it seems like a cliché, it has been reported continuously that most people spend 90 % of their daily lives indoors [2-4]; which implies dependence on electro-mechanical systems to provide a comfortable and healthy indoor climate. Nevertheless, Smith and Timberlake [5] concluded that a building's envelope characteristics dominates other sections of a building system (site, structure, services, and space) with regards to long-term effect on energy used during building operations. Therefore, it is reasonable to focus on efficient building skin design and construction. Numerous researchers have investigated various aspects of building envelope [6-13]. Surprisingly, studies focused on the impact of building orientation, relative to the true north or solar azimuth, and its resultant effect on building energy consumption are scarce in open literature. Albatayneh et al. [14] investigated effect of building orientation and wind speed and direction on the overall thermal performance of a mockup building unit, based on the climate of Newcastle, Australia. It was concluded that correct orientation is a low-cost option to improve occupant's thermal comfort and decrease cooling and heating energy. Other studies examined the effect of building shape, zones, orientation, and window to wall ratio (WWR) on lighting energy requirement and thermal comfort in naturally ventilated houses located in tropical climate [15]. Nonetheless in the aforementioned studies, energy and thermal implications of building orientation were discussed in terms of percentage energy gains and losses. The implications of energy gains or losses, in terms of how the actual energy-cost reflects in the daily life of a building user were not evaluated. Besides, the outcomes of the studies are relevant within the scope of the climates considered. Given lack of literature on the effect of building orientation on building energy, this parametric study was designed and conducted. The main aim of this study is to examine the effect of building orientation on building energy consumption in terms of energy savings or losses towards space heating and cooling, and lighting. As well as scrutinize the electricity cost implications involved. A robust building modeling and simulation procedure based on a large open office building was used.

2. Methodology

Building modeling and simulation approach was used for this study. Based on a reference building, and considering building orientations of south, west, north, and east, building energy simulations were carried out for eight selected locations (4 in northern hemisphere and 4 in southern hemisphere) across the globe. Further details and specifications of the procedure used are explained in the following paragraphs.

2.1. Reference building description

For this study, a representative 10-story (above ground) open office building was used as a reference building. The total conditioned floor area and floor height of building were 6680m^2 and 3.5m, respectively. The U-values for the external wall and roof of the reference building are 0.25 W/m^{2}K and 0.15 W/m^{2}K respectively. The window-to-wall ratio is 70% for south façade and 30% for east and west façades. The window type is 13 mm argon filled double glazed with solar heat gain coefficient (SHGC) of 0.49, light transmittance (LT) of 0.51, and overall U-value of 2.5 W/m^{2}K. All external surfaces of the building are exposed to solar radiation. Figure 1 represents a 3D view of the reference building showing the sun path on a typical summer (i.e., 15th July in the northern hemisphere) and casted shadows on the façade at 9am. The components and thermophysical properties of the external wall and roofing components are listed in Table 1.

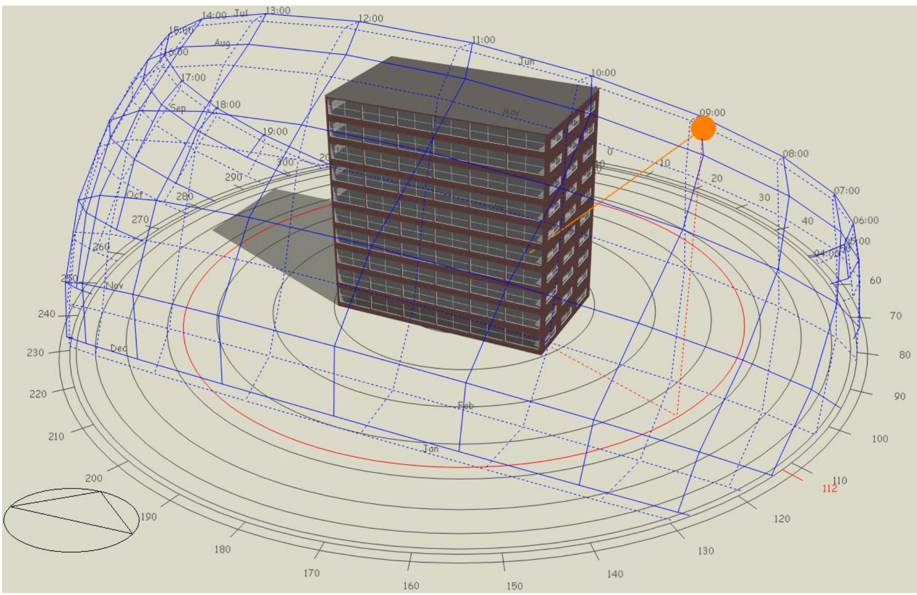


Figure 1. Model of reference building

Table 1. Material layers and thermophysical properties of reference building model

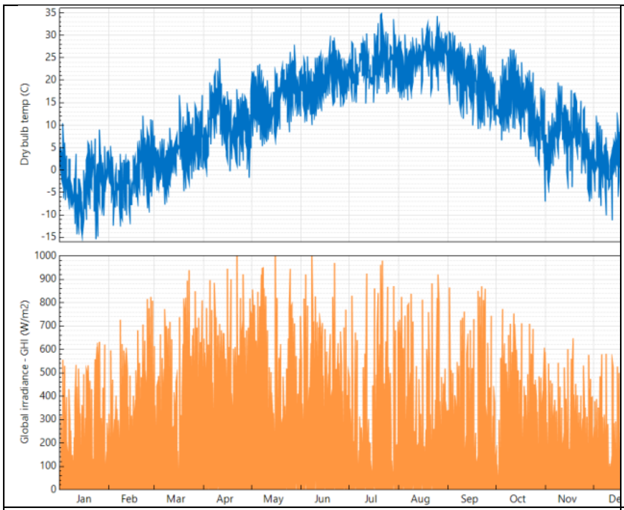
Description	Material	Thickness (m)	Thermal conductivity W/(mK)	Density Kg/m³	Specific heat J/(kgK)
			External wall		
Outer layer	Brickwork	0.105	0.84	1700	800
Layer 2	XPS	0.118	0.34	35	1400
Layer 3	Concrete	0.1	0.51	1400	1000
Inner layer	Gypsum plastering	0.013	0.40	1000	1000
			Roof		
Outer layer	Asphalt	0.019	0.70	2100	1000
Layer 2	Fiberboard	0.013	0.06	300	1000
Layer 3	XPS	0.205	0.034	35	1400
Inner layer	Concrete	0.1	0.38	1200	1000

2.2. Modeling procedure, operaions and schedules

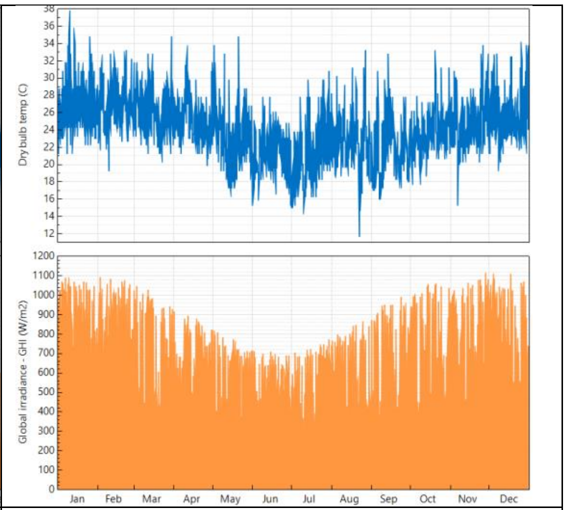
Building modeling and simulation analysis technique was adopted for this study using EnergyPlus (v.9.4). In EnergyPlus, a building's site orientation is the angle of the site plan view relative to north axis. Thus, to rotate a building, the north axis object allows user specified inputs relative to true north, and this technique was employed to examine the effect of building orientations (south-0^{O}, west-90^{O}, north-180^{O}, and east-270^{O}) for each selected location. An Ideal Load Air System (ILAS) heating ventilation and air conditioning (HVAC) system was modeled to compute space heating and cooling loads. This component is an ideal unit that mixes air at the zone exhaust condition with a specified amount of outdoor air and then adds or removes heat and moisture in order to produce a supply air stream at the specified conditions [16]. The HVAC system was controlled by a thermostat based on the dry bulb temperature of the zones. Operational schedules and inputs of ASHRAE Standard 90.1–2016 were used. The building activity type was defined as office which resulted in default occupancy density of 18.58 m^2 zone floor area per person, light intensity of 8.50 W/m^2, and infiltration rate of 0.00056 ($m^3/sec.m^2$) per exterior surface area. Zone thermostat set points were 24°C, reset to 26.7°C during off-hours for cooling, and 21°C, reset to 15.6°C during off-hours for heating. For this parametric study, typical meteorological year data in EnergyPlus Weather (EPW) format for eight selected locations (4 in northern hemisphere and 4 in southern hemisphere) were used. The general descriptions of the selected locations are summarized in Table 2. Additionally, global horizontal radiation and outdoor air temperature profiles for the respective climates are depicted in Figure 2. In all 32 scenarios were scrutinized.

Table 2. General description for selected climates

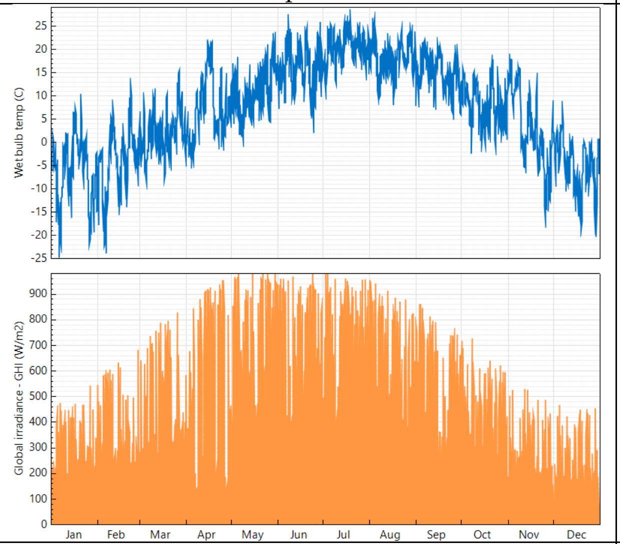
Location	Geographic hemisphere	Koppen climate type	Elevation above sea level	Weather data source
Rio de Janeiro, Brazil	Southern	Aw	3m	SWERA
Johannesburg, South Africa	Southern	Cfa	1694m	TMY
Jakarta, Indonesia	Southern	Af	8m	TMY
Canberra, Australia	Southern	Cfa/Dfa	575m	TMY
Incheon, South Korea	Northern	Dfa	70m	TMY2
Abu Dhabi, UAE	Northern	BWh	27m	TMY
Chicago, USA	Northern	Csb	2m	TMY3
London, UK	Northern	Cfa/Dfa	25m	TMY



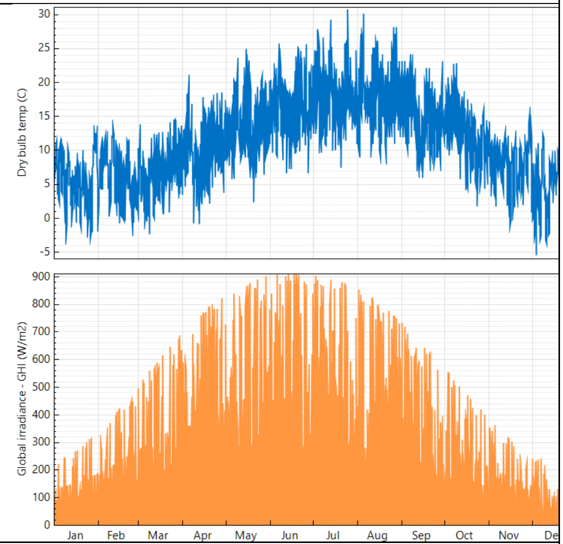
Incheon, Republic of Korea



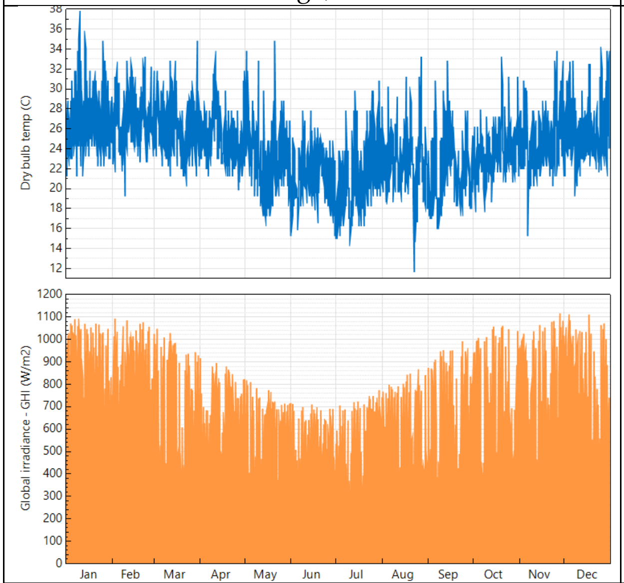
Abu Dhabi, UAE



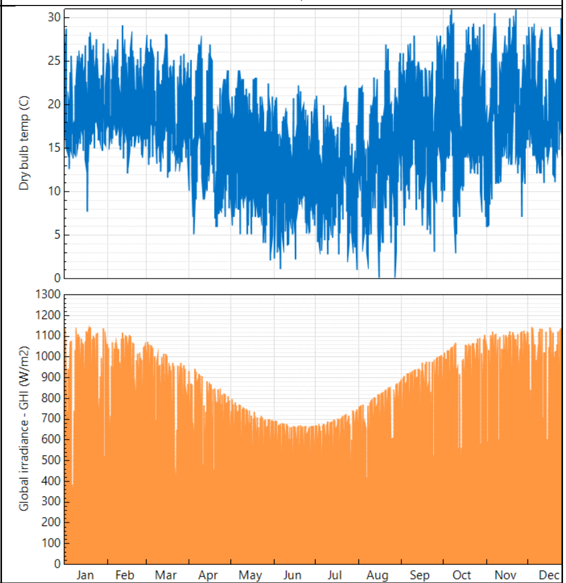
Chicago, USA



London, UK



Rio de Janeiro, Brazil



Johannesburg, South Africa

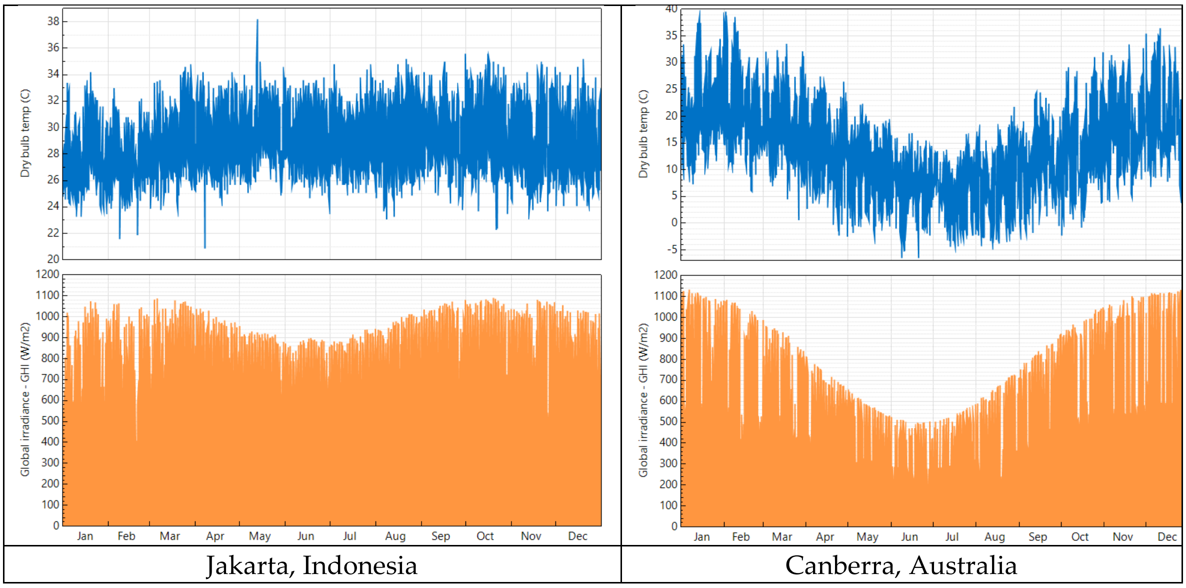
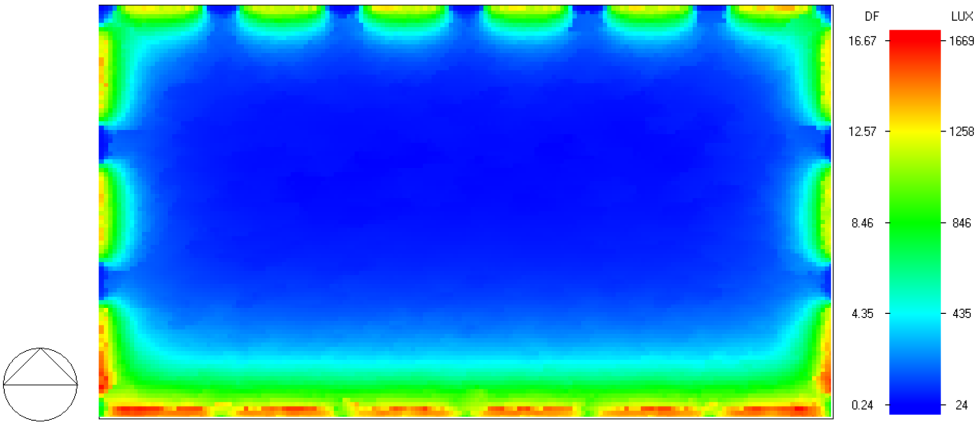


Figure 2. Solar radiation and outdoor temperature profiles

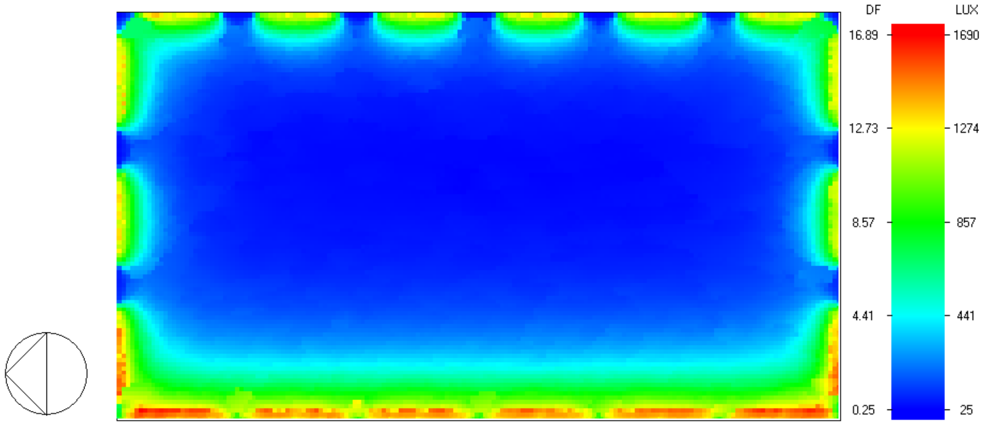
3. Results and discussion

3.1. Daylighting environment

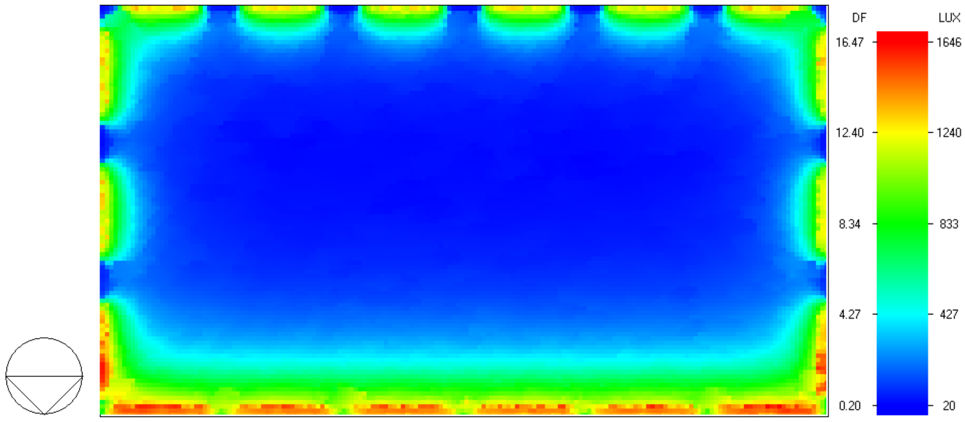
Illuminance maps showing daylit areas for the sixth floor of the building are shown in Figure 3, considering the climate scenario of London. For all the building orientations, daylight factors ranged from 0.2 to less than 17, corresponding to illuminance in the range of about 20-1700 lux. Nonetheless, areas towards the core of the floor, away from windows, received very little daylight, and thus will rely on electrical lighting systems to meet required lighting levels.



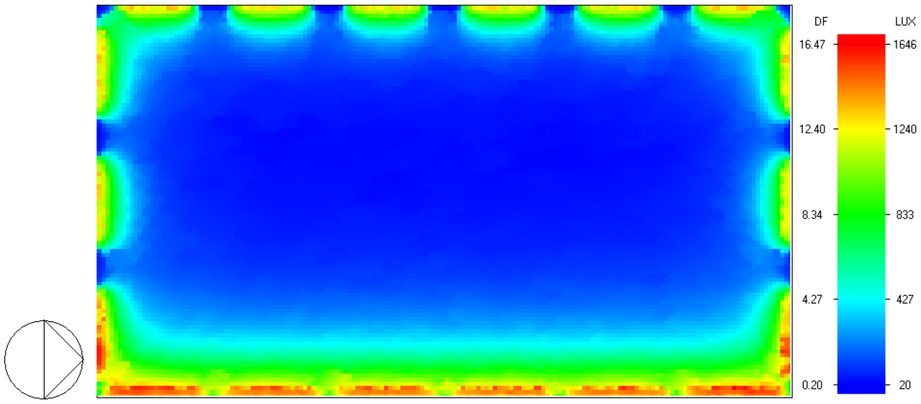
(a) South



(b) West



(c) North



(d) East

Figure 3. Daylight illuminance maps

3.2. Building energy consumption (heating and cooling)

The total building energy use (heating, cooling, and lighting) for the selected locations according to building orientation are reported in Table 3. Worth mentioning that there was no space heating loads for Rio de Janeiro, Jakarta, and Abu Dhabi scenarios. Generally, for locations in the northern hemisphere, the lowest total building energy use was for south orientation while the highest annual building energy use was oriented towards the east, except for Incheon which was west. Conversely, the lowest total building energy use was north orientation for buildings located in the southern hemisphere. For the same hemisphere, similar results showed that the highest building energy was for buildings oriented towards east. The difference between the maximum and minimum building energy consumption on the basis of building orientation, and its related energy-cost implications for the various scenarios were computed and displayed in Table 4.

Table 3. Total annual building energy use according to building orientation (kWh).

Location/orientation	South	West	North	East
		Northern hemisphere		
Chicago	916801.34	940278.22	931960.88	950102.42
London	523163.9	527305.01	525292.46	527785.55
Abu Dhabi	1226570	1256904	1249389	1257432
Incheon	854247.07	864104.43	856257.38	863066.73
		Southern hemisphere		
Canberra	373160.3	386295.7	372950.8	389336.9
Johannesburg	267657.2	285853.5	265131.4	290079.3
Rio de Janeiro	1386831	1392396	1354983	1413274
Jakarta	1675871	1693668	1671155	1693865

Table 4. Building energy use variance and related energy-cost computations.

Location	Difference (max-min energy use per orientation)	Average cost of electricity, USD/kWh	Energy-cost (energy difference × cost of electricity)
		Northern hemisphere	
Chicago	33301.1	0.094[1]	3130.30
London	4621.65	0.237[2]	1095.33
Abu Dhabi	30862	0.1[2]	3086.20
Incheon	9857.36	0.108[2]	1064.59
		Southern hemisphere	
Canberra	16386.1	0.136[2]	2228.51
Johannesburg	24947.9	0.076[2]	1896.04
Rio de Janeiro	58291	0.12[2]	6994.92
Jakarta	22710	0.072[2]	1635.12

[1] EIA electric power monthly [17][2] Global petrol prices [18]

The maximum energy-cost difference to the tune of almost 7000 USD was estimated for the case of Rio de Janeiro. For the said case, this implies that the building oriented towards the north saves energy which is equivalent to about 7000 USD in money terms. Not to mention the added benefits of reduced emissions due to energy savings. The building oriented towards the east in turn uses 58291 kWh energy towards space conditioning and lighting, more than the former building. Largely, a higher cost of electricity per kWh will translate into a wider energy-cost gap. Nonetheless the major contributing factor for the ultimate building energy consumption is determined principally by the building's own specifications, site, and orientation characteristics.

4. Limitations

The focus of this study was to principally investigate the implications of building orientation and its effect on building energy, and how that affects building operation costs. Thus, based on the same reference building model, 32 scenarios were scrutinized. The scenarios did not consider optimization solutions targeting various aspects of the building. The focus was mainly on the building orientation. Also, to generalize and promote comparison of results, irrespective of location, ASHRAE 90.1-2016 schedules were adopted for all the cases. Although realistically, each case may have slightly different schedules for occupancy. However, for the purpose of this study, these limitations do not affect the outcomes reported. Lastly, this parametric study focused solely on office buildings, to efficiently analyze the huge data produced. In future studies, residential buildings could be scrutinized with a similar approach as well.

5. Conclusions

Due to tangible reasons such as land and space constraints, expensive costs of land, inadequate urban planning, perhaps lack of awareness, among others, a large portion of commercial and residential buildings are orientated in all cardinal directions. Motivated to find out the actual energy-cost implications of building orientation, this study employed a detailed building modeling and simulation approach to investigate the building energy and related operational cost implication for a large office building (floor area > $6000m^2$) considering locations in both southern (Rio de Janeiro, Brazil; Jakarta, Indonesia; Canberra, Australia; and Johannesburg, South Africa) and northern (Chicago, USA; London, UK; Incheon, Republic of Korea; and Abu Dhabi, UAE) hemispheres, while assessing south, west, east, and north building orientations for each location. Results showed that the effect of building orientation on the resultant building energy consumption cannot be marginalized. For all locations and orientations considered, the annual energy required for space conditioning and electrical lighting increased by about 1-10% when the best case was compared to the worst case. In terms of energy, this percentage difference was about 4600-58000 kWh/yr and associated electricity costs of 1000-7000 USD/yr were estimated based on electricity prices. Generally, south and north building orientation for locations in the northern and southern hemispheres showed the lowest building energy use, respectively. This agrees well with well-known theories in favor of passive solar design strategies. Studies concerning buildings for other purposes, other than office purpose is essential as well and will be conducted in the future.

Author Contributions: Conceptualization, F.E.B. and J.-H. K.; methodology, F.E.B.; software, F.E.B.; validation, J.-H. K. and F.E.B.; formal analysis, F.E.B.; investigation, J.-H. K. and J.-T. K.; resources, J.-T. K.; data curation, J.-H. K. and F.E.B.; writing—original draft preparation, F.E.B.; writing—review and editing, J.-T. K.; visualization, F.E.B.; supervision, J.-T. K.; project administration, J.-H. K.; funding acquisition, J.-T. K. All authors have read and agreed to the published version of the manuscript.

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Energy Modelling of Multi-Family Residential High-Rise Buildings in the South-Eastern Mediterranean Climate: Retrofit Policy Design

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Abstract: Passive design strategies can reduce heating and cooling demands with integration of more efficient building systems as well as the potential to integrate modular off-site construction technology and its technical systems to offset overall energy consumption. This paper presents an analysis of the development of modular building design elements to improve thermal performance of a base-case high rise residential development before different retrofitting scenarios are undertaken to optimise the building's energy performance and the occupants' thermal comfort in the coastline city of Famagusta, Cyprus. This study adopts a quantitative research design primarily using multi-objective optimisation and the energy simulation of a base-case prototype building in both extreme seasons (summer and winter). The selected representative high-rise residential development is modelled using Integrated Environmental Solutions' Virtual Environment (IES-VE) software where extensive dynamic thermal simulations have been produced to assess existing energy performance and energy effectiveness of retrofitting strategies. The representative apartment units were modelled using dominant representative energy profiles, and in all cases the preliminary results demonstrated that the physical properties of the building led to high levels of discomfort as well as higher than average heating and cooling loads. The results demonstrated that in the non-retrofitted case, the cooling and heating comprised the biggest part (67%) of the total energy consumption, helping with the second phase of the study, which is investigation of effective district scale retrofitting scenarios in the decision-making process to uptake delivery of policy implications with taking into account households' real occupancy profiles in the South-eastern Mediterranean climate.

Keywords: Building performance optimisation; Climate responsive design; Passive cooling design

1. Introduction

With increasing concern over national greenhouse gas (GHG) emissions during the last two decades in Europe, efforts are being made to improve energy efficiency in buildings, aiming to reduce energy demand and consumption, which also results in a reduction in associated GHG emissions and a mitigation with climate change [1]. It has been argued that residential buildings' consumption in Southern Europe is mostly related to summer conditioning (cooling); however, winter demand for heating has risen due to a lack of concern about the importance of occupants' thermal comfort and overheating risks in retrofit interventions [2]. For example, problems in mass housing estates are current topics of research on energy and policy interventions in Famagusta, Cyprus. Modernist low-rise, medium-rise and high-rise residential tower block (RTB) developments often lack indoor air ventilation due to the proximity of other buildings and are often built without consideration of the climatic features of the neighbourhood building site or urban planning laws and regulations [3]. These purpose-built residential building stock models represent only 38% of the existing building stock, but there is growing interest in improving the energy performance of the existing residential building stock, specifically considering occupants' thermal comfort in RTB developments [4].

Many scholarly pilot research projects focusing on European member states have investigated the interplay between government policy on thermal retrofit and current energy efficiency awareness of energy use in the residential buildings at which the policy was aimed. In respect to Cyprus, a main concern is the burden resulting from a legacy of inefficiently built post-war housing stocks [5,6]. There are no measures or benchmarks for building energy performance, nor an official roadmap for regulating 'retrofit interventions' to address energy efficiency [7].

Previous research has determined that there is a lack of policy initiatives and implications in understanding the importance of energy use [8]. According to a previous pilot study, one strategy for rectifying this deficiency is understanding the variance in energy performance in terms of the gap between the design and construction processes [9]. One prevailing opinion here is the need to take advantage of the benefits of implementation of energy efficiency systems. Moreover, researchers have recommended a wider perspective that includes a focus on the energy use of the existing built post-war housing stocks, including considering the importance of occupants' thermal comfort [10].

The study identified key features from policy instruments and retrofitting initiatives across European Union (EU) member states that can improve the possibility of reducing energy consumption and optimising the thermal comfort level of occupants within the housing sector. Our study underlines the importance of adopting comprehensive, interdisciplinary collaboration in order to examine and test the energy performance of base-case representative RTBs in bringing appropriate energy-efficient retrofit interventions to improve building energy performance. We used this novel approach to determine the gaps in knowledge concerning occupants' real-life experiences in energy use and to identify measures that could optimise occupants' thermal comfort and reduce energy consumption through policy instruments.

This paper reports the findings of our environmental monitoring, which we performed during the summer at the post-war social housing estate in Famagusta, Cyprus. The variables measured during the survey are discussed to gain an understanding of the environmental conditions of the surveyed flats and their role in our assessment of both the occupants' thermal comfort level and the risk of overheating experienced in summer. The findings from the thermal surveys, environmental monitoring, and in situ measurements have been critically examined and discussed, and the results of the overheating analysis have been prepared with the intent to offer tangible recommendations for improving the existing energy performance of the flats and the thermal comfort of the occupants. Also, the findings provide significant insights that can inform future policy decisions.

The aim of this study was to provide a critical insight of previous studies that have applied experimental and simulation techniques to evaluate thermal retrofits, with focus on data collection and simulation methods. This paper discusses the findings of three different alternative passive design systems as potential solutions to reduce overheating, particularly in the summer season. In these passive design strategies, it showed the use of natural ventilation systems, appropriate shading devices, and fenestration designs to improve both energy performance of a house and occupants' thermal comfort under the climate change impact. The key innovations to demonstrate the state-of-the-art and development of passive cooling design strategies are as follows.

- To investigate how data-driven building performance simulation may be used to improve predictive capacity and develop robust retrofit solutions;
- To compare on-site walk-through thermal imaging survey campaigns in terms of simulation parameters, temporal resolution and data application, and,
- To identify a range of approaches within the literature, with a bias toward simulating simple performance models over detailed data-driven analysis.

The study objectives are threefold. The first objective is to evaluate the current thermal comfort and energy performance of prototype base case study building in the coastal city of Famagusta where the weather is hot and dry in summer. To accomplish this evaluation, high rise RTB was identified as a base case scenario development, since such structures represent the most commonly built housing typology and building-construction materials considered in this study. The second objective is to evaluate building fabric thermal performance of each occupied space in order to provide a basis for the subsequent research phase. The third objective is to develop and test the applicability of various passive design strategies as potential retrofit measures to the tall residential buildings to achieve improved thermal comfort and reduced cooling energy loads.

The novelty and scientific significance of this study is firstly, the framework developed for optimisation, which achieves effective building performance evaluation (BPE) tools, datasets and scripts. The study will contribute to the strategic design of retrofit interventions to effectively reduce cooling energy consumption by considering occupants' thermal comfort, thermal adaptation and energy use.

1.1. The composition and evaluation of Cyprus's housing stock

The theoretical component of this study consists of a combination of the UK assessment technical procurement and the EU assessment criterion in order to identify the optimum thermal comfort of occupants. Therefore, from the beginning of this study, there were limited pre-existing sources available for the Cyprus context, and this study was aimed at primary data collection to develop the methodological framework. Thus, a case study was necessary to enable the research consortium to achieve the intended aim of demonstrating the condition of the post-war social housing structure. This documentary highlights the stages of housing developments from 1950 to 2017 in Cyprus, as illustrated in Figure 1.

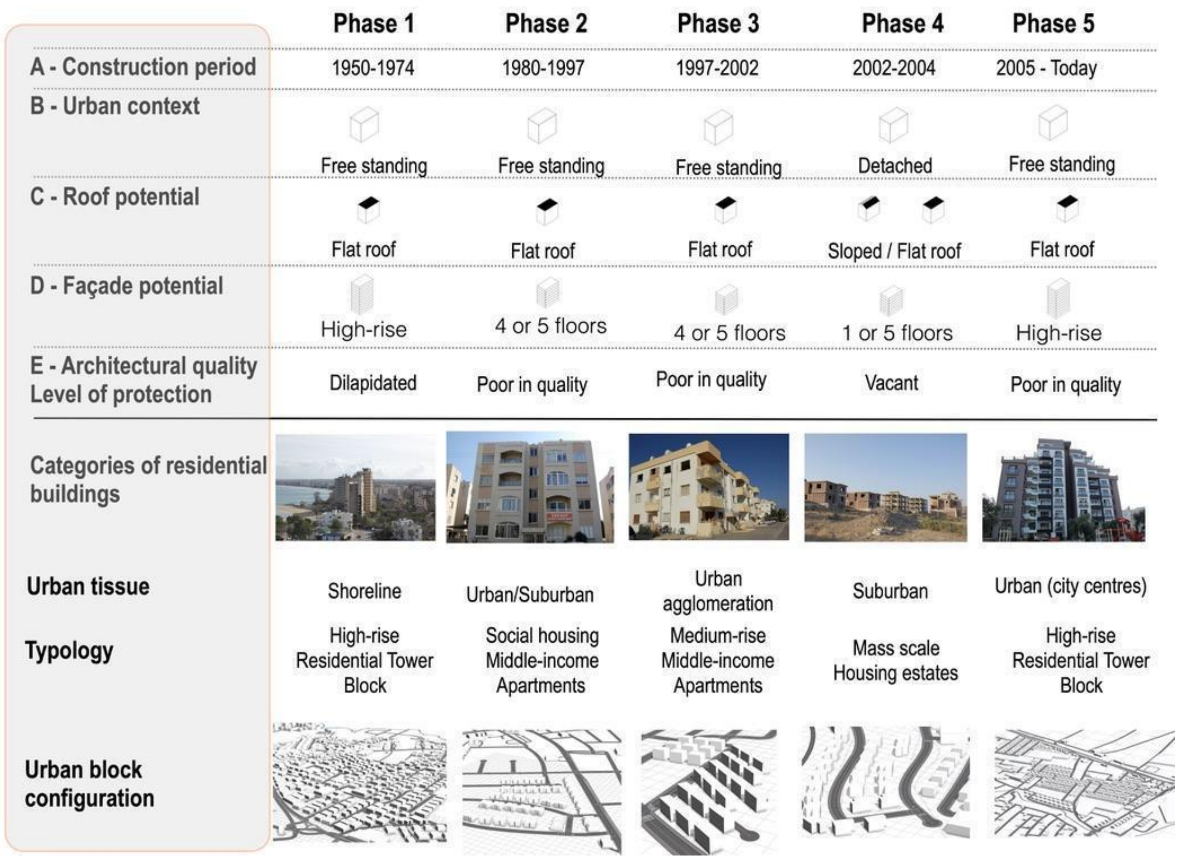


Figure 1. The taxonomy of housing stock in Cyprus.

As shown in Figure 1, Phase I describes the mass housing development from 1950–1974 in the fenced-off Varosha territory from 1950–1960 during the British colonial administration. Varosha and its coastline consisted of single-storey bungalows and two-storey detached houses after the 1960 independence of Cyprus from the British administration. It can be seen that the coastline was handed over to overseas developers where all the high-rise RTBs were built within a 14-year period of rapid mass housing development. According to housing statistics from 1974, 34,000 residential projects were constructed in the Varosha territory; however, this development came to a standstill in 1974 due to the civil war, and the city has been closed to human habitation ever since [11].

Phase II delineates the government's social housing estates, which were built from 1980 to 1997, to answer the needs of the housing shortage for young people. Within a decade of implementing the same residential building typology, these types of housing estates were repeated in all five major cities across the country. All these RTBs had the same floor plan layout, two flats located on each floor, and the same deficient building envelope which did not consider the local climate conditions and topographical conditions of the project sites. The housing stock analysis reveals the way these RTBs were built without informed decision-making in respect to land use planning layout. All these RTBs lacked planning for a social housing structure scheme, and this led to the housing estates having poor air quality for its residents and high thermal conductivity in the summer, which caused an overheating risk and a thermally uncomfortable indoor environment for the occupants.

Phase III illustrates that the construction of these housing estates was continued by privately owned construction companies after 1997, when the government's social housing scheme ended. This has continued to this day. These privately owned construction companies are still building estates using exactly the same method of construction as the government's social housing, which has no land use policy, no consideration of environmental and climatic design principles and no type of ventilation strategies for the occupant's thermal comfort; hence, no lessons have been learnt from this poor construction practice over this 30-year period. Phase IV describes the property boom that was expected after the changing political structure in Cyprus. All these projects were built without the authorisation of the Chamber of Architects and the Department of Town Planning of Cyprus due to the national policy gap from 2002 to 2004. This resulted in attracting both local private construction companies and overseas developers to engage in the construction of these types of mass housing development estate projects located in five major cities in Cyprus, as well as towns in the rural and mountainous areas. The aim was to build and sell these settlements within the surrounding natural habitat without considering the structure of the housing in relation to its surroundings. This led to the abundance of incomplete housing structures left abandoned all over the country as an eyesore and detrimental to the natural habitat.

Phase V demonstrates how the private construction companies' objective evolved into building mass mega high-rise towers and urban block developments throughout the country in towns, rural villages and mountainous regions without ever considering the respective local climate characteristics and topographical conditions. At present, these are unfortunately the only mass housing schemes that are being constructed, and they will cause more environmental and socio-cultural problems now and in the future.

This evolution of housing stock clearly outlines the stages of building mass housing estates in Cyprus and reveals that, starting with four- or five-storey RTBs in the 1990s, which ultimately led to 25-storey skyscrapers, the stages of development had no defined planning scheme at all, no governmental policy nor any control mechanisms – all to detriment of the environment and thermal comfort of the residents. Thus, this study can assist in the establishment of an initial benchmark to guide the development of housing that addresses all the concerns of the residential sector in Cyprus. Based on the findings and related information, government agencies can determine appropriate policies to be implemented in the future for the decision making of retrofit policy design in this south-eastern Mediterranean climate.

1.2. Building performance implications

A pragmatic way of quantifying the effect of thermal comfort is defined by the CIBSE – Technical Memorandum 52 guidelines for new buildings, major refurbishments and adaptation strategies should conform to Category II in BS EN 15251 [12]. A further method has been suggested in the CIBSE Guide (2005), the BS EN 13779 – Ventilation for residential buildings: Performance requirements for ventilation and room-conditioning systems [13]. This assessment criterion has further been put forward to provide basic subsequent information to assess the quality of indoor air and relate these to fresh air ventilation rates required for each occupant [14]. Studies have focused on the assessment of energy performance of implementing state-of-the-art building systems into building retrofitting that may require prediction of the way air moves through the building [14]. This is a research gap that has not been addressed previously in similar studies. Should this approach be employed, it is recommended that the approach to 'overheating' taken here is to measure the indoor thermal comfort independent of the metric used to assess performance of residential buildings [15].

Another assessment method is provided by standard BS EN ISO 13786 – Thermal performance of building components: Dynamic thermal characteristics and calculation methods which is a more direct measure of effective thermal mass, also accounts for the dynamic effects in terms of penetration depth of the temperature fluctuation into the fabric [16]. The adaptive approach is currently implemented in the CIBSE TM59 Guide – Design methodology for the assessment of overheating risk in homes [17]. In order to perform a generally reliable study, a method has been suggested by Fanger in the 1970s and a practical application has also been demonstrated by Holmes and Connor in 1991 [18-21].

From this point of view, the CIBSE AM 11- Building performance modelling (2015) provides guidance on the use of detailed thermal models. According to what stated in the norms BS EN 13786: 2007, it has been assumed that if the heat gain to a space is below 35W/m2 there is unlikely to be a need for mechanical cooling [22,23]. It should be noted that state-of-the-art building systems and the implementation of effective retrofit interventions are encouraged in the first instance to reduce requirements before costlier and shorter life span systems are installed. It is noteworthy that this approach improves the cost-effectiveness of energy savings and increases the efficiency of buildings for the duration of their operational lives [24-26]. Furthermore, a recent study suggested by CIBSE Guide F - Energy efficiency in buildings in 2020 gives further detail on low-energy design principles [27]. However, the more it is known about the manner of both applicable and feasible design strategies which are put forward and the most effective solution is prioritized. Hence, more appropriate energy demand calculations must be undertaken throughout the early design stages of retrofitting scenarios to quantify these measures.

2. Materials and Methods

A quantitative research design was employed, involving the development of a building energy models for the existing residential tower blocks (RTBs), incorporating high-level building parameters and the energy use of the occupants; analysis of the existing energy performance of post-war social housing development estate; undertaking solar exposure analyses and dynamic thermal simulations (DTS); the investigation of representative apartment units to model the energy performance of a retrofitted RTBs' energy demand for cooling and occupants' thermal comfort during the overheating period, taking into account passive cooling design principles; and designing a prototype residential tower block as a climate-responsive building to improve energy efficiency using the simulation data for building performance evaluation. As an initial step, the performance of a case study building was modelled and simulated by employing Integrated Environmental Solutions' Virtual Environment (IES-VE) software add-in Apache-Sim Dynamic Thermal Simulation. Additionally, an ASHRAE 7-point scale was used to assess indoor air thermal comfort temperature levels to validate the adopted benchmark criterion as recommended by the CIBSE TM59 during the hottest summer month of August [28]. In this study, the dynamic thermal performance simulation studies of each representative apartment unit were carried out in an analytical energy simulation environment between May and September, the peak demand period for cooling energy use, as shown in Figure 1.

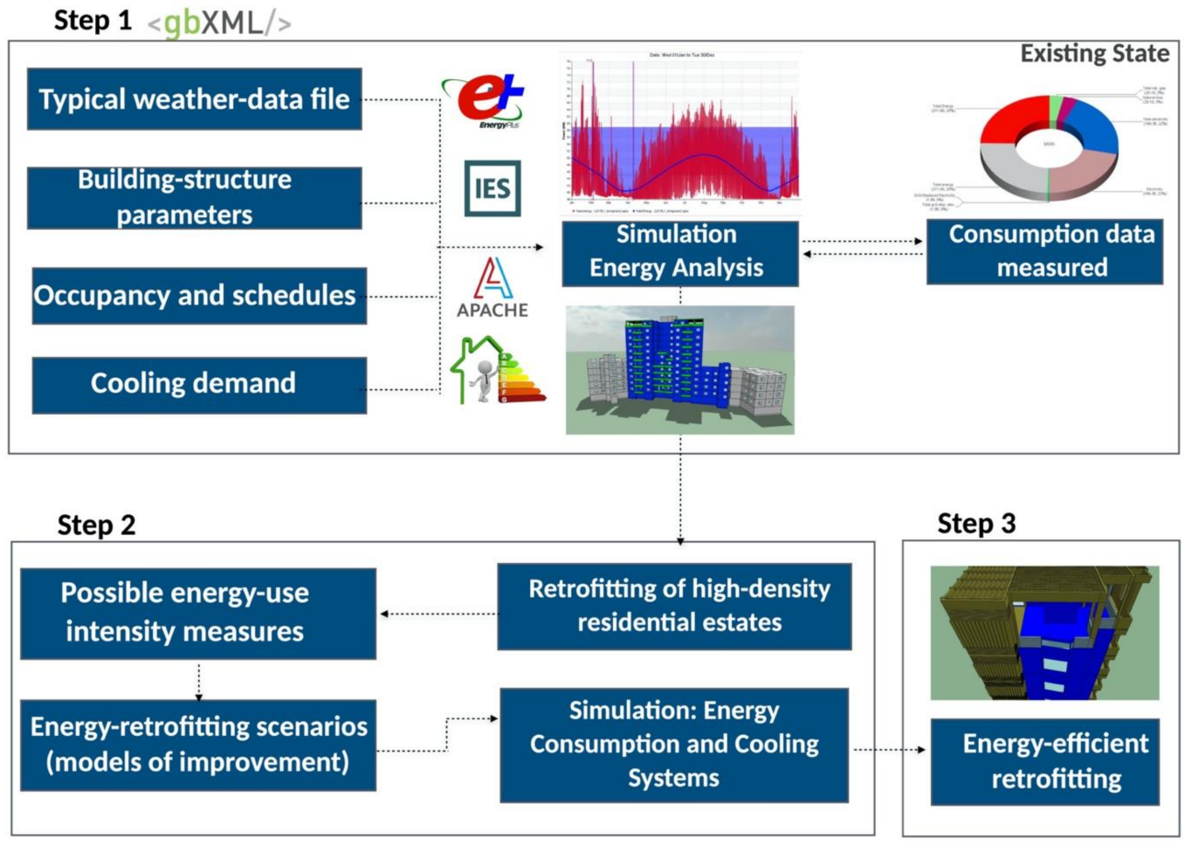


Figure 2. The methodological workflow developed for the building energy simulation study.

To fulfil the research aim and objectives, the periods were spread throughout the summer with the aim of measuring the risk of overheating in the RTBs. In each of the occupied zones (i.e. living rooms and master bedroom spaces), calibration studies were taken of the characteristics needed for energy use per area (naturally or mechanically) in order to take into account occupancy, the electrical energy use of equipment, internal temperature, the energy use of artificial lighting and of mechanical plants (A/C units). The aim of the selection is to capture a variety of space energy uses using relatively simple assessment benchmarks to import the data to the IES-VE simulation software for testing the validity of simulation results by investigating the daylight impact factor into each occupied space and thermal properties of representative apartment unit's under-investigation.

2.1. Prototype residential tower block development as base-case scenario

The Lordos RTB development is a miniature city, built in phases, which took over five years to complete; it is home to multiple storeys of flats, interconnected public spaces, vegetated private balconies, thresholds, passageways and vegetation. The main aim was to build a continuous urban landscape using a combination of staggered volumes, which move forward and backward in relation to the street and waterfront. The construction of the apartments began in 1968; the first dwelling was occupied in 1973 [29]. Most dominant in the district were the large high-rise blocks. This housing estate contains 118 apartment units in 12 different floor plan designs; the blocks are 30–40 meters long and 13 storey high, as shown in Figure 3.

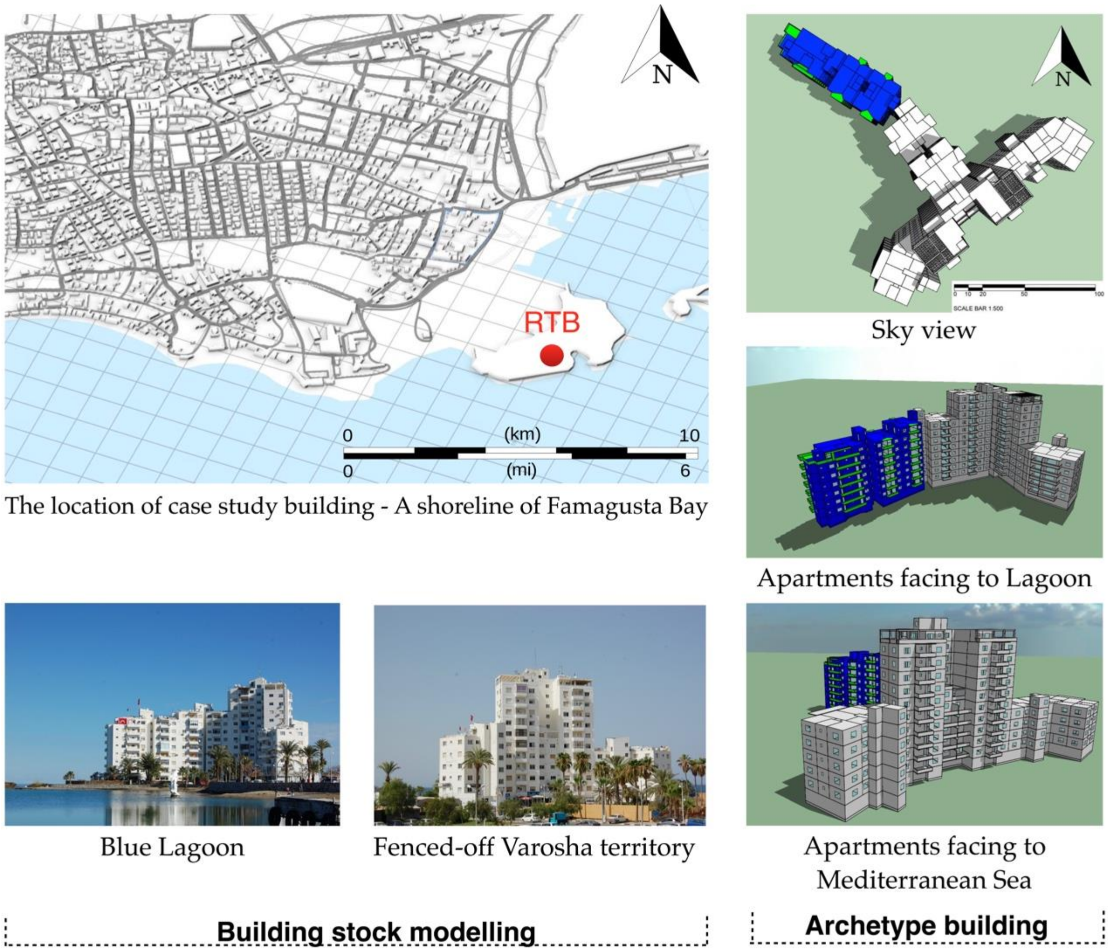


Figure 3. The location map of high rise post-war social housing development estate in Famagusta, Northern Cyprus; base-case RTB development, built in the 1970s; analytical energy simulation model of a southwest-facing apartment unit within the adjacent RTBs.

The case study building is representative of high-rise residential developments constructed by privately owned construction companies in the 1950s and 1970s. The conditioned gross floor area of the case study multi-family apartment unit is 75 m2. The original U-values were 2.35 W/m2K for external walls, 1.23 W/m2K for the internal walls, 1.2 W/m2K for the roof and 2.10 W/m2K for the windows and doors. Thermal specifications of construction materials are made according to the benchmarks of the British Construction Codes and Practices – Law 1959, which is the most recent data set available at the time of undertaking the research for this study [30].

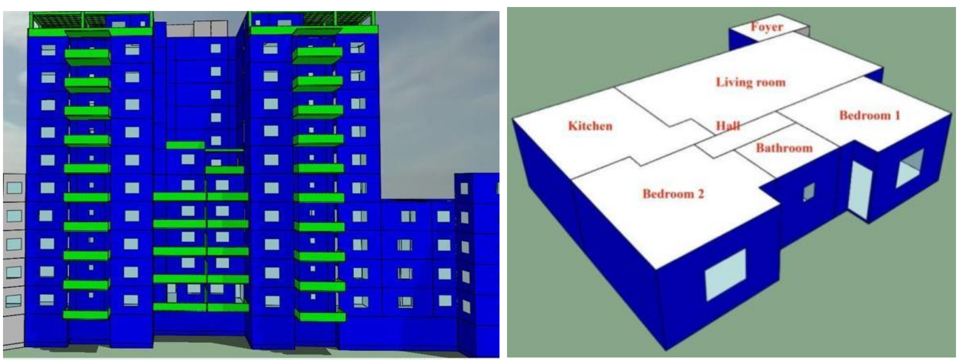


Figure 4. **(a)** The tested and simulated prototype RTB for a base case scenario development; **(b)** The analytical energy model of a representative apartment unit's under-investigation.

The building geometry was created for its initial existing state, every floor and apartment with correspondent thermal zones and subdivisions, as shown in Figures 4 (a) and (b), indicating clearly which zones and spaces are not heated like balconies, and storage areas.

2.2. Building modelling simulation

To provide sufficient resolution for the analysis of occupants' thermal comfort it was deemed necessary to use a dynamic thermal simulation (DTS) model. The Integrated Environmental Solutions Virtual Environment (IES-VE) suite was selected as the most appropriate application for this purpose. In terms of validated performance, IES-VE is understood to meet a number of international standards including CIBSE TM 59 and is also accredited for use to European standard EN 15251 as previously discussed in section 1.2. It is also necessary that the IES software suite offers a number of features collectively that were found to be beneficial to the analysis. These included the following: close reproduction of the existing building geometry, detailed breakdown of the energy results by end use and zone, and ability to externally control the model settings (construction and zone profiles) to measure both the quasi-steady state and dynamic thermal scenario analysis, as shown in Figure 5.

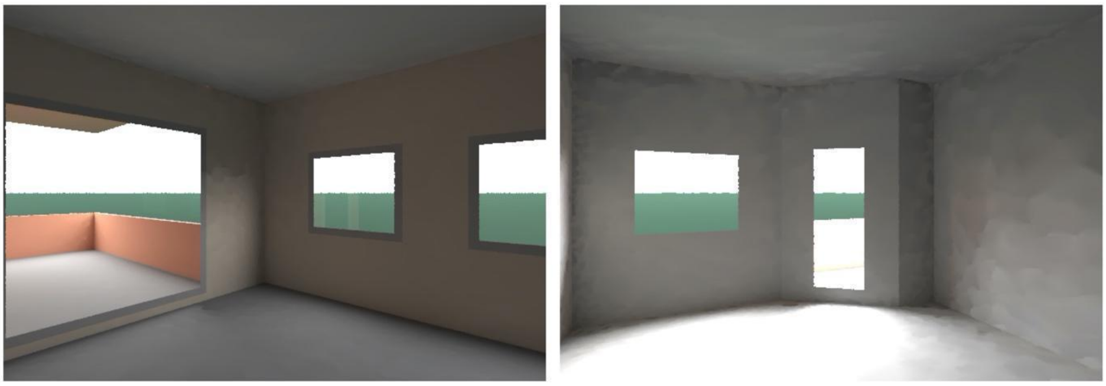


Figure 5. The interior view of thermal zoning of a living room and bedroom spaces for each representative flat unit in the RTBs.

The IES version used throughout was IES-VE 2021.1.0.0. Specifically, the Thermal Comfort assessment task of the IES software suite was found to be an application that could offer to measure the 'adaptive thermal comfort' of a prototype RTB. It is also of interest to consider that in combination with the dynamic thermal Simulation (DTS) components of the IES software, it was possible to assess the energy performance of material changes concurrently. To assess the energy performance of a prototype RTB, thermal templates were constructed in the IES platform of Apache-Sim. These templates define the space conditioning systems (Apache Systems) and gain variation profiles for zones within the building, as shown in Table 1.

Table 1. Contextual features and simulation parameters of prototype RTBs.

Building performance factors		Internal heat gains in the simulation
Number of floors	12	Occupants: 3 W/m^2
Area-to-volume ratio [m^{-1}]	0.33	Appliances equipment: 8 W/m^2
Floor surface of a typical tested room	32.5 (m^2)	Lighting: 2 W/m^2
Room volume of a typical tested room	102.7 (m^3)	
Window size	1.5 x 1.2 (m^2) per window opening	
Exterior window ratio	0.21	
Number of subjects involved	1 male and 1 female (parents), 1 boy and 1 girl	
Age of the subjects	Between 2 and 40	

As previously mentioned, the aim of the selection is to capture a variety of space energy uses using relatively simple assessment benchmarks to import the data to the IES simulation software for testing the validity of simulation results. Notably, all simulations were performed utilising CIBSE Test Reference Year (TRY) weather files from the neighboring city, Larnaca, for evaluating whole year building performance, including Design Summer Year (DSY) for the summer. Finally, three criteria were used for quantifying building performance: (i) annual energy demand, (ii) overheating risk assessment and (iii) thermal comfort in the summer. Comfort analysis was based on BS EN 15251 for identifying adaptive thermal comfort temperature limits, considering fixed limits in the summer for a naturally ventilated building.

3. Results and Discussions

The following sections discuss the existing energy performance of a prototype RTB, using the results and analysis of data collected from the outdoor thermal imaging survey, in-situ measurements and dynamic simulation modelling.

3.1. Thermal imaging survey

The case study RTBs were surveyed, and infrared thermal imaging was conducted with a thermal camera (Fluke TiS20) twice each day during the winter period, in the late evening and in the early morning, to avoid possible mistakes due to direct solar radiation. The thermal imaging survey investigating heat losses and assessing the overheating risk of a building were undertaken between 25/12/2017 and 12/01/2018. (see Appendix A.1 and A.2). A thermal imaging survey was carried out before this work to diagnose the building and, taking these data into account, to define optimal retrofitting strategies. The survey results of the base case for the RTB buildings demonstrated that most heat losses resulted from air infiltration, mainly through exterior walls without insulation and through windows (provoking a high annual energy demand for heating), as shown in Figures 6 (a) and (b).

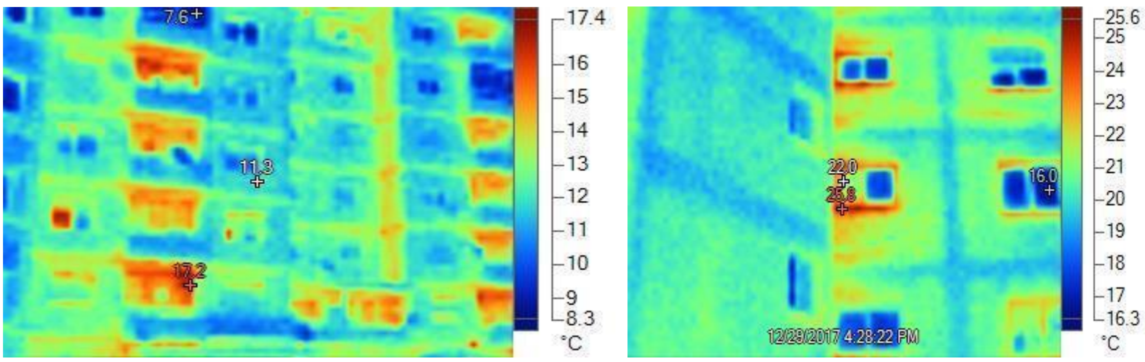


Figure 6. (a) Southeast elevation showing heat loss through the external wall, possibly due to insufficient building envelope insulation. Image taken 28/12/17 between 06:30 and 07:54 a.m. **(b)** Southeast elevation showing significant heat loss through windows and heat loss through wall junctions and cracks on building surface. Image taken 28/12/17 between 16:30 and 17:45 p.m.

All calibration studies were conducted using the SunCast simulation tool platform to validate the data from both the thermal imaging survey and in-situ measurements, as described in Section 3.2.

3.2. Solar exposure analysis

In this base-case model, the building performance evaluation simulation tool was used for assessing current energy performance of representative flats as follows; Sun-Cast (Solar Analysis), Radiance-IES (Daylighting), and Apache-Sim (Dynamic Thermal Simulation) platforms of the Integrated Environmental Solutions software suite. The objective is to identify the worst-case scenario before testing efficiency of systemic retrofit strategies in the following phase of this study. This section explicitly describes the building modelling simulation studies and analysis that were carried out and outlines the results of daylight impact factor on overheating, thermal comfort and energy use aimed at optimizing occupants' thermal comfort and reducing energy consumption concurrently.

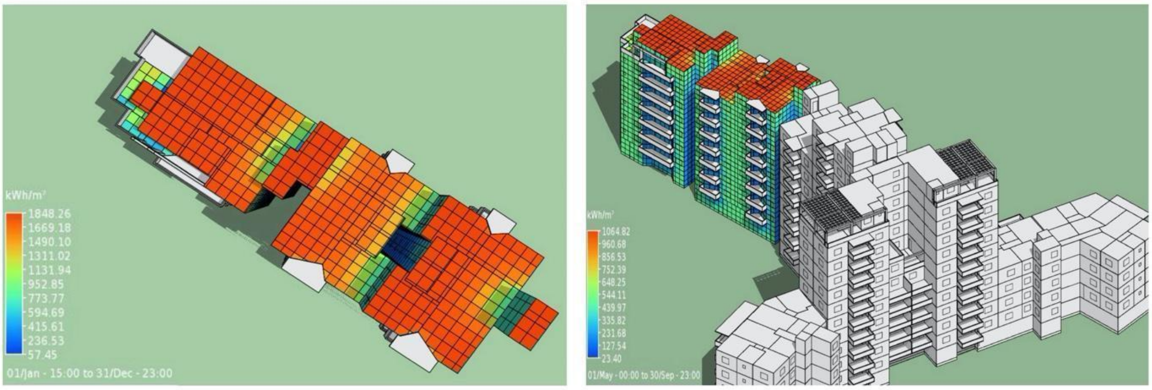


Figure 7. SunCast simulation demonstrating that monthly exposure to solar radiation exposure on the roof surface reaches 1,848.26 between January and December 2020 and, the southwestern building envelope reaches 1,064.82 between May and September 2020.

Figure 7 illustrates the maximum solar radiation when it occurs as well as the mean values for each floor level in the representative RTBs. The SunCast simulation analysis demonstrates that the annual maximum number of hours of exposure of surfaces to solar radiation occurs on the roof surface (approximately 1,848.00 hours), followed by the southwest facade of the building (approximately 1,064.92 hours). The survey results confirm that the upper floor level flat is most susceptible to overheating, followed by the intermediate floor along with the ground floor.

Figure 8. The sun path diagram demonstrates that the southwest-facing block experienced high levels of solar radiation most of the day in July and August 2020.

Additionally, in Figure 8, the solar path diagram shows that the angle of the sun varies throughout the year, affecting the solar gain during two periods, particularly in July and August 2020. It was found that the total surface area of the building envelope exposed to solar radiation flux reaches a maximum value of 1,848.26 W/m2K during the year.

3.3. Daylight impact factor on occupant's thermal comfort and energy use

The daylight simulations shown in Figure 9 were taken from the analysis carried out in a selection of the worst-case representative living room unit between January and December under overcast standard sky conditions on the horizontal surfaces. This simulation analysis allowed us to understand the daylight impact factor on energy use in regard to overall understanding about the overheating issues experienced in the RTBs. As previously mentioned in section 3.2, the inefficient building envelopes absorb high solar radiation throughout the year, and it creates a thermally uncomfortable environment for its residents.

Figure 10 illustrates the daylight factor (DFs) on the surfaces within the main rooms are above 292.5lux indicating that the rooms will appear well lit. In the service areas, however with no direct access to natural light from the windows, the light levels will be below the 50 lux value. From these results, it was found that all occupied spaces, particularly southwest-facing living rooms, have experienced overheating risk issues due to direct solar radiation and high levels of daylight impact on occupants' thermal comfort. These findings strongly correlate with each other while assessing the overheating risk of each occupied space at home. Nevertheless, the daylight analysis provides subsequent information to identify energy efficient and cost-effective retrofit interventions that will be taken in the following phase of the study.

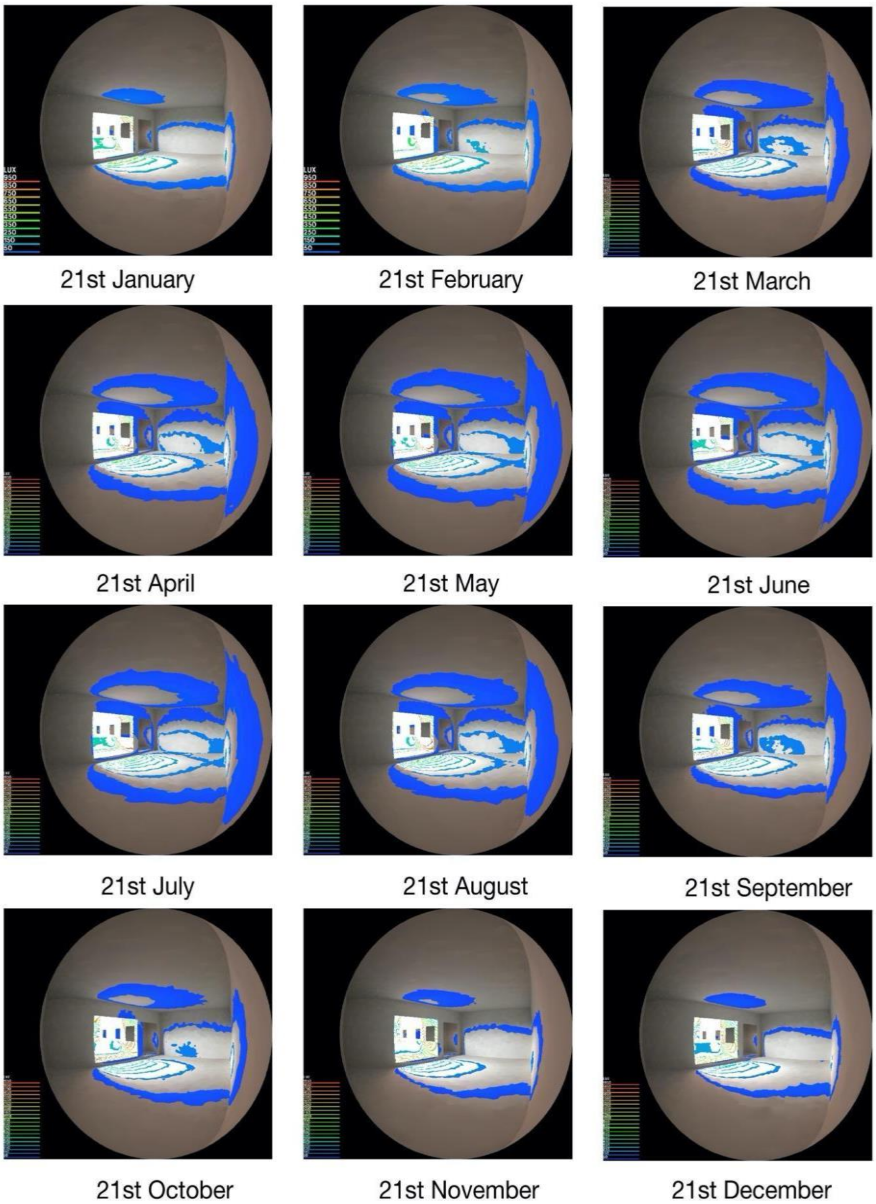


Figure 9. The daylight impact factor analysis of the upper-floor representative flat's living room between January and December 2018.

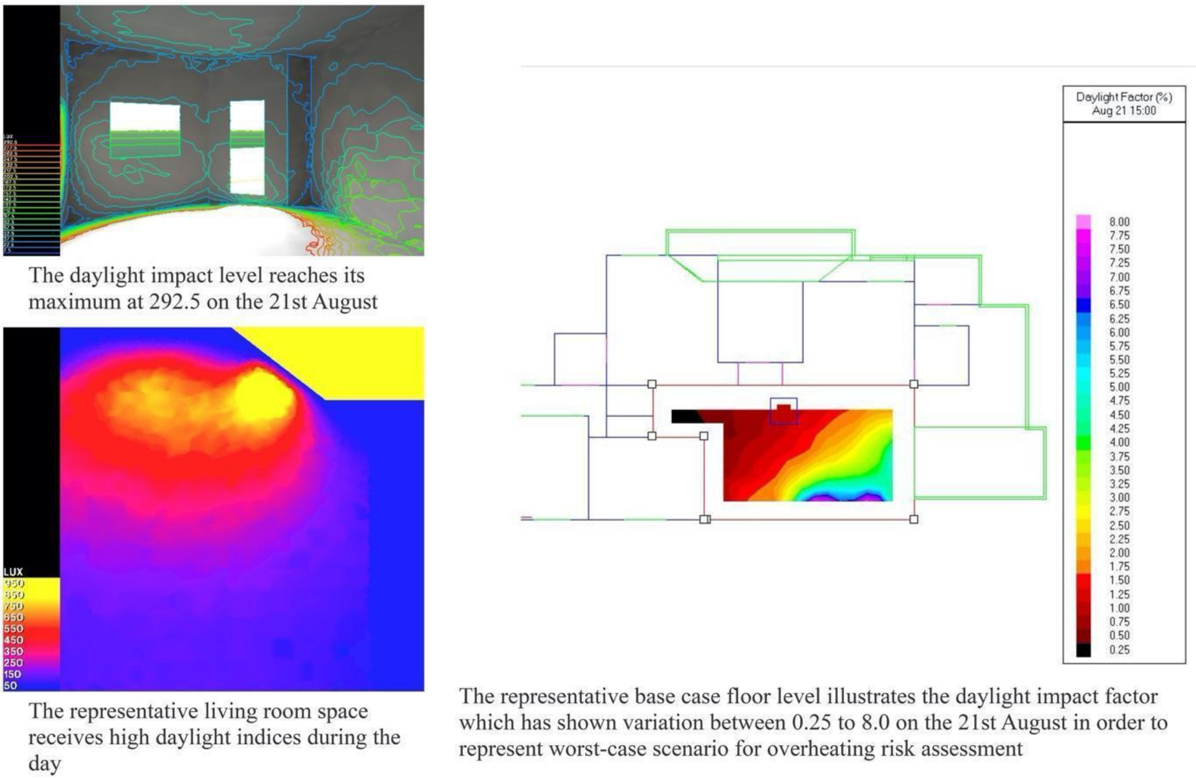


Figure 10. The daylight impact factor analysis of a representative base-case southwest-facing flat unit during the hottest summer day of 21st August.

As can be seen in Figures 9 and 10 of the representative flats, only three external surfaces are exposed, and all three show different heat gains throughout the year with high daylighting levels in the summer. This creates overheating risk due to the lack of shading systems installed on the building envelope. It should be noted that upper-floor flats showed the greatest overheating risk issues due to the impact of the deficient building envelopes. Hence, all the bedroom spaces on the upper and intermediate-floor flats are under a higher threat of overheating when compared to CIBSE TM 59 overheating criteria. Notably, the living rooms are also susceptible to overheating, but from different factors; they have large window-opening ratios with no shading, and all of them face to southwest orientation, exposed to high intensity sunlight through most of the day. These factors together lead to overheating issues and a high degree of occupants' discomfort, particularly in the summer.

3.4. Energy use

As previously stated, the Apache-Sim (Dynamic Thermal Simulation) tool was used to carry out thermal analysis performing predictions of the heating/cooling energy loads in this ill-performing occupied space in the flat and the following results are for the living room unit (as an example), which was simulated between January and December in order to assess total energy use. In Figure 11 shows that the specific monthly peak demand for electricity use in the base-case reached up by 77.8 kW between January and December.

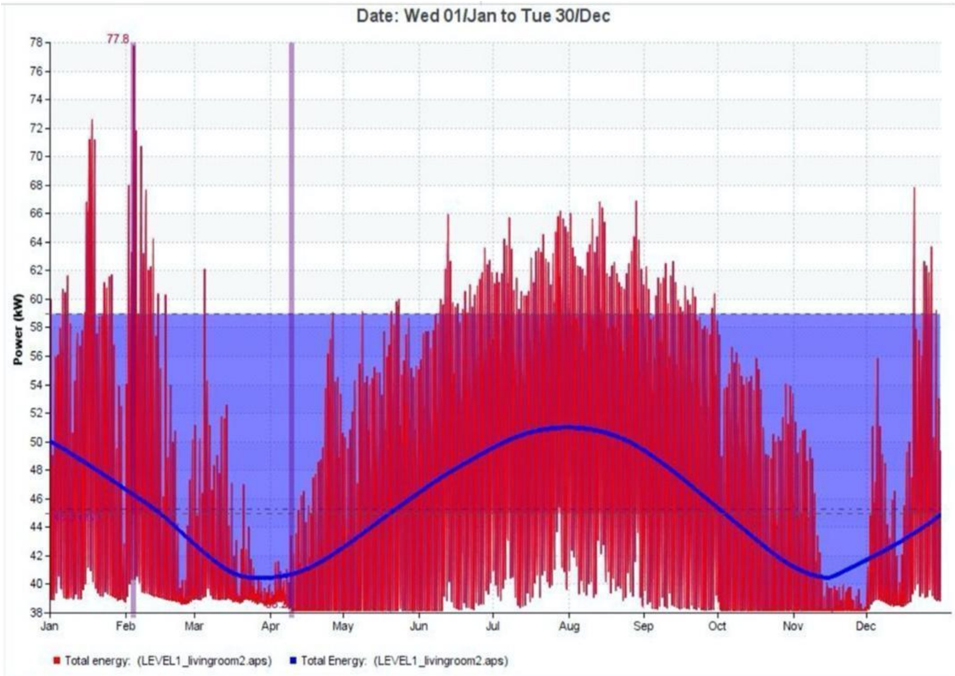


Figure 11. The overall energy consumption of the worst-case representative flat unit reached its peak at 77.8 kWh in February.

It can be seen that the house owners are predominantly reliant on using wall mounted air-conditioning units in this particular apartment unit. However, the energy consumption fluctuations in Figure 12 demonstrate that the monthly peak energy demand in the flat was above 57.4 kW between mid-May and mid-September, and further simulations led to a consumption of 53.2 kW in August on the monthly cooling load of the living room unit, while in the worst performing bedroom unit 1 specific monthly heating load reached up approximately 35.3kWkW in February as shown in Figure 13.

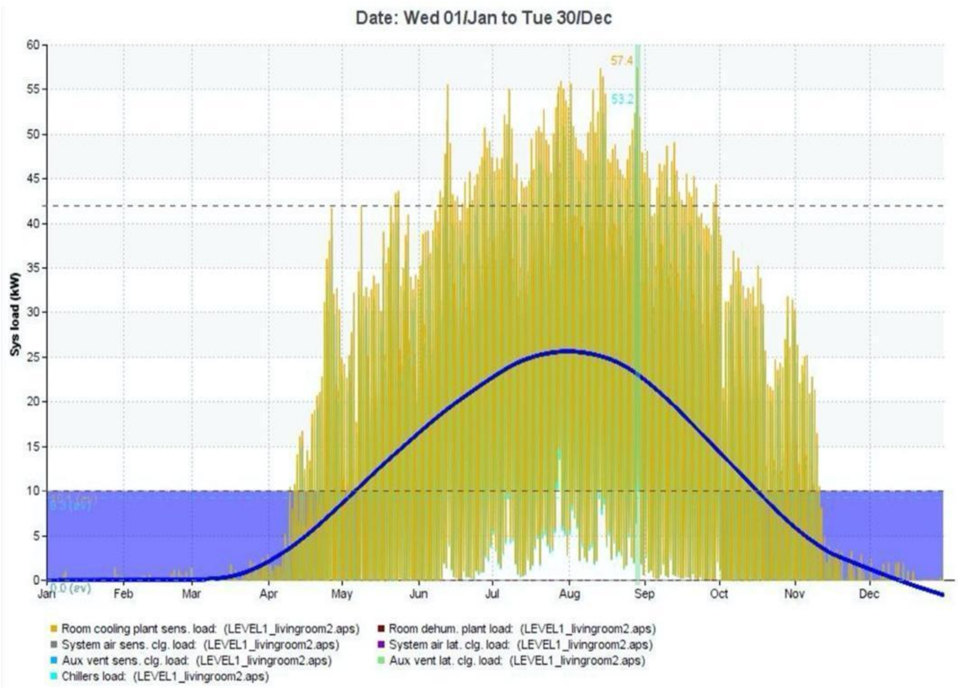


Figure 12. The overall cooling energy consumption of the worst-case representative flat unit reached its peak at 57.4 kWh at the end of August.

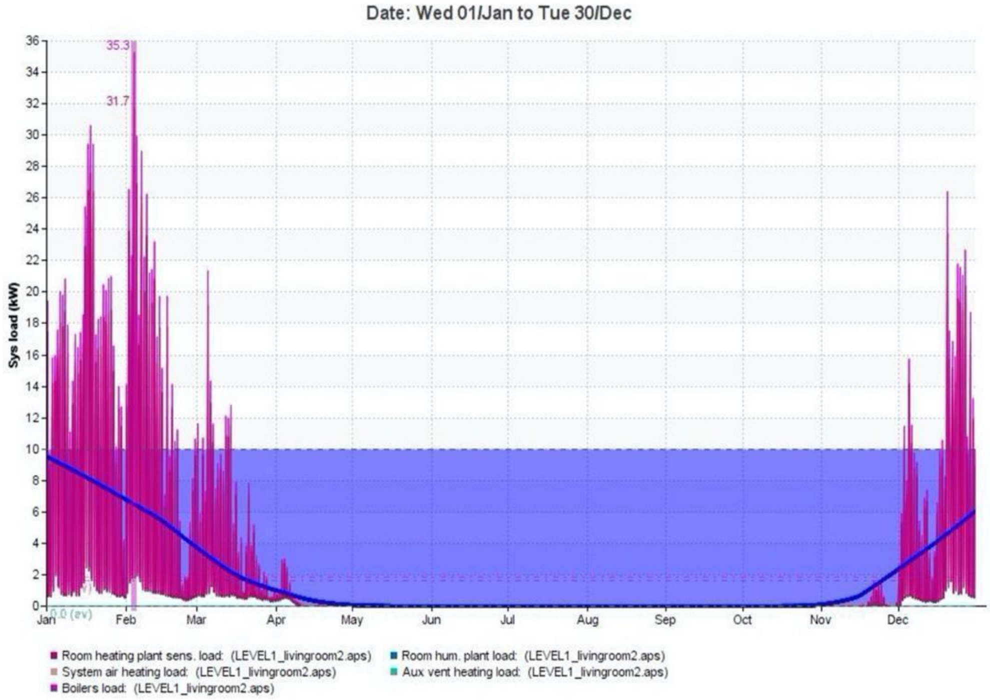
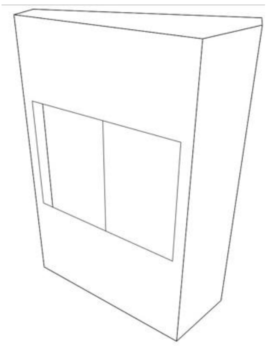
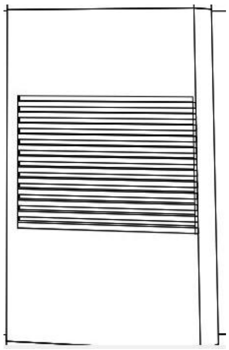
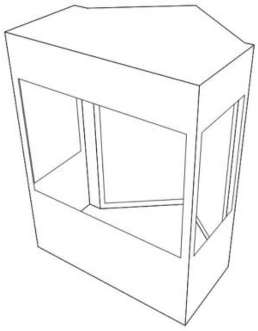
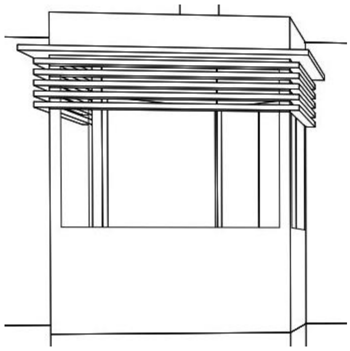


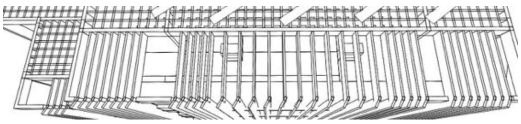
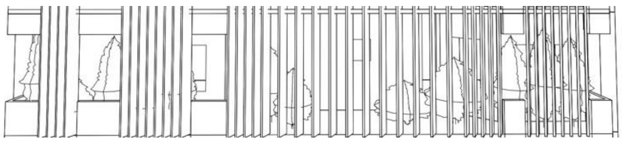
Figure 13. The overall heating energy consumption of the worst-case representative flat unit reaches its peak at 39.3 kWh in February.

From the dynamic thermal simulations in order to assess current energy consumption of representative upper-floor flat units, the results reveal that the occupants spent high expenditures for their energy bills, particularly in the hottest summer month of August. In order to reduce energy consumption and optimise occupants' thermal comfort, several retrofit interventions were implemented on the building envelope. The following step has been the evaluation of state-of-the-art passive cooling design strategies implemented on the building envelopes to help reduce overheating risk of the case under study with a focus on the 10th floor-level flat unit. In order to compare the overheating and thermal comfort of various retrofit scenarios when there is no Heating, Ventilation and Air Conditioning (HVAC) system for each scenario, the thermal performance of the upper-floor level was studied comparing the hours of discomfort by using CIBSE TM 59.

To understand the efficiency of a passive design system and its integration into contemporary residential buildings, it is essential to examine the effectiveness of the thermal properties of the representative base-case RTB development as a case study. The following steps evaluate potential passive design strategies to reduce overheating risk and to optimise occupants' thermal comfort for the worst-performing south-facing RTB. For this analysis, five design alternatives were tested to assess the efficiency of each as a potential retrofit scenario, as shown in Table 2.

Table 2. Specifications of passive design strategies on those of existing base case.

Sunscreen fixed blade (S1)	**Venetian blinds (S2)**	**Overhang (S3)**	**Venetian blind – Roller blind (S3)**
			
• Outdoor solar shading, pre-oriented blades fixed to the façade. This shading could also have vertical blades; this case, most effective for south/west orientation, is more frequent in residential building applications. • The blades can also be applied to shield balconies. • Blade selection: ellipsoidal, arcaded, triangular, gull wing etc. • Blade materials: extruded aluminium, formed aluminium sheet or bent, wood, PVC, porous ceramic etc. • Horizontal blade height (mm): 25–1,200 • Blade intersection (mm): 70–150 Max length (mm): 8,	• Solar shield for outdoor use with adjustable and packable blinds. • The packaging of the blinds allows a very compact folded element once rolled in. • The typology can also be applied to screen balconies other than windows. • The opening of the shutter can be the classic hinged, folding, sliding. • The blinds can also be adjustable, allowing good modulation of radiation and light. Blind material: wood, aluminium, PVC, etc.	• Overhang fixed opaque, made out of different materials, consisting of horizontal and vertical elements to create a grating pattern. • Blind section: arched • Blind materials: aluminium, alloy etc. • Blind supports: steel etc. • Blind height (mm): 58–95 • Blind width (mm): 500–4,500 • Screen height (mm): 400–5,000	• Double glazing, integrating into the interior chamber of variable thickness a venetian blind, roller or pleated. • The sliding of the tent takes place in a sealed package containing desiccants to ensure the control of humidity and vapour condensation. • Venetian blind, with respect to roller blind, provides a vision of the outside, even screening down, because it has oriented slats. Max dimensions (mm): 32 (pleated and venetian blinds)

Vertical Sunscreen (S4)	**Fixed overhang (S5)**
	
• The sunscreen consists of operable vertical blinds or grilles anchored to a structure perpendicular to the façade. • Blind material: extruded aluminium, bent or formed aluminium sheet, PVC-coated copper, wood, glass. • Structure material: aluminium, galvanised steel. • Blade height (mm): 70–1,500 • Blade length (mm): max 6,000 Blind step (mm): 70–150	• Overhang, fixed vertical, opaque, made with different materials (sheet metal, treated wood, plastic materials etc.). • Anchored to the wall with an autonomous structure or structurally integrated. • The shields may also have a vertical arrangement perpendicular to the façade; in this case, they are most effective for east and west orientations

When all strategies were taken into account and all representative sample flat units were simulated with the relevant thermal conductivity level of the RTBs, the results reveal that the living room in the southeast-facing upper-floor flat exhibited the highest cooling demand with a decrease of 21.69%, while Bedroom 2 demonstrated a cooling demand of 21.60%, as shown in Figure 14. These values reveal a decreased demand for cooling-energy of 78.49 kWh/m2 in the intermediate floor and 69.79 kWh/m2 in the ground floor. It should be noted that when all strategies are implemented, the annual energy consumption can be reduced by 28.1% (compared to the minimum level case), to 11.3 kWh per year.

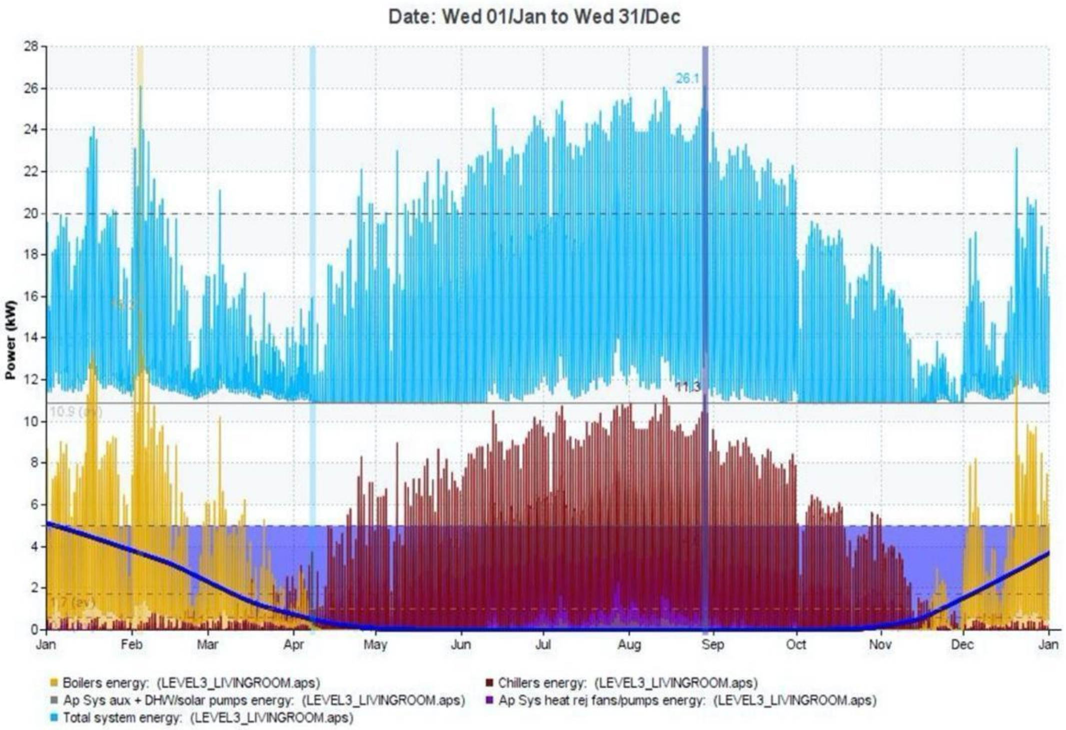


Figure 14. The overall energy consumption of the worst-case representative flat unit after implementation of state-of-the-art energy efficient materials onto the building envelope between January and December.

Additionally, starting from these base case studies, when the adaptive set-point is used, the decrease in the cooling demand is related to taking into account passive design measures such as natural ventilation, in the case of the heavier construction materials and its systems. This is due to the strong effect of heat loss from the heavyweight structures caused by additional discharge rate during the night-time. This is because the adaptive indices have been developed according to the occupants' thermal sensations and preferences. In this study, the adaptive comfort temperature represents the acclimatisation system set-point as autonomously managed by the occupants, including the external climatic conditions of the simulated and tested indoor space. This is due to the fact that the measured outdoor temperature is above the comfort level zone which is shown in Figure 15. The findings illustrate that there is a significant temperature difference between outdoor and benchmark comfort levels of the indoor environment.

In addition, the annual energy consumption of the typical multi-family apartment unit with a medium weight and light weight structure are more or less the same as the one with heavyweight structure. The annual energy consumption of medium weight RTBs were found to be 134.7 kWh, 111.8 kWh and 98.5 kWh per year in comparison to the median case level respectively. The annual energy consumption of S1, S2 and S3 are 136.6 kWh, 112.6 kWh and 98.9 kWh for these three design interventions respectively. The findings revealed that the total annual energy consumption of the S 4 is slightly lower than the S5 (ranging from 0.3% to 2.0%) for all other three design interventions' thermal fabric efficiency.

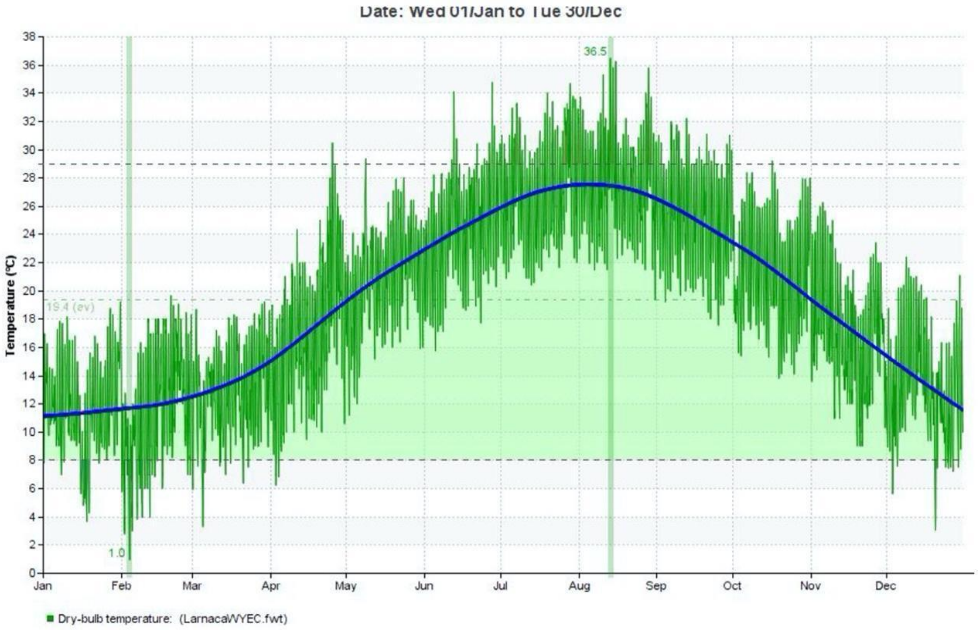


Figure 15. The indoor air temperature fluctuations of representative upper-floor level flat units before retrofit interventions were undertaken.

Figures 16 and 17 summarise the overall cooling demand reductions connected to the introduction of the variable set-point in summer are shown for all three representative sample flats. The results point out that during the cooling season, the cases reveal significant differences based on the adaptive temperature set-point of the heavy weight construction materials, in particular for this base case model RTB, which is not provided with any insulation layer. This can be clearly seen in the base case and in the retrofitted case, while only the night ventilation strategy, allowing the loss of the stored heat, significantly reduces the calculated need of the heavy weight conventional building.

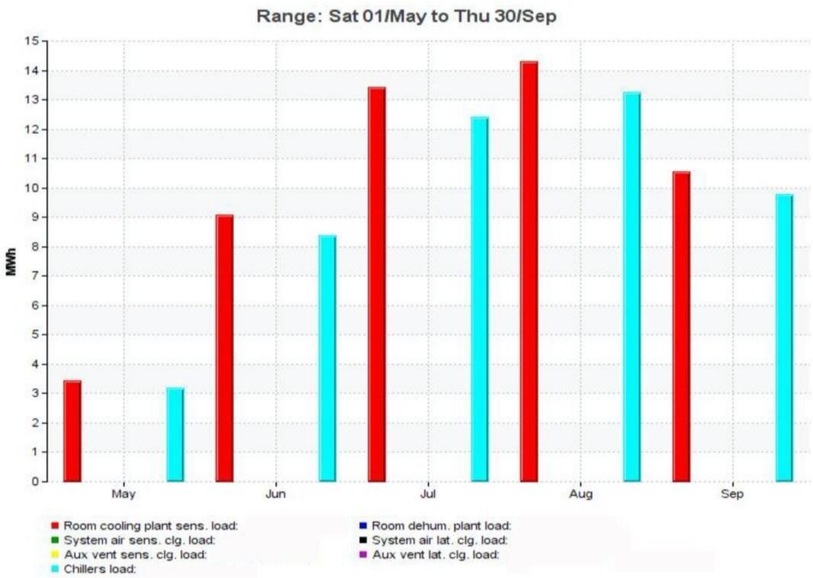


Figure 16. Distribution of overall cooling energy consumption of the base case representative upper-floor flat unit before retrofitting.

Furthermore, it is important to highlight the fact that comparing the base case and retrofitted case, the reduction in the cooling demand assesses for the heavy weight constructions tend to decrease as the height of the floor level and orientation of the flat, while in case of implementation of state-of-the-art energy efficient building materials into retrofitting the trend is inverse. This is due to the fact that in the upper- floor flat unit, there is a larger gap between the conventional set-point temperature and the occupants' expected one.

Moreover, energy savings achieved through improvement of building fabric are similar for the heavyweight, medium weight and lightweight structure. For the medium weight structure, with the design parameters of the base-line scenario taken into consideration, the total energy saving is 27%, while with the passive cooling design strategies implemented onto the building envelope, the total energy saving is 67%.

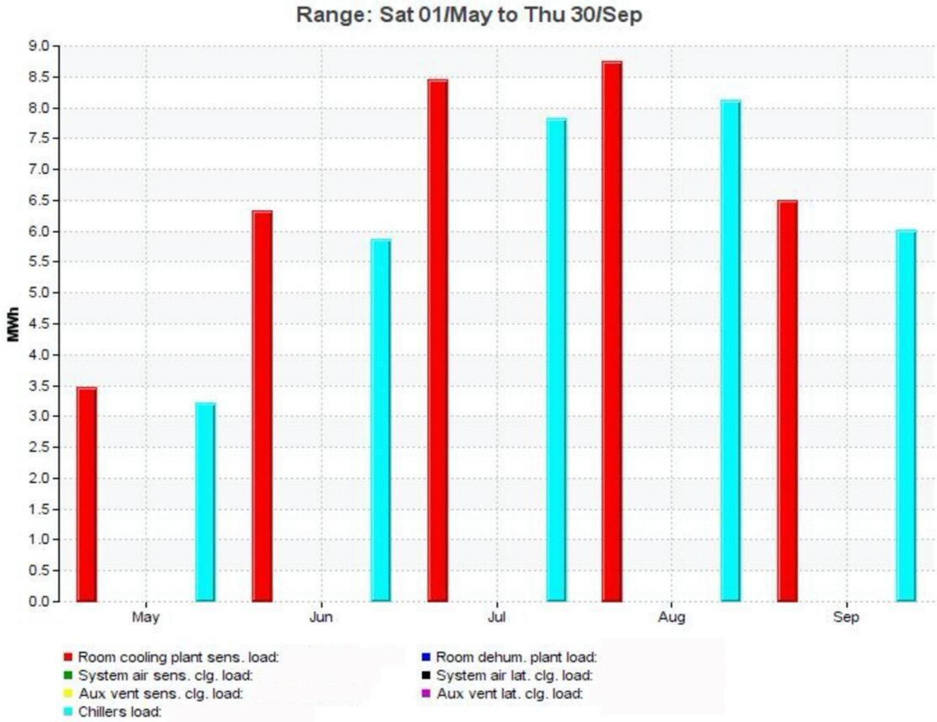


Figure 17. Distribution of overall cooling energy consumption of the base case representative upper-floor flat unit after retrofitting.

It can be seen that the zones under consideration within the case study RTB's sample flat units are found to exceed the acceptable limits of the CIBSE TM 59 criteria as shown in Figure 18. The worst-case calculated building space is the living room as it incorporates the internal heat gains from the open plan layout design kitchen as these are interleading rooms. The flat units with poorer ventilation performance were shown to be in the worst-case representative ground floor flat unit. This is attributed to the opening ratios and material properties of the double-glazed windows. These flat units are constructed with three exposed external walls allowing for a higher rate of heat transfer. Comparing the dynamic thermal simulation results shown in Figure 18, in order to take into account, the location of the flat units on a different level, the height of the RTB influences the air infiltration rates of the flat units.

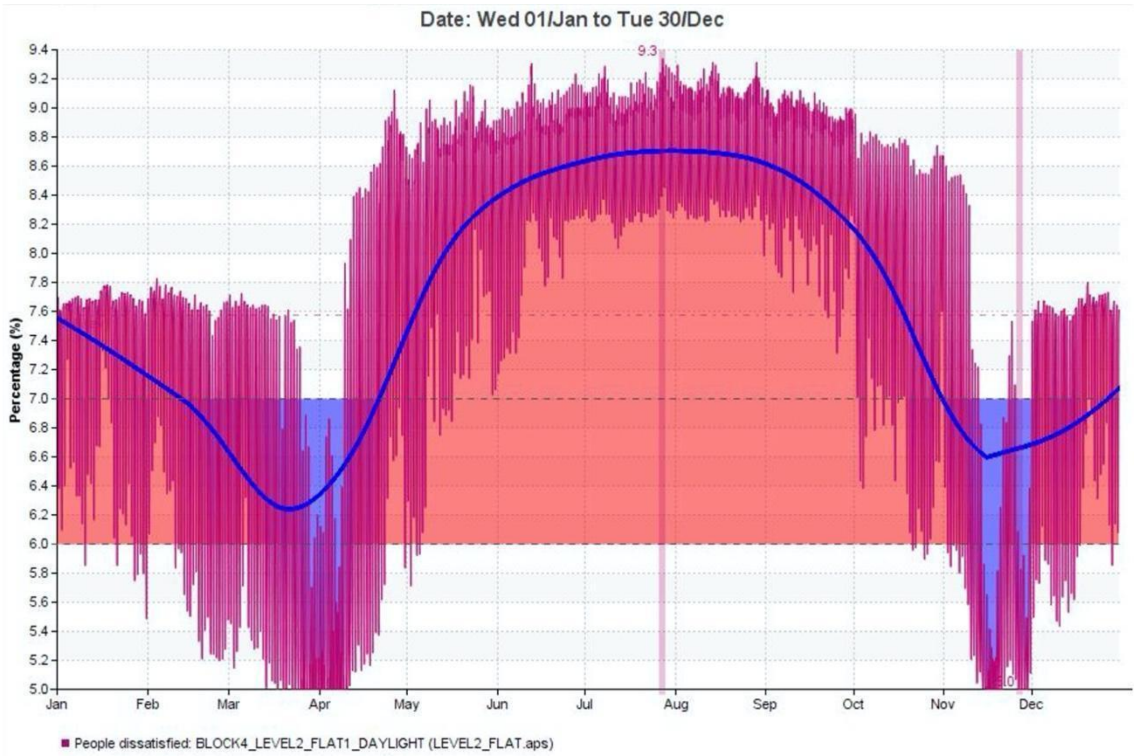


Figure 18. The fluctuation diagram represents the Predicted People Dissatisfied (PPD) levels after implementation of all three selected retrofit interventions.

The prototype RTB is subjected to effects from "buoyancy-driven air movement". Because of this approach, hot air from the lower levels rises up through the building and with no means of escaping the living zones, accumulates on the top levels. Combining this with the effects from the building envelope corresponds to the inadequate thermal performance of the worst-case first floor flat unit for all three criteria as defined by the CIBSE TM 59, as shown in Figure 18.

The struggle against climate change requires an investment in retrofitting existing residential buildings, particularly those considered most vulnerable (with uninsulated thermal envelopes) and those whose occupants are more susceptible to energy poverty. In these retrofits, we must actively consider the reduction of energy demands to minimum levels by performing interventions on the thermal envelopes of the buildings. In the three cases of surveyed and simulated RTBs in Famagusta, Cyprus, the positive impact on indoor temperatures and comfort of retrofitting the envelope was shown. With this action (retrofitting the facades, roof and windows and reducing infiltrations) and with very minor reliance on cooling systems in the summer, a decrease in indoor air temperature of between 2 °C and 4 °C was achieved.

In both the present situation and by the year 2050, with respect to climate change, the retrofitting measures proposed for the thermal envelope would allow for residential buildings with almost zero cooling demands in some European locations. The key factors which would contribute to this objective are the design criteria for the envelope, taking the following into account: (a) the climate, the differences between floor levels and the orientation of the buildings will require greater or lesser levels of intervention (i.e. thickness of insulation); (b) orientation towards the south for greater solar gains; (c) the position of the dwelling in the building, so that all apartments have the same energy demands and (d) ventilation incorporating occupants' thermal comfort in the RTBs. Figure 19 delineates the key outcomes of this empirical study to demonstrate the contribution to knowledge for the development of effective retrofit design policy in the South-eastern Mediterranean basin.

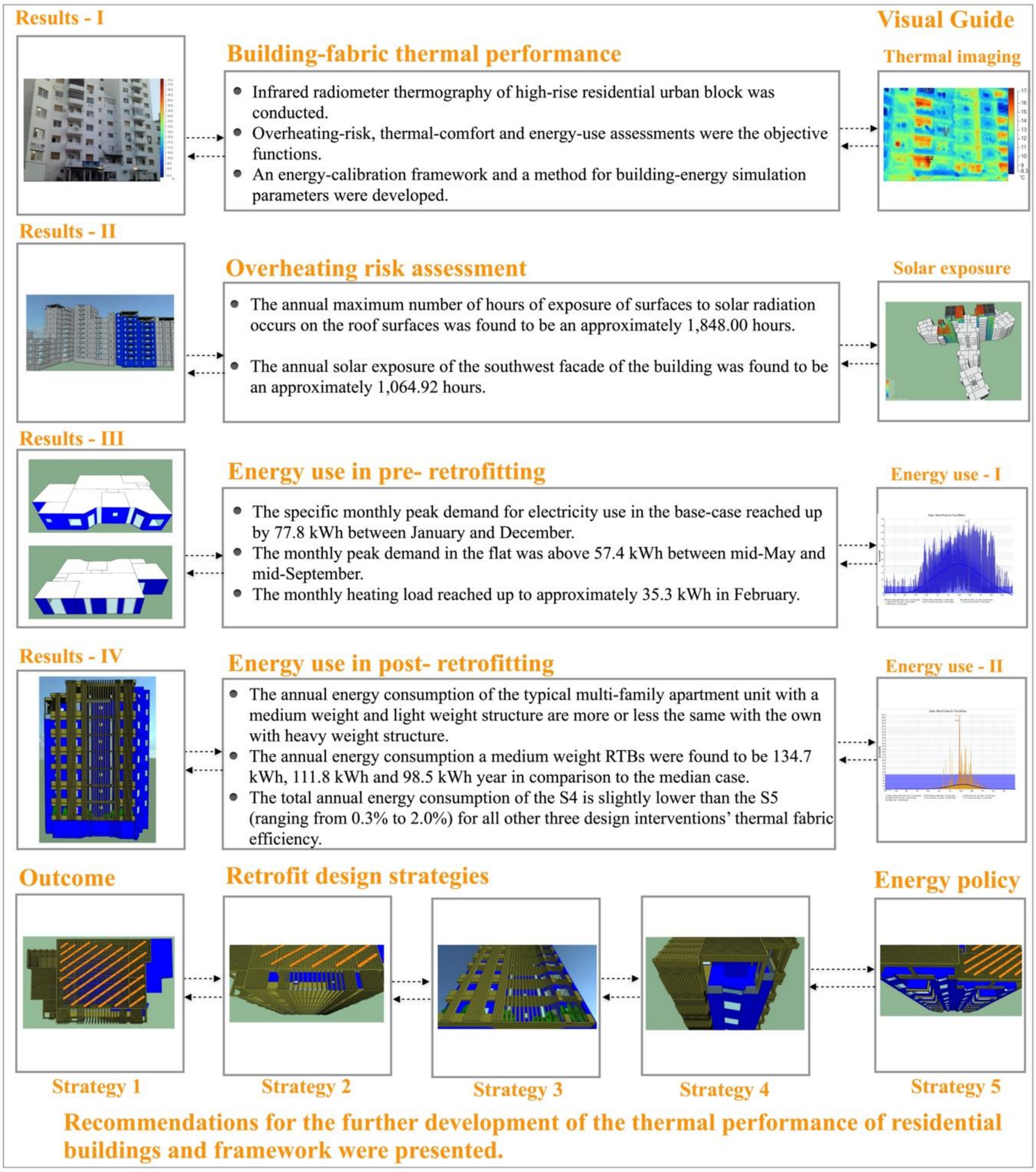


Figure 19. The step-by-step development of key research subjects, conceptual framework and outcomes in retrofit policy design.

In the case study building, according to current standards, overheating and the energy demand necessary for maintaining an adequate thermal comfort are boosted significantly. In this southeast-facing building, an excessive risk of overheating has been observed on the ground floor, and there is important overheating on floors under the roof, which creates thermally uncomfortable indoor conditions for households. At the same time, energy demand in use in the upper-floor flats annually exceeds 237.1 kWh/m2. In collective high-rise residential buildings without rehabilitation of the building envelope, overheating and increases in cooling demand are even greater. In southeast-facing RTBs, the cooling energy demand will be over 120.1 kWh/m2 in flats on the intermediate floors and is more likely to be 101.7–153.1 kWh/m2 in flats on the upper floor where, in this building typology, the cooling demand increases an average of 38%. It is worth highlighting that this kind of thermally insufficient building typology occurs frequently in social dwellings, so those flats with the worst conditions will be inhabited by the most socioeconomically vulnerable population.

4. Conclusions

The study aimed to evaluate the risk of overheating and potential ways to overcome this through the implementation of both energy-efficient state-of-the-art and passive design strategies (i.e. shading and natural ventilation) into a tower block in Famagusta, Cyprus. The results illustrated the necessity of considering passive measures in a state-of-the-art retrofit of existing RTB developments. This paper concludes that a thorough economic appraisal is required to select the most environmentally and economically viable forms of retrofitting. A building performance evaluation method of modelling and simulation was embedded, and to assess the existing cooling energy consumption patterns and thermal comfort levels, conditions in three different RTB developments, with high retrofit potential, a sample of representative prototypes built over three distinct eras were selected. A thermal imaging survey was conducted at each RTB for both summer and winter seasons to understand heat losses/solar gains through the building envelope and to assess the overheating risk of the occupied spaces.

The experience gained from this study as well as the knowledge presented aim to benefit the retrofitting of existing inefficient post-war residential building stock in bringing a significant energy consumption reduction to the residential sector. The study also attempted to identify key features from policy instruments and retrofitting initiatives across EU member states, which currently implement similar policies, most specifically other southern EU member states that have similar building regulations. The climatic condition of Cyprus is also similar to that of numerous Mediterranean countries outside Europe, which are currently in the process of implementing energy performance directives to upgrade their existing residential building stock and reduce energy consumption within energy-efficient building systems. Therefore, this study adds significant value to efforts to achieve energy savings by redefining passive design elements into retrofits of inefficient post-war residential building stock; this is an exemplary study for similar building typologies from similar construction eras across Europe. The findings illustrated the necessity of considering integrations of the off-site modular building technology in any state-of-the-art retrofit of existing high-rise residential buildings in a hot and humid climate zone. Furthermore, the significance and impact of the paper will be valuable for similar district scale retrofits in the area and neighbouring countries with a Mediterranean climate.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A.1

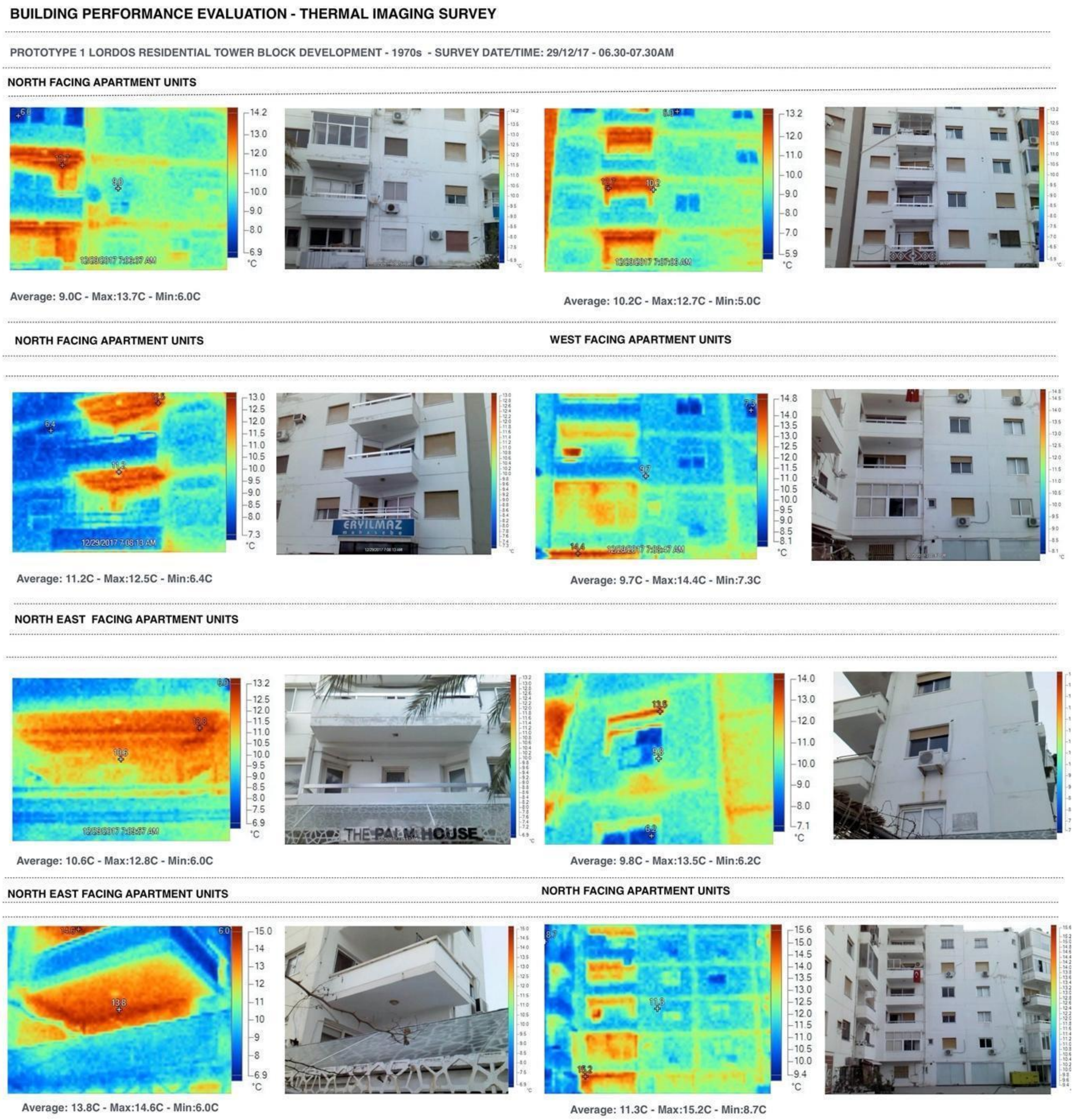

Figure A.1. Meta-analysis of building fabric elements recorded early in the morning.

Appendix A.2

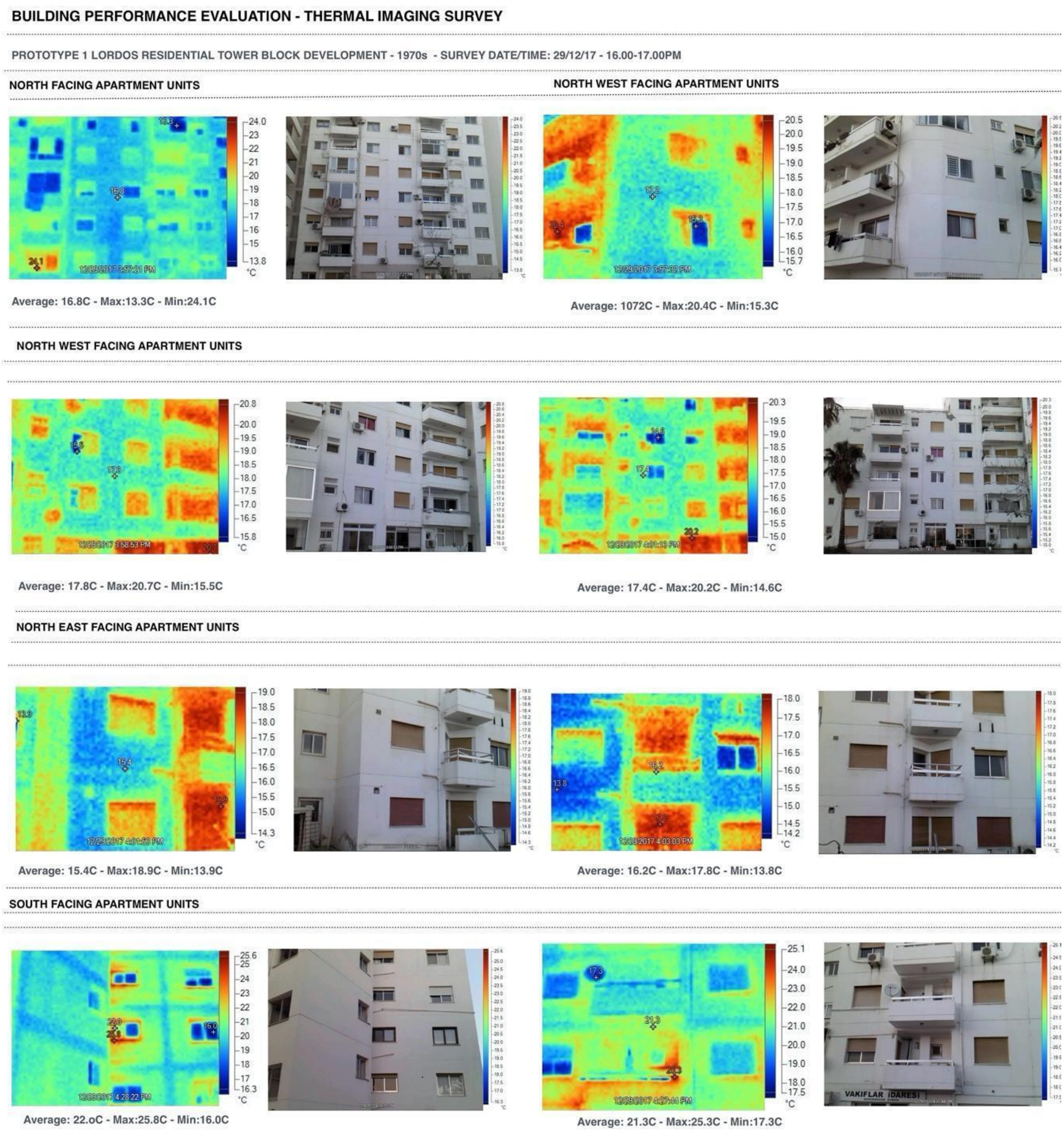

Figure A.2. Meta-analysis of building fabric elements recorded late in the afternoon.

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Performance Analysis of an Energy Efficient House under Hot and Humid Climatic Conditions: Towards Net Zero Buildings

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Abstract: This paper presents the results on the design and performance analysis of an efficient solar house designed for the Solar Decathlon Middle East 2021 in Dubai, United Arab Emirates, with the aim of minimizing the energy consumption for the specific UAE climatic conditions, with particular regard to the consistent use of air conditioning throughout the year. The main objective of the project is to design and test the performance of an efficient house using state-of-the-art green and sustainable building design strategies and technologies toward the goal of achieving an energy self-sufficient building powered with solar PV (net zero energy building – balance the energy demand and supply using renewable and clean energy technologies). Detailed building energy performance simulation was performed using the modeling and analysis of Design Builder/Energy Plus software. The sustainable building design strategies include: bio-sustainable cork panels (to highly insulate the envelope of the conditioned volume), highly reflective cool coating of the outer envelope, passive cooling and ventilation, night cooling strategy, high-performance air-conditioning unit, and energy management system to optimize energy consumption. The results include the daily, monthly, and yearly cooling load calculations, comfort conditions, and energy consumptions (cooling, lighting, and equipment) under Dubai weather conditions. The annual electricity intensity of the solar house for both lighting and cooling is 130.9 kWh/m^2 (13.4 kWh/m^2 for lighting and 117.5 kWh/m^2 for cooling).

Keywords: Solar House; Energy Efficiency; Sustainable Design; Cork Panels, Cool Roof Technology; Passive Cooling; High Efficiency HVAC; Solar Tracking Shading; Building Energy; Performance Analysis.

1. Introduction

The United Arab Emirates is one of the main ten nations with the most noteworthy power utilization per capita [1]. Residential buildings are prevailing in power utilization and liable for 33.08% of absolute power utilization in the UAE [1, 2]. The development of sustainable energy systems is needed for the reduction of the building energy consumption (energy demand) and the enhancement in the energy conversion process for electricity generation (supply). The development of sustainable and more efficient energy systems for the demand side [3] and the integration of renewable power systems to meet the building electrical loads [4]–[7] are crucial towards net zero energy buildings and to balance the energy supply and demand. Sun-based PV systems are the immediate wellspring of power and can be handily carried out on existing and new residential and commercial buildings [4]-[7]. UAE is among the nations favored with the gigantic capability of PV energy generation. Innovative methods and strategies are needed for the development of sustainable and more energy efficient buildings. This will help to reduce the building energy consumption (energy demand), reduce the capacity of the renewable power system, and to balance between the supply and demand.

Several studies are reported in the literature on the development of sustainable and more energy efficient buildings. Chunxiao Wang et al. [8] developed a design experiment using model oriented software architectures (MOOSAS) for the predictions of building energy efficiency. The results highlighted the effectiveness of rapid predictions of building energy efficiency in supporting early-stage architectural design. The energy efficiency of the final design outcomes improved significantly after the use of MOOSAS, with the mean energy use intensity decreasing by 10.2%. Zeyu Wang et al. [9] reviewed recent work on machine learning (ML)-based building energy efficiency from the perspective of model application and promotion. The paper addressed promising future research directions that may promote the implementation of ML models in building energy efficiency applications. The energy performance of existing Saudi housing stock based on recently reported survey data was investigated by M.S.Al-Homoud, and M. Krarti [10]. It was reported that due to the common use of energy intensive equipment including air conditioning, almost half of the electricity generated in KSA is consumed by the residential buildings. Several priorities in both policies and research studies have been identified to reduce energy demands and associated negative environmental impacts of Saudi residential buildings. The recommendations include the adoption and enforcement of comprehensive energy efficiency codes and standards, foster the use of building performance tools to design and retrofit buildings, the use of smart and intelligent energy management tools, and integrating renewable energy systems for on-site clean energy generation. Building Information Modeling (BIM) was used to improve energy efficiency in buildings [11]. A case study was developed in which two classrooms of an educational building, located in the Amazon region – Brazil, were subjected to three-dimensional modeling and energy simulations in BIM software. The results showed that the strategy based on daylight contribution generated energy savings of around 8% for one of the rooms, and 12% for the other, while the one that exploited the use of natural ventilation was able to reduce energy consumption by about 7% for one of the rooms, and 9% for the other. Amel Limam et al. [12] investigated the use of thermal characterization of bio-based materials (Aleppo Pine wood, cork, and their composites) for building insulation. The results show that the Algerian Aleppo pine wood has two different values of thermal conductivity in the parallel and perpendicular directions and the Algerian black agglomerated cork is a good insulator. The sandwich assemblies of wood-cork are good insulators that can be used in the field of construction. Cool roof technologies [13]-[18] (applying a white coating of the roof) are also used to reduce the energy consumption of the buildings (average of 10-20% energy reduction).

The main objective of this study is to test the performance of an energy efficient and self-sufficient house under hot and humid climatic conditions. It consists of incorporated passive design strategies, including natural ventilation and cooling measures such as sun shading, cool roof technology, bio-sustainable cork panels (to highly insulate the envelope of the conditioned volume), advanced glazing systems provided by the house envelope that are effectively reducing the overall cooling load of the house. Solar energy is the main source of energy production in the house, using photovoltaic panels, which are integrated on the rooftop of the house. The bifacial solar PV, azimuth tracking, coated rooftop, BIPV-Façade, and energy storage technologies are integrated in a unique and optimum way to maximize clean energy production. Bifacial solar PV panels are adopted with azimuth tracking system to harvest maximum solar energy. Coating the rooftop with white cool paint is a solution to reduce the heat absorbed into the envelope, as well as to increase the albedo of the surface (reflection of sun light) which is further enhancing the energy production by bifacial PV panels. BIPV panels on the façade are also designed to harvest solar energy during sunrise and sunset. In order to reduce the electrical energy consumption, the most efficient available appliances were selected for the house without compromising the quality or performance. This study will serve as a reference to integrate different energy efficient technologies in order to reduce the building energy consumption and improve the energy production from PV and move towards net zero energy residential buildings.

2. Methodology

2.1. Solar House

The energy efficient solar house is designed to address the sustainability, innovation, and energy efficiency goals complying with Solar Decathlon Middle East (SDME) rules. With an 84 m^2 occupied floor area, the gross volume of the designed house is 330.2 m^2 as shown in Figure 1. The surface to volume ratio is 1.07, the walls surface area (vertical) is 118.5 m^2, the windows surface area (vertical) is 36.8 m^2, and the window/wall surface area ratio is 0.31. The primary objective is to reduce the energy consumption of the building and produce clean energy to meet the electrical loads. The goal of limited energy consumption is achieved in four steps: innovative building design, integration of cooling strategies in a unique way to reduce the HVAC consumption, selection of highly energy efficient home appliances, and intelligent home automation. The building is designed in innovative ways to reduce the conditioned volume, highly reflective cool coating is applied on the outer envelope to limit the direct sun heating, passive and night cooling additionally reduce the HVAC consumption. The selection of high energy efficient home appliances helps to reduce the electrical loads of the house. Finally, intelligent home automation is implemented to manage and optimize energy consumption by mutual communication of occupants with devices. A novel solar PV system is designed to meet the electricity demand of the solar house. Several technologies, i.e. bifacial PV panel, azimuth tracking, BIPV façade panel, and energy storage, are integrated in a unique way to maximize the energy production by the solar system.

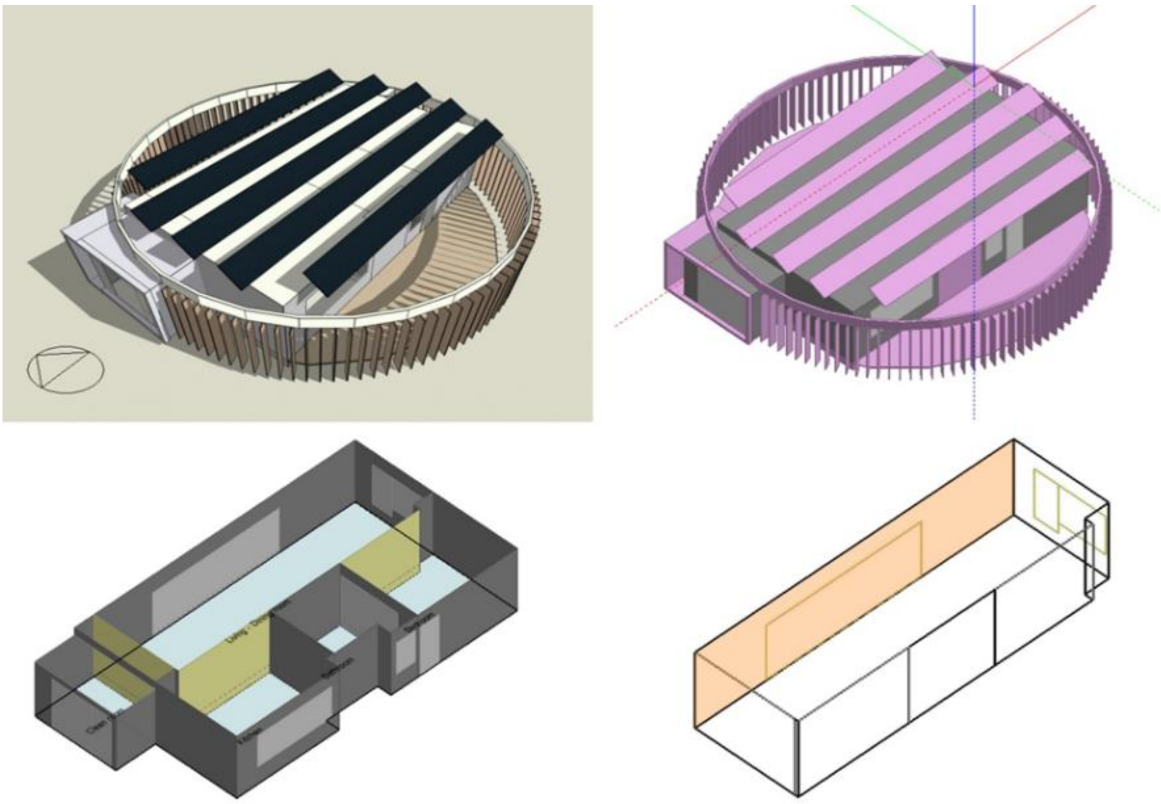


Figure 1. Energy Efficient Solar House modelled with Design Builder/Energy Plus

2.2 Energy Efficiency Measures

The energy efficiency measures for the solar house include: (1) bio-sustainable cork panels to highly insulate the envelope of the conditioned volume; (2) highly reflective cool coating of the outer envelope of the conditioned volume, to limit the transmission of the sun radiation inside, and therefore limiting the AC consumption; (3) PV-thermal modules producing hot water and at the same time electricity to feed the system's circulation pump; (4) Solar-tracking system to enhance the PV and PV-thermal modules efficiency; (5) high-efficiency bifacial roof PV modules, benefitting from the radiation of the cool-coated roof; (6) solar-tracking shading system to prevent overheating of the inner envelope and therefore limiting the AC consumption; (7) passive cooling and ventilation thanks to the optimized shape and orientation of the building that harvests the desert breeze to enhance the cross-ventilation and assist the regular cooling systems; (8) night cooling strategy (hybrid strategy); (9) high-performance air-Conditioning unit (Daikin, capacity = 5.28 kW, EER = 9.10 [(Btu/h)/W], COP = 2.67); (10) home automation to ease house management and communicate with the occupants, challenging them to optimize energy consumption day after day; and (11) energy efficient appliances in a connected environment that promotes an innovative way of living the household.

2.3 Cooling Load Calculation and HVAC modeling

Design Builder was used in this study for both cooling load calculations and for the HVAC system modeling. It provides a range of environmental performance data such as annual energy consumption, maximum summertime temperatures, and HVAC component sizes. It generates performance data using the Energy Plus dynamic simulation engine. The software has some other typical uses such as evaluating façade options for overheating and visual appearance, visualization of site layouts and solar shading, and calculating heating and cooling equipment sizes. It is capable of displaying the environmental performance data without needing to run external modules and import data and any simulation required to generate the data starts automatically. In addition, Energy Plus 'Compact HVAC' descriptions provide an easy way into a detailed analysis of commonly used heating and cooling systems. On the other hand, the simulation has been run in compliance with the SDME rules. Design Builder runs hourly and sub-hourly simulations, where results can be displayed yearly, monthly, daily, or hourly. All below simulations are run on a sub-hourly base, to obtain the most accurate result. However, for easier readability, in relation to the annual energy performance analysis, the simulation outcome is displayed with histograms representing monthly means. Instead, the contest week simulation results are displayed with hourly data.

The occupation density has been tailored to simulate the real 3 occupants (minimum number requested by the SDME rules), behaving as per the default activity profile for generic living/dining area of the house as inherited by the software library, which is built according to ASHRAE. Lighting level has also been assumed as default from the software for LED lighting with automatic control, accounting for the requested 300 Lux target luminance. The ventilation rate has been calculated as per ASHRAE Standard 62.1-2010. Infiltration occurs only when the rooms are depressurized (AC system is not active), so it has been simulated equal to 0.5 ac/h at a 30% continuous rate.

2.4 Input Conditions - Weather Conditions

For the simulation analysis, the weather data is obtained from meteonorm 7.2 server by adding the location coordinates (latitude: 24.7602°, longitude: 55.3633°). Monthly average values of irradiance (global horizontal irradiance (GHI) and diffuse horizontal irradiance (DHI)), ambient temperature, wind velocity, and relative humidity are presented in Table 1. Figure 2 shows the wind conditions in Dubai (year, season, and during the contest period). The main wind streams are moderate-strong warm humid wind from North-West (from the shore) in summer; strong cold medium-humid wind from North-West (from the shore) in winter daytime; moderate warm dry wind from South (from the desert) in summer; and moderate-strong sandy dry wind from South (from the desert) in winter.

Table 1. Weather Conditions.

Site	SDME-UOS Site		Country		United Arab Emirates
Region	Asia		**Source**		Meteonorm 7.2
Latitude	24.7602°		**Longitude**		55.3633°
Values	**GHI**	**DHI**	**Ambient Temperature**	**Wind Velocity**	**Relative Humidity**
Month	kWh/m²	kWh/m²	°C	m/s	%
January	119.2	48.2	18.7	3	61.9
February	125.2	55	20.5	3.3	57.1
March	168.9	68.2	24	3.5	48.3
April	186.9	74.4	28	3.5	40.3
May	219.2	83.2	33	3.5	35.5
June	207.6	91.9	34.1	3.3	42.4
July	188.4	95.6	35.8	3.4	43.7
August	192.2	91.5	35.7	3.4	43.2
September	170.4	75	32.6	3.11	51.1
October	155.9	58	29.7	2.8	49.9
November	126.2	49.1	24.7	2.8	57.6
December	108.8	47.4	20.7	2.8	63.9
Year	**1968.9**	**837.5**	**28.1**	**3.2**	**49.6**

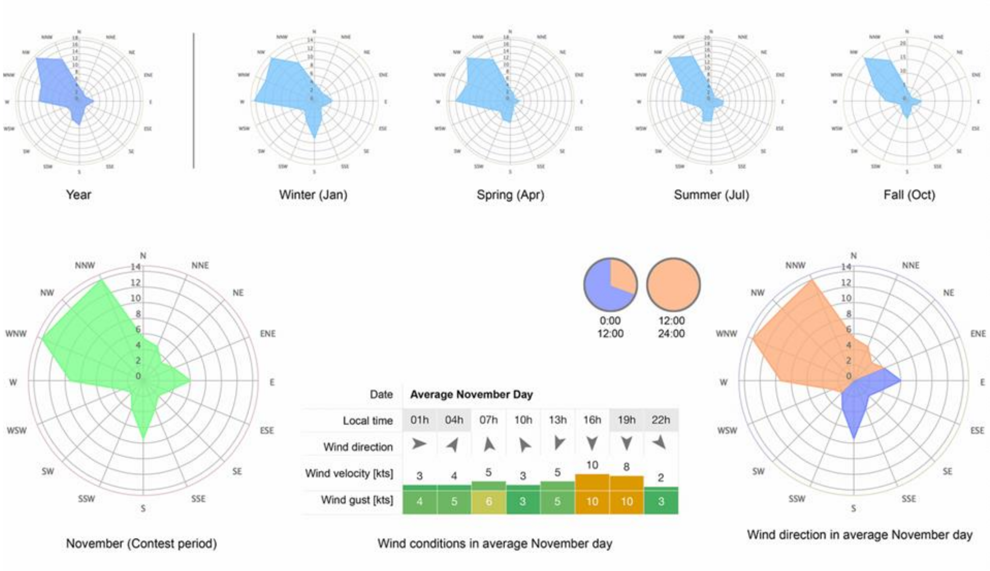
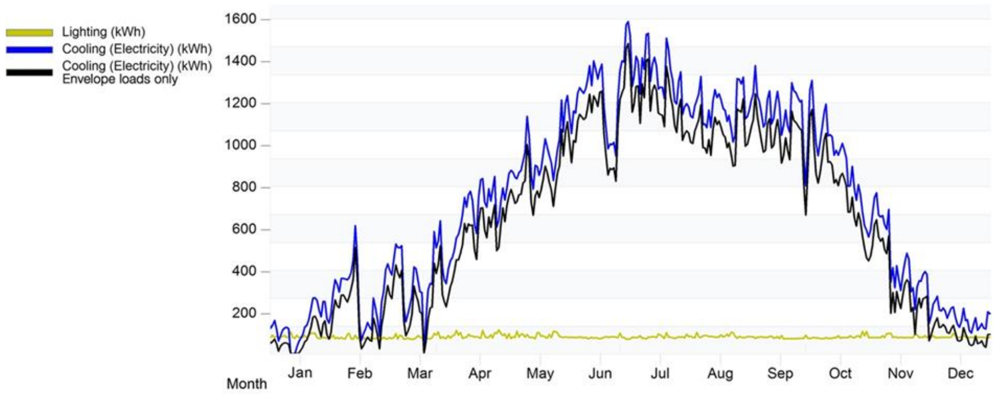


Figure 2. Wind rose for Dubai: year, season, and contest period. Source: https://www.windfinder.com/windstatistics/dubai

3. Results and Discussion

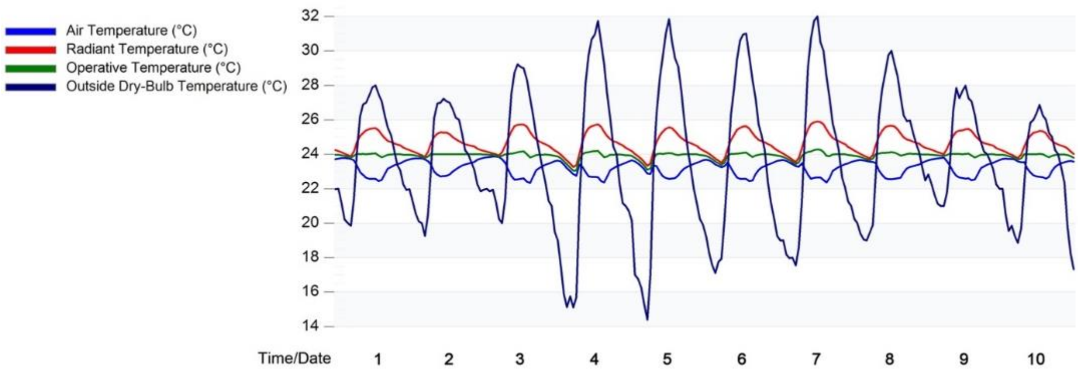
This section includes the results of the modeling and simulation analysis: (1) annual performance of the energy efficient house in Dubai (comfort conditions and energy consumption), and (2) performance analysis of the house during the SDME contest period (11th November - 20th November). The results of the comfort conditions inside the house include the dry bulb temperatures (air temperature inside the house; radiant temperature - average surface temperature of the roof, walls, and floor; operative temperature - average temperature between the air temperature inside the house and the radiant temperature; and the outside dry bulb temperature); relative humidity (RH%), and the total fresh air supply inside the house. The results show the comfort conditions (air temperature of 22 - 23°C and RH = 50-55%) are achieved during the hottest day (July-August) in Dubai. The yearly internal heat gains (lighting; occupancy; appliances; solar gains through the roof, walls, glazing, doors; and infiltration), and the sensible, latent and total cooling loads (kW) were also calculated. Figure 3 shows the annual electricity consumption for solar house in Dubai. The peak electricity consumption for cooling is about 1600 kWh for the months of June-July. The annual electricity consumption for lighting and the air conditioning system are respectively 1373.3 kWh and 9994.1 kWh. The total electricity consumption for both the lighting and air conditioning system is 11,367.4 kWh. The energy intensity for both lighting and cooling is 135.3 kWh/m² (16.3 kWh/m² for lighting and 119.0 kWh/m² for cooling).



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lighting (kWh)	100.7	83.0	92.5	98.6	105.7	90.4	95.2	100.4	89.1	95.3	94.0	95.9
Cooling (Electricity) (kWh)	151.8	280.6	375.5	709.5	1016.4	1340.0	1594.3	1371.3	1320.5	1098.4	530.5	205.2

Figure 3. Annual Electricity Consumption for the Solar House.

The comfort conditions and the energy performance of the solar house during the contest period (11th November - 20th November) are shown in Figures 4-5. Figure 4 shows the comfort conditions (dry bulb temperatures – outside design temperature, air temperature inside the house, and the radiant and operative temperatures). The results show the comfort conditions (air temperature of 22.4 – 23.8°C and RH = 50-55%) are achieved for the solar house in Dubai during the contest period (November 11th-20th). Figure 5 shows the electricity consumption breakdown during the contest period for the solar house in Dubai. The electricity consumption for lighting and the air conditioning system during the contest period are respectively 22.1 kWh (263.0 Wh/m^2) and 145.8 kWh (1735.7 Wh/m^2). The total electricity consumption for both the lighting and air conditioning system during the contest period is 167.9 kWh. The energy intensity for both lighting and cooling is 1998.8 Wh/m^2.



Time/Date	1	2	3	4	5	6	7	8	9	10
Air Temperature (°C)	23.5	23.5	23.1	22.4	22.6	22.6	22.8	23.5	23.8	23.7
Radiant Temperature (°C)	24.5	24.5	24.9	25.3	25.5	25.5	25.5	24.6	24.0	24.0
Operative Temperature (°C)	24.0	24.0	24.0	23.8	24.0	24.1	24.1	24.0	23.9	23.8
Outside Dry-Bulb Temperature (°C)	23.0	24.0	25.1	29.3	30.5	30.6	29.1	23.0	21.0	19.9

Figure 4. Comfort Conditions of the Solar House during the Contest Period (11th November - 20th November)

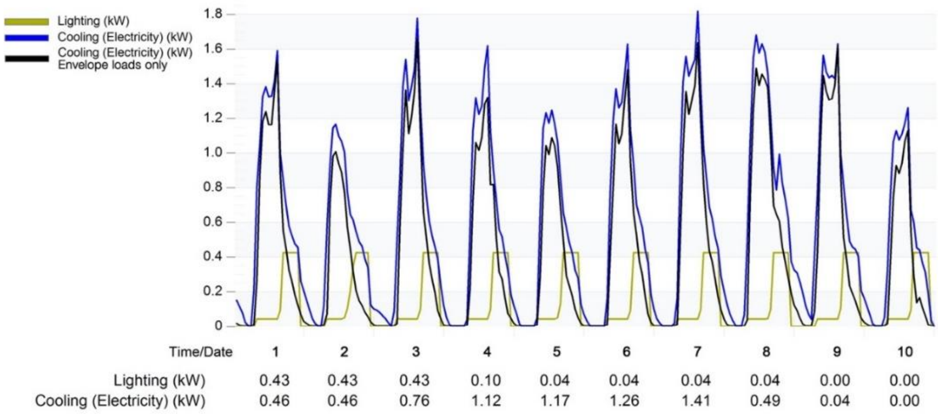


Figure 5. Electricity consumption breakdown during the contest period (11th November - 20th November)

4. Conclusions

Performance analysis of an efficient solar house designed for the Solar Decathlon Middle East 2021 in Dubai, United Arab Emirates is presented in this study. Green and sustainable building design strategies and technologies (bio-sustainable cork panels, highly reflective cool coating of the outer envelope, passive cooling and ventilation, night cooling strategy, high-performance air-conditioning unit, and energy management system to optimize energy consumption) toward the goal of achieving an energy self-sufficient building powered with solar PV were investigated. The results show that the annual electricity consumption for cooling and lighting (combined as per SDME meter), shows a building performance of 135.3 kWh/m^2, highlighting that the large share (90%) is accountable for the energy losses through the envelope (117.5 kWh/m^2 considering the heat fraction of the house loads; 99.1 Wh/m^2 considering the envelope performance only); while lighting, sized and inputted as per real illumination design project (all dimmable LED devices), is responsible for only 16.3 kWh/m^2 (10%). The same analysis during the contest period generally confirms the annual assessment, showing a predicted improvement in the cooling share (1735.7 Wh/m^{2}equal to 87%), versus the lighting (263.0 Wh/m^2 equal to 13%), due to the milder November climate.

Author Contributions: The individual authors contributions are as follow: “conceptualization, V. Belpoliti, C. Ghenai, and F.F. Ahmad; methodology, V. Belpoliti, C. Ghenai, and F.F. Ahmad; software, V. Belpoliti; validation, V. Belpoliti, C. Ghenai, and F.F. Ahmad; formal analysis, V. Belpoliti, C. Ghenai, and F.F. Ahmad; investigation, V. Belpoliti, C. Ghenai, and F.F. Ahmad; resources, V. Belpoliti; data curation, V. Belpoliti; writing—original draft preparation, C. Ghenai; writing—review and editing, V. Belpoliti, C. Ghenai, and F.F. Ahmad; visualization, V. Belpoliti, C. Ghenai, and F.F. Ahmad; supervision, V. Belpoliti; project administration, V. Belpoliti; funding acquisition, V. Belpoliti and C. Ghenai.

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Conflicts of Interest: “The authors declare no conflict of interest.”

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Passive Cooling Strategies for High Thermal Performance Buildings in Hot Climate

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Abstract: Urban development in many parts of the United Arab Emirates (UAE) has significant impacts on the environment. The use of glazed façades that exposed to the hot climate of the UAE has increased in popularity. This modern architectural pattern increases the operational costs and energy consumption due to the higher solar gain. Thus, improving the ecological performance of building industry in the UAE and minimizing/preventing the negative impact of urban development on the natural environment are the main concerns for building engineers, developers and stakeholders seeking for environmentally friendly buildings in the country. Throughout the world, passive cooling strategies have been developed to overcome this major drawback of glazed facades. Passive cooling techniques such as thermal mass, wind-towers, and courtyards can already be found within the traditional architectural fabric of UAE like Bastikia and Shindagha districts in Dubai. It is also applied to modern urban development such as Madinat Jumeirah in Dubai. Other cooling passive strategies, including the use of Double Skin Façades, vegetated green wall and Plant-Shaded techniques are also applied to reduce the heat-gain effects. Recently, the use of passive cooling techniques have been adopted within Abu Dhabi building codes to maintain the new vision of the UAE towards building sustainability. This paper investigates different alternatives of passive cooling strategies for reducing cooling load of contemporary buildings design in extremely hot climate of UAE. These techniques include Vegetated living wall (VLW), Plant-shaded wall (PSW), and Vertically Integrated Greenhouse (VIG). The study demonstrates the potential benefits of passive cooling strategies not only to minimize the negative impact on the natural environment, but also to reduce the cooling load and the air-conditioning cost. The experimental results of the study show that Vegetated and plant-shaded strategies can reduce peak time indoor air temperature by at least 5 °C during the hot summer period, and reduce the peak air conditioning energy demand by up to 20% in case of using vegetated living walls, and 18.5% in the case of using plant-shaded walls.

Keywords: Hot climate, passive cooling strategies, plant-shaded wall, vegetated living wall, thermal performance.

1. Introduction

The urbanization trend, which is rapidly developed in many cities around the world, has significant environmental consequences, including high non-renewable resource consumption and high levels of air pollution. The main issues of sustainable building development are minimizing the impact on the natural environment and improving the ecological performance of urban development. As a result, the major challenges of urban sustainability are energy efficiency, healthy environment, and biodiversity conservation. Approximately 45% of all worldwide energy consumption is devoted to buildings. Nearly 30% of this energy is used to heat, cool, and ventilate buildings. In hot climates, air conditioning is a major energy user that represents a serious barrier to achieving the building's greening targets [1]. Power plants and distribution networks supply a greater amount of energy during peak air conditioning times due to the increased cooling system capacity and energy consumption. Despite that fact, the environmental impact of buildings is often underestimated, while the costs of building green are overestimated. Therefore, in cities like Abu Dhabi and Dubai, sustainable building techniques in terms of energy usage are critical in order to adapt ecologically friendly building conditions.. The main question could be asked is: "how could cities with hot climate and rapid urban development sustain their building practices in term of energy efficiency?"

Due to the hot summer temperatures in United Arab Emirates (UAE), where the external ambient temperature may reach 50 °C in the summer season, almost 70% of the total energy is consumed in air-conditioning (AC) [2]. A considerable improvement in the AC systems performance during hot summer time aligned with energy conservation could be achieved by utilizing passive cooling strategies for high thermal building performance. Inclusion of Vegetated Living Wall (VLW), Plant-Shaded Wall (PSW), and double skin façades with Vertically Integrated Greenhouse (VIG) have been widely used as environmentally friendly energy saving techniques due to their high energy performance. The absorption/releasing of heat by vegetation provides a latent heating/cooling for the surrounding environment.

The study investigates the applications of Vegetated Living wall and Plant-Shaded techniques as passive cooling strategies to reduce heat gain and lower cooling demand in indoor spaces. The investigated techniques are examined, and their thermal performance are discussed and analyzed. In order to provide a real financial incentives of using plantation on and around the building façades, the study also analyzes a Cost-benefit Analysis of the examined techniques, taking into consideration the tradeoff between the energy savings of the building skin and the real installation and operation cost; while the related environmental benefits are ignored at this stage.

2. The Performance of Sustainable Building Skin

Using building skin as a way to separate indoor spaces from the outdoors is an important concept for energy efficiency as it allows buildings to adjust to local weather conditions including heating, cooling, ventilation, and natural lighting. In addition to controlling heat transfer and solar radiation, it affects the air flow and the energy performance in buildings. As a result, ventilation and daylight need to be balanced with thermal protection appropriate to the climatic conditions [3]. Besides material selection, daylight, ventilation, and air-conditioning, building skin design is an important factor in determining how much energy is used in buildings. For optimal energy efficiency, engineers should integrate building skin design with interior design and daylighting. Building forms, volumes, openings, glazing systems and the orientation of the building have also a significant influence on the efficiency of the building skin. In a hot climate, the main strategy is to control heat gain by preventing solar energy from entering the indoor space and allowing adequate daylight [4]. Building construction details also play an important role in the design of the building skin. To guarantee the required thermal performance, appropriate detailing systems, including the choice and placement of the insulation material, are essential. The heat transmission occurs through conduction, convection and radiation. As examples, Figure 1 represents typical reduction in solar transmission through Clear glass; double glazed heat-absorbing glass; and double glazed reflective glass.

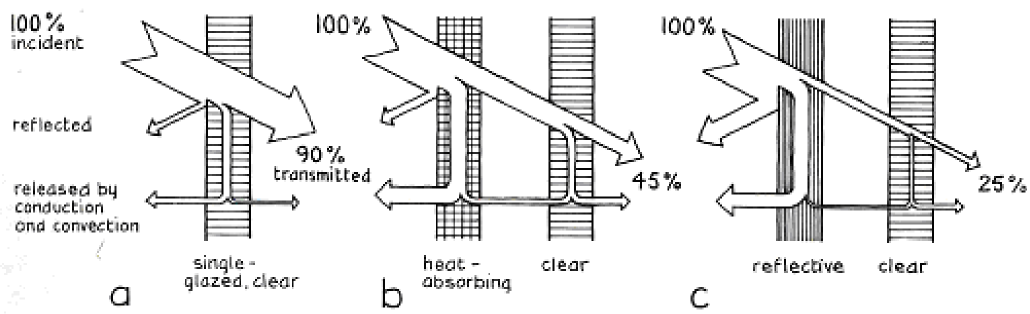


Figure 1. Typical reduction in solar transmission through: a) transparent glass; b) double-glazed heat-absorbing glass; and c) Reflective double glass [3]

Thermal conduction is the place where heat is conducted through the outer skin of a building. The conductivity of building materials or components is the amount of heat that is conducted through a unit of area in unit of time for the unit temperature differences between the surfaces of the building skin (thermal transmission coefficient U-valor); the lower the U-value, the better the insulation. Table 1 shows the U-value of various wall construction details as examples. With convection process, air flow collects heat from warmer surfaces and transfer it to the colder surfaces. Radiation involves the transmission of energy through electromagnetic waves [3].

Table 1. Thermal transmission coefficient U-value (W/m2◦C) [3]

	Wall Construction Details	U-value (W/m2◦C)
1	105 mm outer brick leaf; unventilated cavity; 100 mm lightweight block inner leaf; plaster.	0.95
2	105 mm outer brick leaf; unventilated cavity with 50 mm insulating layer; 100 mm lightweight block inner leaf; plaster.	0.70
3	Outer weather boarding; building-paper backing; timber frame; incorporated 50mm glass-fiber quit; foil-backed plasterboard.	0.60
4	105 mm outer brick leaf; unventilated cavity; incorporated 50 mm quilt; polythene vapor check; plasterboard.	0.50
5	Window; single-glazed, wood frame.	5.60
6	Window; double-glazed with 20 mm air gap, wood frame.	2.50

A natural passive cooling system is an alternative for maintaining a sustainable building façade and reducing cooling loads. Moe than 40% of the undesirable heat comes in through windows and walls, and almost 30% comes in through building roof [4]. To limit the impact of radiant energy, a reflective water-resistant coating and installation of a heat barrier are essential. This can reduce the heat gain by almost 25% [5]. Additionally, light-colored surfaces effectively reflect a percentage of the heat. Reflective window coatings also can reduce the heat by approximately 35% [6]. Sun-coating films can reflect as much as 80% of the incoming sunlight [5].

Vegetated Green walls can reduce the effects of heat gain and therefore reduce the indoor air temperature. The internal as well as external surface temperatures of the green wall remain cooler than the surface temperatures of the bar wall during the peak day time (Figure 2). Several studies have shown that the external surface of a green wall is up to 10°C cooler than bar wall; therefore the U-value of the green wall is usually lower and helps in reducing the cooling loads [6]. There is an evidence that green wall reduces cooling load by shading walls and windows from incoming solar energy. The effect of vegetation resulting in a 5 °C reduction in the inner temperature which provides a reduction in cooling load by almost 20% in annual energy consumption [7]. Through simulation, a 100% greenery coverage with plants of higher shading coefficient, proved to achieve about 18% drop in cooling load [8, 9].

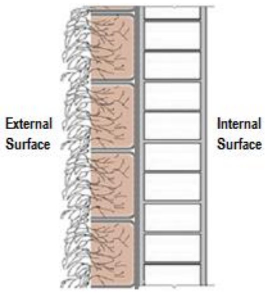


Figure 2. Vegetated Green Wall

Plantations have also been used as barriers to urban noise pollution. The acoustic insulation of vegetated green walls is greater than that of bar walls (up to 30 db) [10]. Green walls can also help to protect building surfaces and increase the lifespan of the building skin. This is provided by keeping rain off the building while allowing moisture to escape, reducing the expansion and contraction of building materials, and shielding the walls from wind and solar radiation that could harm the materials. The green wall approach has an aesthetic impact on buildings and can help to mitigate the lack of green space in urban areas.

The use of vegetation around building façades can also help to increase the building skin's thermal performance. Plant-shaded walls, in addition to vegetated green walls, are a common approach for lowering wall surface and interior space temperatures by reducing heat gain provided by vegetation leaves, evaporative cooling generated by the irrigation system, and heat resistance caused by the plant acting as heat insulators (Figure 3) [7]. The peak time indoor air temperature and the peak air conditioning energy demand can both be reduced with this strategy. Furthermore, using plant-shaded walls minimizes wind influence and helps in humidity regulation within the building zone. Trees provide a variety of ecosystem services, including carbon sequestration, improved air quality, and reduced storm water runoff [11]. As a result, hot air can rise over solid surfaces and be replaced by fresh air, which helps reducing the heat island effect [12]. Summer peak temperatures can be reduced by 1-5°C via evapotranspiration [13]. Heat convection occurs when the air temperature is higher than the temperature of the wall surface. Plants also contribute to this phenomenon by controlling their temperature and keeping it lower than the surrounding air through transpiration.

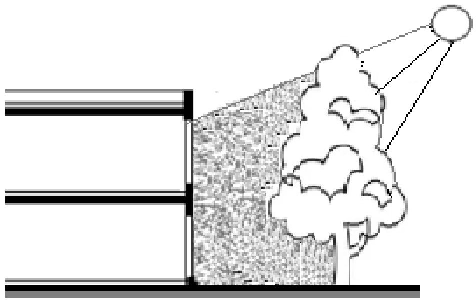


Figure 3. Plant-shaded wall

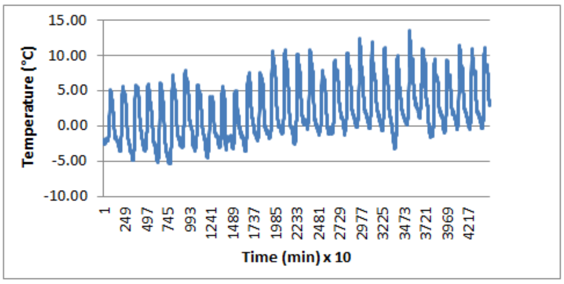
Plant shaded wall reduces the radiative interchange between the ground and the wall surface, lowering the urban surface temperature. Additionally, employing trees as windbreakers helps protect buildings from the hot summer wind. Furthermore, trees-shade diminish glare and diffused light from the sky, as well as heat gain and hence cooling load and energy consumption [14]. When plants are used to provide shade on a building's wall, the amount of shade that is provided can be simply adjusted. The light coverage ranges from extremely light 10% coverage to very dense 80% coverage depending on the plant species chosen, its height, physical qualities, and density. Furthermore, a layer of air is contained within the vegetation, limiting the transfer of heat through the building's wall and lowering the ambient temperature through shadowing and the plants' evapotranspiration process. In the winter, the plant-shaded wall acts as a wind buffer, reducing the amount of energy lost due to inside heating. As a result, using plants to shade walls has year-round thermal benefits, as well as economic and energy savings. Tree shade reduced wall surface temperatures by up to 9°C and external air temperatures by up to 1°C in hot summer conditions. [15]. Tree form and placement influence shade availability on building surfaces, which has an impact on building energy use. Similar to green wall technique, there are various challenges that affect the use of plant-shaded walls, including the primary costs associated with plantation and maintaining trees, such as acquiring materials, initial planting, and ongoing maintenance activities and irrigation.

Thermal performance of the vegetated green wall and plant shaded wall as passive cooling techniques have been examined by the author and summarized in the following sections. Cost Cost-benefit Analysis of the examined techniques has been covered in the study, taking into consideration the energy saving, cooling load reduction, and the payback period of each technique.

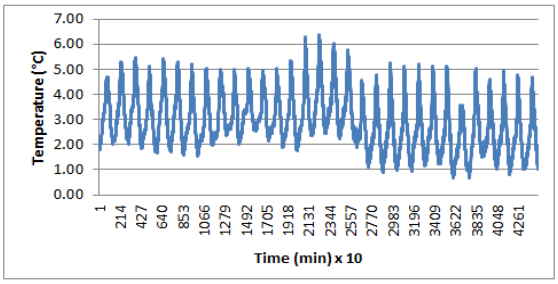
3. Thermal Performance of Vegetated Living Wall

To examine the thermal performance of vegetated green wall technique of building façades, an experimental work was conducted on a case study building located in Al-Ain, UAEU (Liwa International School). Al-Ain city is characterized by a very hot and dry climate with summer daytime temperatures range from 35◦C to 50◦C and winter daytime temperatures range from 25◦C to 35◦C. The School was covered with modular Vegetated Living Wall (VLW) which composed of plastic boxes installed connectively on the building facades; drip irrigation pipes; and plant foliage [7]. As part of an experimental work which was carried out by the author and his team, a vegetated green façade of the school building was examined during the summer season (July and August) to investigate the thermal performance of the vegetated living wall in the hot climate of Al Ain city. Two identical classrooms were examined, one with bare wall and the one with vegetated living wall. Both classrooms facing the south-eastern direction. Two data loggers were used to measure temperature at four locations: external ambient air temperature; external surface temperature; internal surface temperature; and internal ambient air temperature.

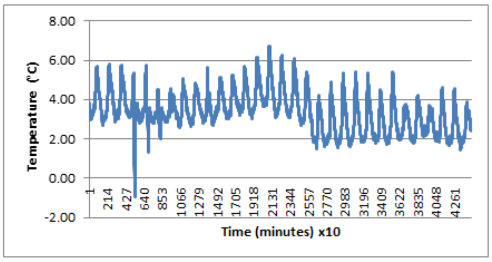
The result shows that the peak external surface temperature on bare wall stayed around 54°C while the peak temperature on the vegetated living wall remained at an average of 48°C. Similar trend was observed for the rest of the duration of experiment with slight variation in the magnitude of the temperature regulation. The reduced external surface temperature on the vegetated living wall yields a reduced internal surface temperature compared to bare wall. The internal surface temperature on the bare wall stays at an average of 52°C while the internal surface temperature on the vegetated living wall stays at 46°C which shows a similar trend and magnitude of temperature regulation as of external wall. This drop in internal surface temperature yields a drop in indoor ambient temperature with living wall compared to bare wall with an average of 6°C. The result also shows that the internal surface of the green wall remains cooler than the internal surface of the bare wall during both the peak day time (with a difference of 4-6 ºC) and the peak nighttime (with a difference of 1-2.5 ºC). The reduction in the internal surface temperature and the ambient air temperature of the vertical living wall system is occurred mainly due to: the decreased heat gain caused by vegetated living wall; the evaporative cooling caused by the irrigation water; and heat insulation caused by low thermal conductivity of the plant foliage and the soil. In conclusion, the shading effect of the vegetated green wall can reduce peak time indoor air temperature by 5-7°C for the month of July, and reduce the peak air conditioning energy consumption by about 20%, which is in agreement with previously reported work [7]. The daytime external, internal and indoor temperature differences between bare and vegetated living walls are presented in Figure 4.



a. External surface temperature difference



b. Internal surface temperature difference



(c) Indoor ambient air temperature difference

Figure 4. Daytime temperature difference between bare and vegetated living wall

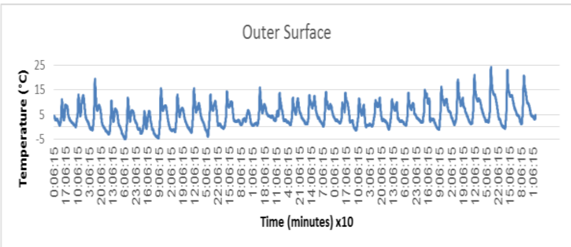
4. Thermal Performance of Plant-Shaded Wall

Two identical residential building façades have been tested in Al-Ain City, UAE); unshaded façade (bar wall), and Plant-Shaded façade (Figure 5), both are facing south eastern direction (same direction of the vegetated living wall case study). To determine the temperature regulation effect of Plant-Shaded Wall (PSW) on indoor spaces, temperatures at four locations were recorded for both residential building façades: external ambient air temperature; external surface temperature; internal surface temperature; and internal ambient air temperature in hot summer period (July and August; same period of experimental work of VLW).

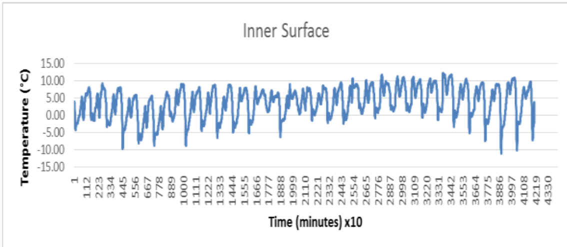
a. Unshaded Façade b. Plant-Shaded Façade

Figure 5. Plant-Shaded Façade case study, Al-Ain, UAE

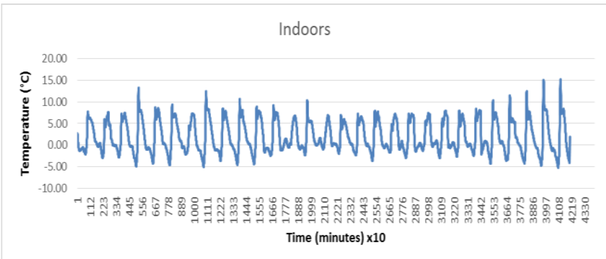
The experimental result shows that the peak external surface temperature of the unshaded façade reached 55-56 °C, while the temperature on the external plant-shaded wall peaked around 50-51 °C for most of the experimental duration [16]. A reduction of around 5 °C has been achieved on the external plant-shaded wall surface. The reduced external surface temperature on the shaded wall naturally resulted in a reduction of the internal wall surface temperature compared to the internal base wall surface temperature. The internal surface temperature of the bare wall peaked at around 51 °C, however the plant-shaded wall peaked at around 46 °C which shows a drop of 5°C. The indoor ambient air temperatures through bare wall peaked at around 47 °C on the average, while the shaded wall peaked on average at 39 °C, showing a drop of about 8 ºC. The daytime external, internal and indoor temperature differences between bare and plant-shaded walls are presented in Figure 6.



a. External surface temperature difference



b. internal surface temperature difference



c. Indoor ambient air temperature difference

Figure 6. Daytime temperature difference between unshaded wall and plant-shaded wall

5. Funding and Results: Cooling Load Reduction and Economic Benefits

The test rooms of both vegetated and plant-shaded building façades were simulated in e-Quest energy modeling software, using Al Ain weather data entering construction details of the test rooms. The selected walls which are constructed from hollow concrete blocks with thickness of 20 cm are covered by white Cement Stucco from both sides with a heat absorbance value of 0.6. The indoor control conditions were kept at 25◦C temperature with no humidity control and 0.5 Air Changes per Hour. This Air Changes per Hour generally prevails in conditioned space due to air infiltration in this type of construction. In order to compare the results, the heat removal rate to keep the indoor air at control temperature was calculated from the measured outdoor temperature and the fixed indoor comfort temperature of 25◦C with following equation:

$$Q. = \varrho V.Cp\Delta T,$$

where Q. and V. are heat removal and the volume flowrate of air respectively, ϱ, Cp and ΔT are the air density, specific heat capacity and temperature difference between outdoor ambient and indoor control temperature.

The results show that the simulated and experimental temperatures are in close agreement. The heat gain from the living wall as well as the plant-shaded wall was processed to calculate the cooling loads of the used techniques and compared with the cooling load of the unshaded bare wall. As presented in Table 2 and Figure 7, the results show that for vegetated living wall, the cooling load reduced from 1.35 MWh to 1.07 MWh resulting in 20.5% energy saving for cooling system due to the use of green wall [4]. However, the use of plant-shaded wall can reduce cooling load from 1.35 MWh/year to 1.10 MWh/year in the tested space (predicted based on average daily savings) resulting in 18.5% energy saving for cooling system due to the use of plant-shaded technique.

Table 2. Cooling load and energy saving of vegetated Living Wall and Plant-shaded wall techniques.

Passive Cooling Technique	Cooling Load (MWh)	Energy saving of Cooling Load (%)
Bar Wall / Unshaded	1.35	0.00 %
Vegetated Living Wall	1.07	20.5 %
Cooling Load Saving -Vegetated Living Wall	0.28	
Plant-Shaded Wall	1.10	18.5 %
Cooling Load Saving – Plant Shaded Wall	0.25	

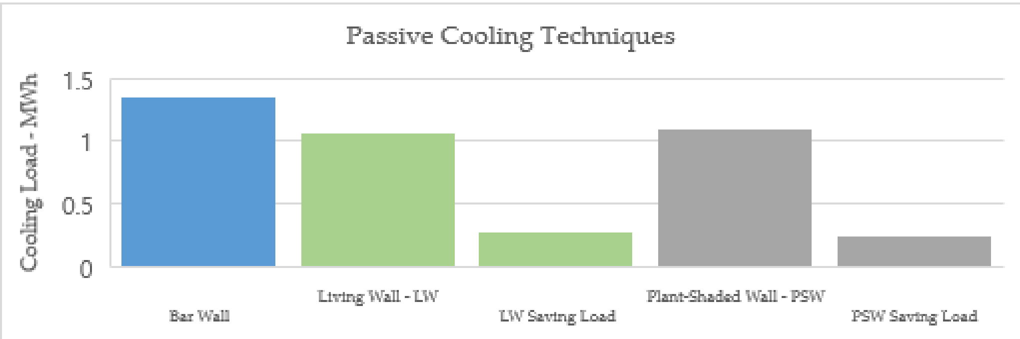


Figure 7. Comparison of experimental cooling load in MWh for the test rooms of vegetated Living Wall and Plant-shaded wall techniques.

As discussed above, the use of vegetated living wall and plant-shaded strategies reduces the cooling load on one hand and improves the environmental condition on the other hand. However, the main issue should be raised is the economic impact; "are these passive cooling strategies economically sustainable?" To answer this question, a study on the cost-benefit analysis of both the vegetated living wall and the plant-shaded was carried out by the author [16, 17]. The study covers the initial cost of the greenery systems, irrigation system including the amount of water, maintenance cost, and running costs to calculate the total cost per unit area of the tested façade. The cost-benefit analysis was based mainly on determining simple payback period considering the capital and operating costs while energy savings and increased rental value are included as benefit while ignoring the environmental benefits and inflation rates at this stage. The average temperature reduction on the external surface, internal surface and indoor space between day- and night-times reflected the cooling energy saving. The drop in average temperature represented the energy saving and the drop in peak temperature represented the reduction the capacity of the HVAC system. The cost-benefit of the used techniques is calculated through the energy savings caused by reduced cooling load and increased rental rate, using the international leveled energy cost.

Table 3. Cost-benefit of vegetated living wall and plant-shaded wall techniques

Passive Cooling Technique	Cooling Load Reduction (MWh)	Total Cost per unit area (m^2) US$	Energy Saving Cost US$	Payback Period Year
Vegetated Living Wall	0.28	250	133	11
Plant-Shaded Wall	0.25	39	122	4.5

A comparison between the cost-benefit of vegetated living wall and plant-shaded wall techniques is summarized in Table 3. The study concluded that for the vegetated living wall technique, the total cost per unit area (m^2) is 250 US$, while, the cooling load reduction is 0.28 MWh, the energy saving cost is 133 US$/year/unit, and the payback period is 11 years. However, for the plant-shaded technique, the total cost per unit area (m^2) is 39 US$ (much lower than the cost price of vegetated living wall), while, the cooling load reduction is 0.25 MWh, the energy saving cost is 122 US$/year/unit, and the payback period is 4.5 years.

The cost-benefit analysis results conclude that the total cost of the used modular living wall system might not be the best economic sustainable option of the green wall, as the installation costs are high comparing with similar systems using plastic mesh living wall system. The payback period of the vegetated living wall is quite high in comparison with the plan-shaded wall technique. It is expects to achieve reduced payback period, particularly for the vegetated living wall system once the environmental impacts as well as the use of graywater for irrigation system are included as subject of future study to make the use of greening systems economically.

6. Conclusions

Improving energy performance in buildings is the main concern of building construction development in the United Arab Emirates. The use vegetation on and around building façades has gained increasing popularity in many cities like Abu Dhabi and Dubai to improve thermal performance in buildings, increase energy efficiency and reduce cooling loads. The study concludes that vegetated living walls reduces the indoor ambient temperature by an average of 6°C in comparison to the bar wall. This reduction is achieved due to the decreased heat gain caused by the vegetation; the evaporative cooling caused by irrigation; and heat resistance caused by low thermal conductivity of the plants. With the indoor ambient temperature reduction, the cooling load can be reduced by up to 20.5%. Similar to the vegetated living wall, the peak indoor air temperature showing a drop of almost 5 ºC. The decreased temperature caused by the shading effect and heat resistance reduces the peak air conditioning energy demand by 18.5%. The economic analysis of vegetated living wall and plant-shaded wall concludes that the payback period of VLW technique reached 11 years however for PSW system, the payback period reached 4.5 years. A further reduction on the payback, particularly for the use of vegetated living wall, is expected once the environmental benefits are included. Additionally, VLW and PSW techniques contributes directly to sustainability, energy saving, air quality, and sound control.

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Conflicts of Interest: there is no conflict of interest.

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Parametric Design and CFD Analysis to Enhance Natural Ventilation in a High-Rise Building; Preliminary Results of a Case Study in the UAE

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Abstract: Buildings' energy efficiency must be tackled at the early design stage. In the UAE, the lack of attention for local typologies and techniques, makes buildings heavily depending on air conditioning. Especially high-rise constructions that, far from traditional typologies, are often designed with the sole purpose of being iconic.
Although Dubai has five months of pleasant weather, very few towers make use of natural ventilation, which could be used to achieve better IEQ and to activate passive cooling strategies.
This study employs the latest design tools - advanced computer aided software, computational fluid dynamics (CFD), and parametric/generative design - to create an energy-efficient and sustainable tower that maximizes natural ventilation to reduce the annual air conditioning operation.
The methodology includes two main phases: (1) CFD is used to analyze sites with different urban fabric, density, and typologies, with the objective of selecting a poorly ventilated area to serve as ideal project site and prove the benefits of the new tower concept; (2) parametric design would optimize the building shape to minimize solar radiation and maximize the collected wind flow.
Next phases of the research include the parametric design of the façade (of the selected optimized tower-shape) and the study of the apartment/office units to further enhance indoor natural ventilation.

Keywords: Parametric design; Generative design; CFD analysis; Natural ventilation; High-rise buildings

1. Introduction

1.1. Project Overview

UAE aims to be a successful role model and a global hub for the new green economy, in order to strengthen competitiveness and sustainability of the country and to preserve its environment for next generations. Hence, the prime minister of the UAE and Ruler of Dubai, H. H. Sheikh Mohammed bin Rashid Al Maktoum, has founded the UAE Green Growth Strategy [1].

The strategy plays a vital role in making the UAE one of the world's pioneers in this field. A program was released to outline the strategy's guidelines, which focus on several aspects such as energy, agriculture, sustainable design, constructional polices, and investment.

The six major fields, stating policies and program, of the Growth Green Strategy which are:

- Promoting the production and use of renewable energy.
- Encouraging investors to invest in the "Green economy" to create an environment that hosts new green innovations and inventions.
- Raising eco-friendly houses and buildings while preserving the environment through urban planning guidelines.
- Dealing with the effects of climatic change, promoting local organic agriculture to keep the ecological balance.

- Reducing electricity use and relying on natural resources, reuse of water and recycling waste.
- Applying and promoting the innovated green technology.

1.2. Problem Statement

High-rise buildings are one of UAE's (and especially Dubai's) icons. They helped in catalyzing the world attention and emphasizing the city scape. Moreover, they serve the economy through tourism and real estate, offering end-users a type of living that has today become a status symbol. Nevertheless, they are often characterized by high energy demand, in a country's where 80% of the total consumption is already accounted to buildings. Such uncontrolled energy use means an increase in climatic risks, environmental hazards, and CO2 emissions [2].

The high energy consumption of the built environment has been a widely spread problem in Dubai for the past decade. Among the reasons behind it there are evident ones such as the uncontrolled used of air conditioning (AC) and the broadly used and poor construction systems, but also more implicit ones such as the inappropriate imported building's typologies (and design), which are not studied for the specific climatic conditions. The above-mentioned reasons must be addressed in a holistic manner, to reach a comprehensive solution to the problem. So, if relying on an active AC is a waste of resources, while passive cooling could be enhanced by natural ventilation, such holistic strategies must be approached from the early design stage.

Natural ventilation is the action of supplying air and extracting air from an indoor space. It provides a healthy life as the oxygen in the fresh air helps the organisms to have a better blood pressure and heart rate. It increases energy levels and the immune system. It gives the sensation of relaxation and comfort [3].

Yet, many towers in Dubai do not make use of natural ventilation.

1.3. Project Objectives

Once identified the inefficiency of imported high-rise design to Dubai, the aim of the project is to study an alternative efficient design solution that enhance sustainable strategies to reduce the building energy consumption. Specifically, the research utilizes advance software running computational fluid dynamics (CFP) calculation, to understanding wind behavior in different urban fabrics/typologies. Previous studies have analyzed the effect of wind patterns around towers [4], also assessing how shape affects the airflow around the different surfaces [5] and parametric/generative design to model numerous iterations and find the building shape that best serves the purpose.

The expected result of the study is to identify the most optimized high-rise building shape that enhances the collection of natural wind-flow to contribute to the indoor environments' passive cooling, and therefore limit the use of air conditioning (AC).

1.4. Limitations

The software is fed with input data, to reduce the number of calculation variables, collected form literature (i.e., for building physics) and/or local authorities (i.e., for climatic data). Therefore, the study relies on the correctness of such data.

The work is based on the outcomes of the said software, which operates iterative computations toward a converged (optimized) result. The design obtained with this study must be considered one among several other possible outcomes achievable by modifying the software input data.

The project does not expect to reach a totally passive building. It is believed that, in the UAE, the harsh summer period will still need using AC systems. The study merely hopes to find a design strategy to limit the AC use-period during the year.

2. Materials and Methods

The research methodology is divided in the following phases:

1. Analysis of different sites in Dubai (diverse urban fabric type, building typology, and building density) to select the most suitable for the continuation of the study: a site with poor wind flow conditions will be selected, to act as worst-case scenario where to test the benefits of the above-described design strategy.
2. Parametric/generative design is performed to test numerous iterative potential high-rise shapes/models, under the parameters of solar radiation and overall wind flow. This phase focuses on processing the climatic phenomena with advance computer-aided computations in order to find the tower shape with the least total sun radiation on façade, and maximum envelope surface characterized by air flow.

3. Results

3.1. Analysis of different urban fabrics

The study started with the investigation of the effects of wind on different site, characterized by different urban fabric types, building typologies and density.

Three different zone in Dubai, respectively defined by three urban fabrics were studied: Jumeirah - Umm Suqeim 3, Sheikh Zayed road - Zabeel area, and Dubai Marina. Autodesk CFD (for accurate simulation) and Autodesk Flow Design (for clearer visualization graphics), combined to Rhinoceros and Grasshopper, have been used for CFD analyses. Three parameters are sought after in these simulations: wind speed, direction, and pressure.

Table 1. Comparison of the three selected sites

Site	Distance to the sea	Buildings' heights	Density level
Jumeirah - Umm Suqeim 3	Closest	Low-rise	Least dense
Sheikh Zayed road - Zabeel area	Far	Mixed rise	Less dense
Dubai Marina	Close	High rise	Dense

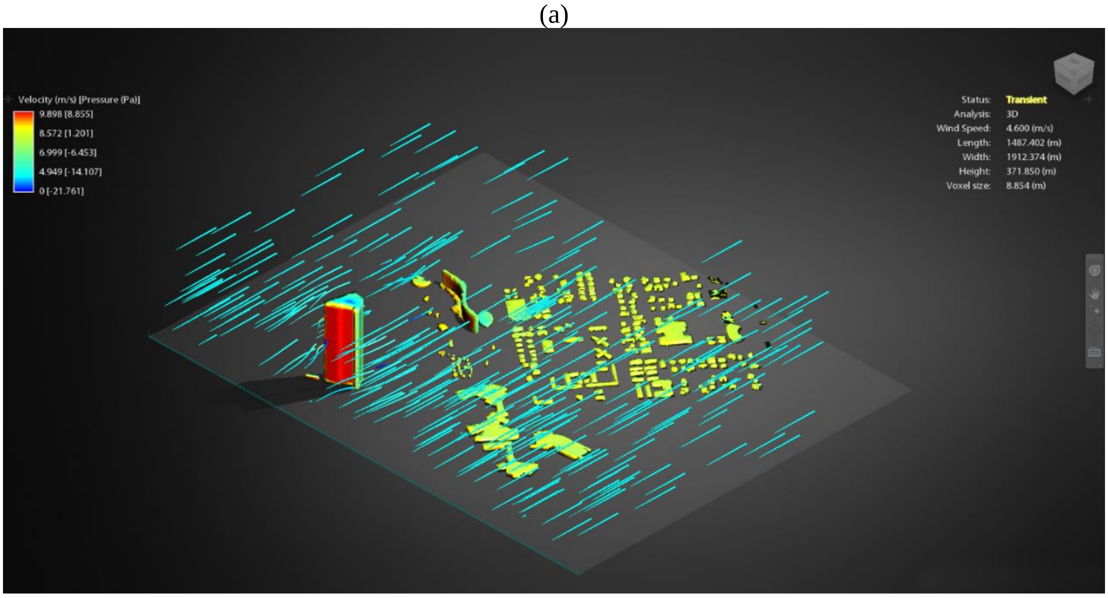
The CFD simulation of Figure 1 shows that Jumeirah - Umm Suqeim 3 has a uniform air movement and the fastest wind speed, equal to 6 m/s at 100 m height. This is most likely because it is close to the sea and no buildings (mostly low- to medium-rise) obstructs the direct wind flow from the shore. As a consequence, the buildings do not seem to be significantly deprived of the natural ventilation resource.

The CFD simulation of Figure 2 clearly shows that wind in Sheikh Zayed road - Zabeel area has two types of movement: horizontal and vertical. This is occurring because the buildings are close to each other, and their significant difference in heights. The recorded wind speed is less than in Jumeirah - Umm Suqeim 3, equal to 4 m/s at 100 m height.

The CFD simulation of Figure 3 shows how Dubai marina has a strong direct airflow coming from the shore overall affecting the first line of buildings toward the sea direction. Due to the vicinity between the buildings, the wind in Marina's inner part is the only residual flow passing through the high-rise constructions. This results in poor ventilation of the area: the wind reaching through the first layer of dense and tall towers is both low in speed in pressure.

Based on the above CFD simulations results, the highlighted area of Dubai Marina, shown in Figure 4, suffers from slower wind speed by 30% to 60% than the sea front line, with a final value equal to 2m/s. For this reason, Dubai Marina was selected as ideal site where to test the new tower design concept strategy.

(a)



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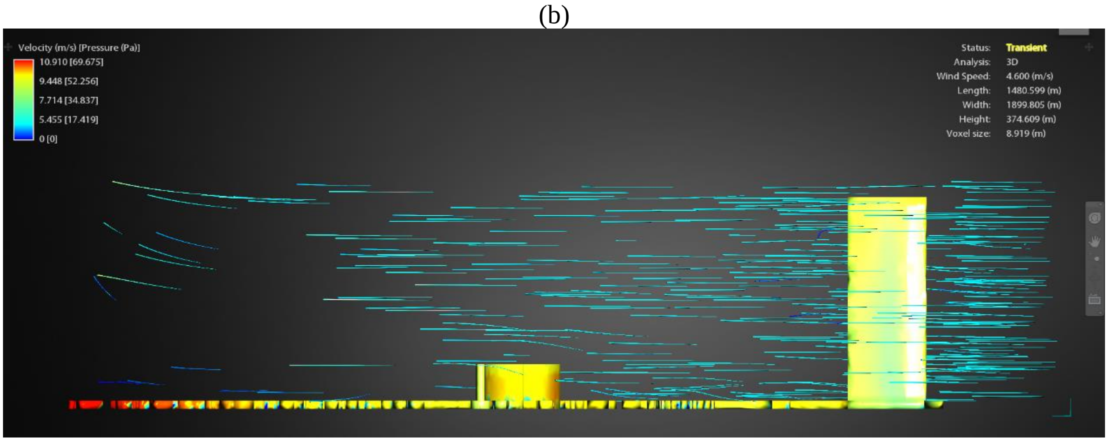
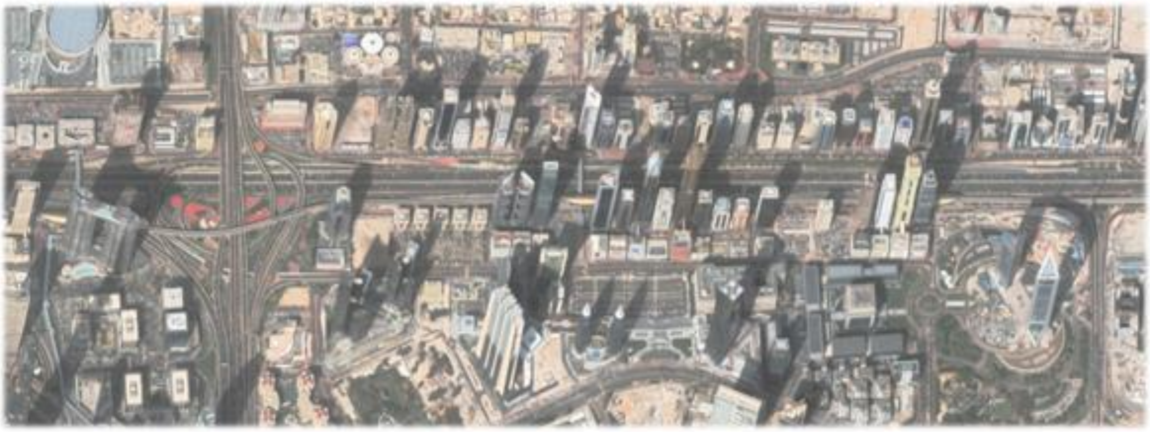


(c)

Figure 1. Top view of Jumeirah - Umm Suqeim 3 (a) and CFD simulation results in isometric view (b) and section (c).



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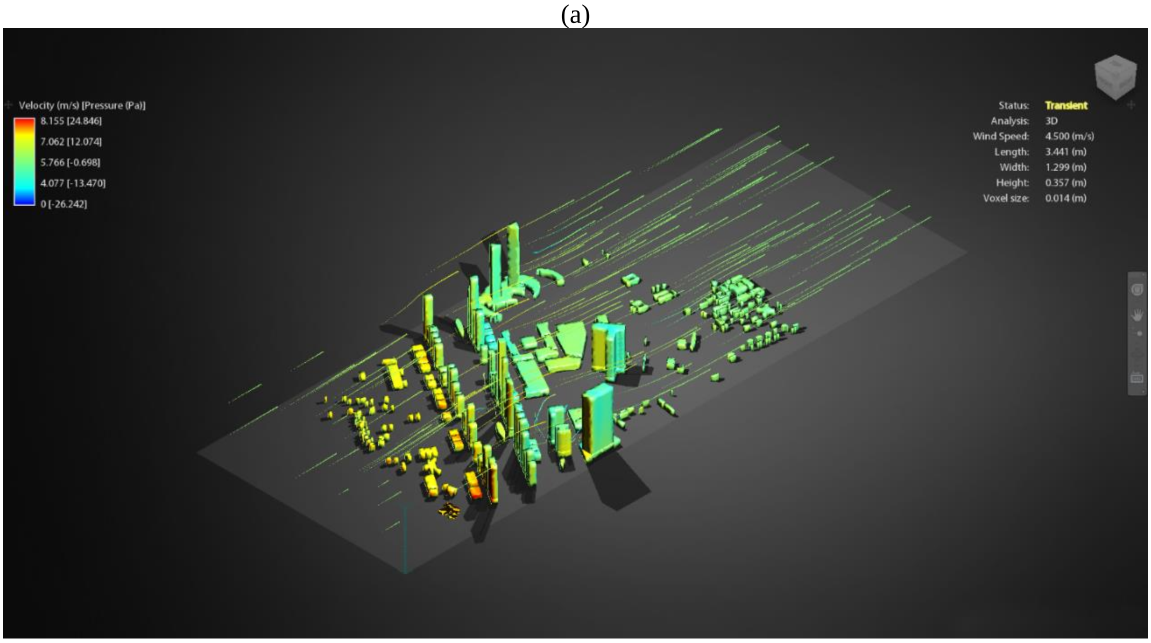

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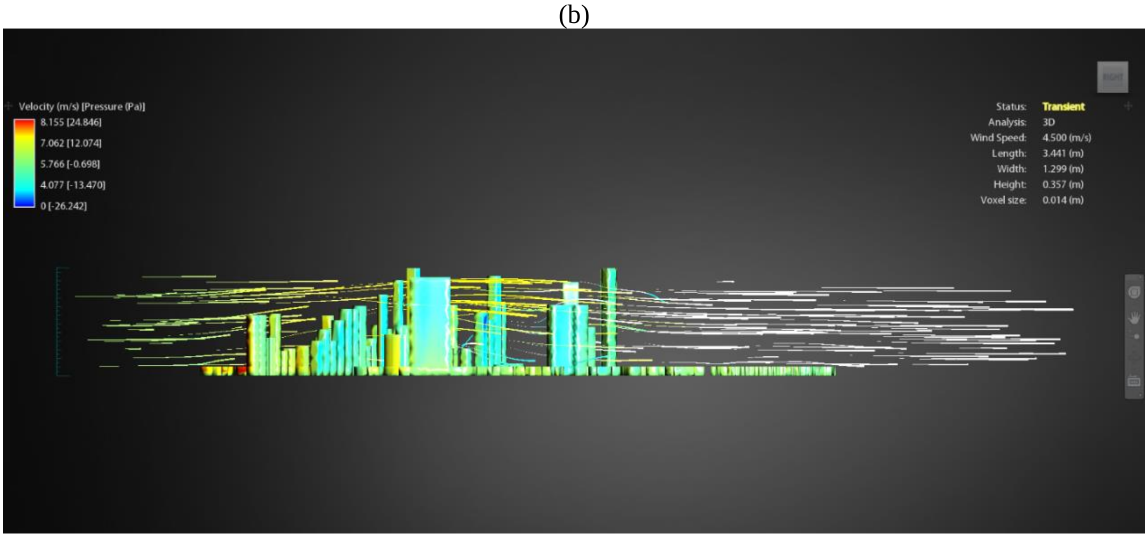
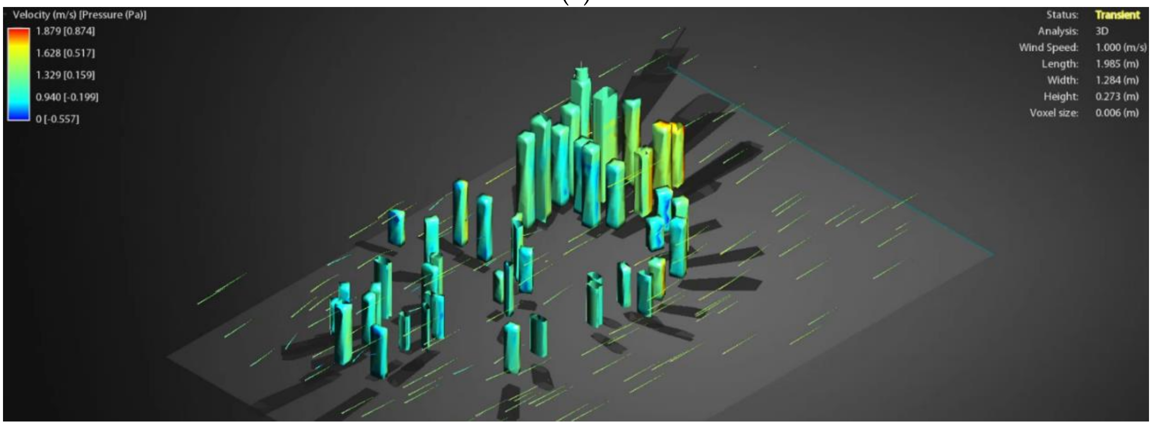


(c)

Figure 2. Top view of Sheikh Zayed road - Zabeel area (a) and CFD simulation results in isometric view (b) and section (c).

(a)



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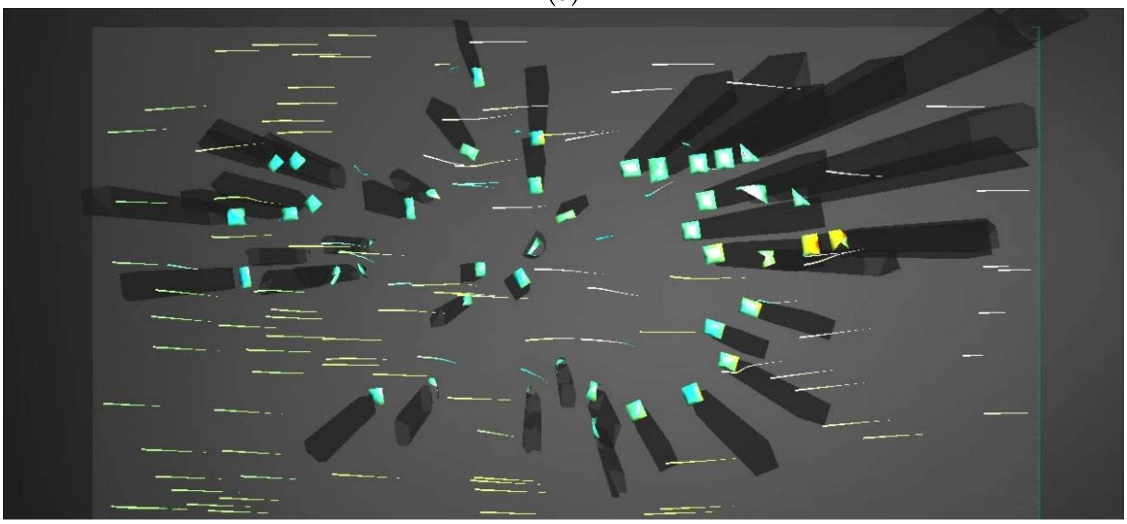
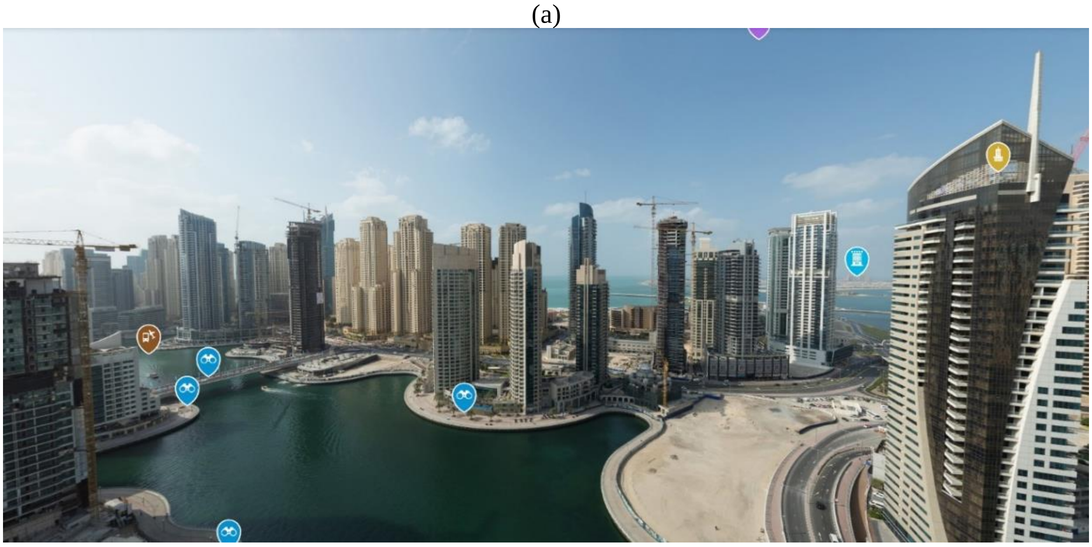


(c)

Figure 3. Top view of Dubai Marina (a) and CFD simulation results in isometric view (b) and top view (c).

(a)



(b)

Figure 4. Selected empty site in Dubai Marina, highlighted in top view (a) and visible in a bird-view picture (b).

3.2. Generative design simulations

3.2.1. Principles of computational generative design

Generative design involves a particular way of approaching the design intent, involving design-related issues and standards during the design process. Computational tools and techniques enable the processing of information and create various outputs as solutions to a given design problem. These techniques have been described as 'generative design', 'parametric design', or 'algorithmic design' to only name a few, and commonly, these computational tools have been introducing innovative form-finding systems [6]. Generative Design is a method that generates forms by adjusting parameters according toa strict set of rules and algorithms being derived from computational tools such as Rhinoceros [7], Grasshopper [8]. Algorithms and programs allow for a multi-constrained design process to develop computational geometric models and generative design that work together in such a way that the designer can interact with it to virtually explore design alternatives. These is done with careful considerations of the parameters and constraints of the building and of real-world contexts [9].

Computational generative design was used to set the constraints such as height, setback, and structure radius, taking advantage of the computer's computational capabilities, aiding the exploration of design alternatives. These allowed to control the general outcome of the structure, regarding its shape, size, and general elements that would be shown in the exterior. The parameters have then been set to determine more specific details that the structure should consider. The first program used was Rhinoceros, then various plug-ins were employed to input and adjust parameters.

3.2.2. Software set up: constraints and parameters

The first step is feeding the program with constraints, then setting the parameters and allowed range for each of them. Using the software Rhinoceros with Grasshopper numerous masses can be generated. Then the Ladybug analysis simulates the generated mass in the site-specific climatic conditions (sun radiation and wind feature).

Generative design constraints for the structure included tower height, site setback, and tower radius as these are also the site's restrictions from building codes. Dubai Marina is a high-density mixed-use area, since the economic value of land that does not make low- and mid-rise constructions feasible options. So, the height-target is the first constraint fed to the software and was derived from the average height of nearby structures, representing a reasonable mass for the tower to come. The second constraint is the site setback, which was to conform with the building code offset and to comply with communal open spaces in Dubai Marina. The third was the tower radius, derived from the most efficient use of the land allotted for the new tower (the total buildable area was derived from the total land area and reasonably split to provide proficient space for the structure and open space).

Major parameters of the building are the twisting angle, orientation, and shape of the floor section. The outcome presented in the charts generated by the program allow identifying which of the strategies have high potential to be efficient (in regard to enhancing natural airflow on the building envelope). As the software trials, by iterative process, produces more and more efficient outcomes, the further generation of attempted simulation would build on the best previous result, ideally converging to the best possible one (or better, to a set of best possible ones. In fact, the constraints provided are not enough to allow the software converging to a unique result). More than 2000 tower shapes, each unique and different, have been generated and tested by the software, Figure 5 shows a screenshot of the software while running the iterative simulation of the potentially optimized tower shape).

Figure 5. Screenshot from the parametric/generative software, while running a set of potential shapes and analyzing the sun radiation and wind-flow on their surface.

3.2.3. Iterative simulations

Environmental simulations with Rhinoceros and Grasshopper were assisted by two plug-ins:

- Ladybug runs climate analysis, importing precise weather data, and performed radiation analysis, shadow studies.

- Butterfly was used to gather data regarding specific airflow modelling and to run CFD analysis. This program rigorously validates several simulations and exports them to geometry or common airflow simulations. These include urban wind patterns, indoor buoyancy to model thermal comfort, and effectiveness of ventilation.

The summation of all these programs allowed to automatically generate masses to be examined and climatically evaluated according to the site's conditions, Figure 6.

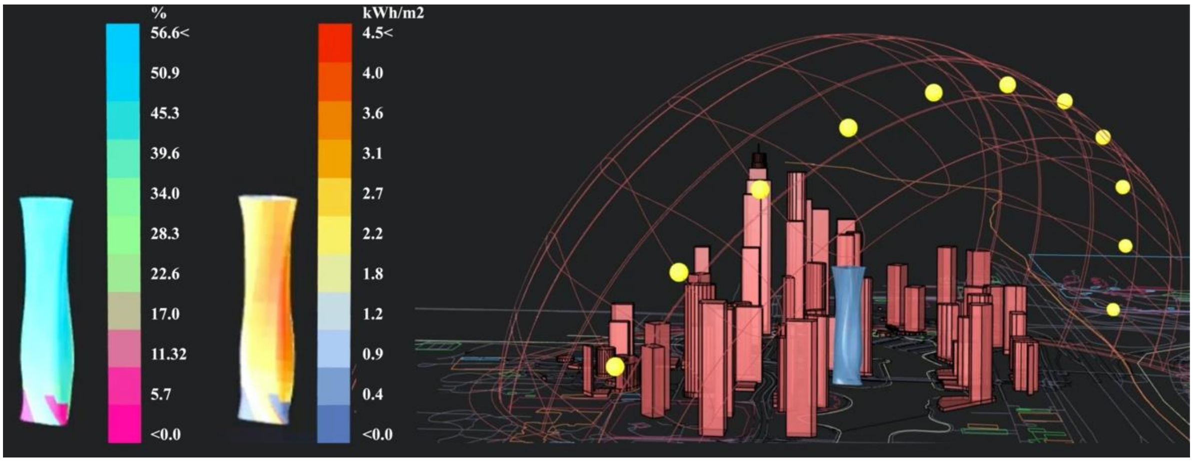


Figure 6. Screenshot from the parametric/generative software, while running the environmental analysis on a selected model. On the right, the massing inside the site at Dubai Marina; on the left, the same shape tested for sun radiation and percentage of surface-area receiving wind flow.

Figure 7 shows the outcome of one example of the above-described simulation process, highlighting:

1. Tower model in two representations, the first showing the smooth mass and the second showing it as a building divided in floors.
2. Significant cross sections of the model, showing the forms used in this specific case by the software during the iterative process.
3. Performance analysis in regard to maximum air flow and minimum sun radiation (both measured as collected by the model's surface). The case study in the figure shows the good performance (highlighted in green) in the two assessments.

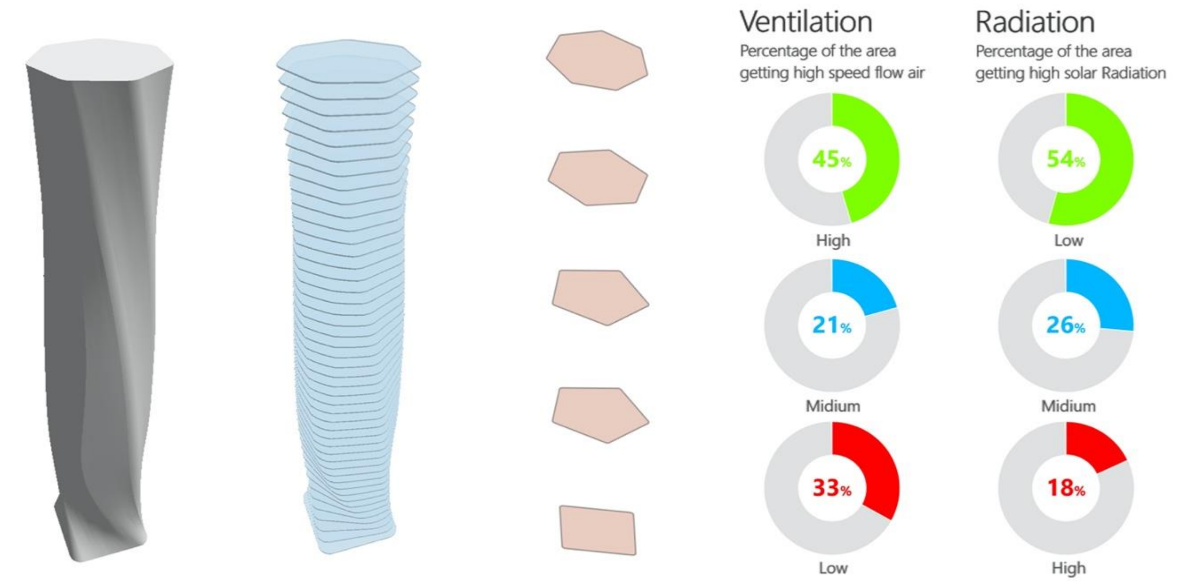


Figure 7. Sample of a detailed analysis outcome for a potential tower shape

4. Discussion and Conclusions

The paper discusses the computational parametric process to design a naturally ventilated high-rise building located in an unfavorable position with regard to wind exposure. The study was assisted by parametric and generative design software that allowed, via a gradual and iterative process, to optimize the building shape that would allow collecting the most wind flow, with the aim of channeling it to enhance façade back-ventilation or to activate indoor ventilation.

So far, the research allowed obtaining the optimized building shape, Figure 8. The helicoidal-like shape allows the residual wind reaching the tower to be collected at the top and distributed down along the envelope's surface.

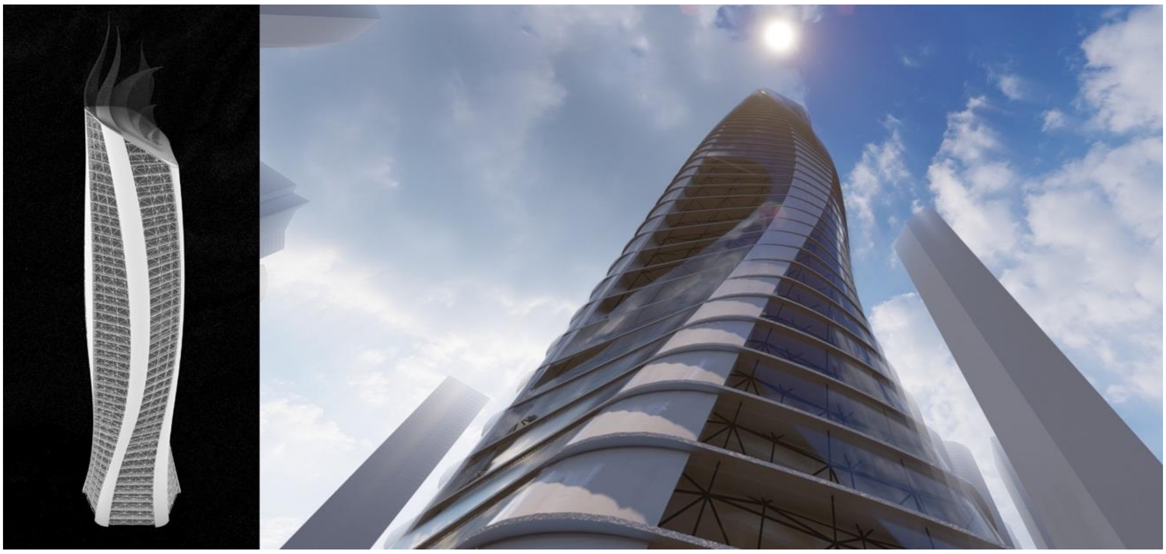


Figure 8. Architectural development of the most optimized parametrically designed shape.

This sole result will allow more portions of the façade to be interested by airflow, and more units in the building to be able and use it for natural ventilation. However, more investigations are required to study and quantify the amount and quality of air improvement. The future steps of the research include:

- Development of the building core to channel the wind collected at the top of the tower, assisted by deflectors, and distribute it at the different floors, Figure 9). Quantification and degree of efficiency to be verified by a detailed CFD simulation.

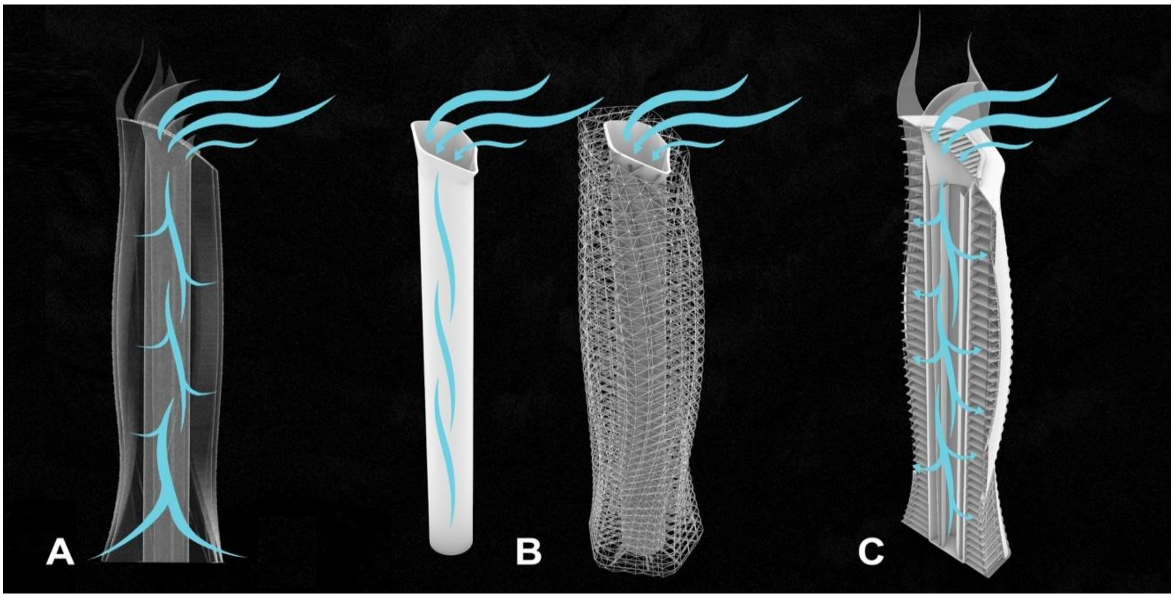


Figure 9. Conceptual development (A) of the building core (B) to channel the air at the different floors (C).

- Development of a parametrically designed double-skin façade to even the distribution of the air on the building envelope. The wind flow on the outer surface of the building's envelope, already distributed more evenly due to the modelling process, can be further channeled through the gap of a double-skin façade: the external cladding system would be composed of modular perforated tiles (in the form of pockets) that can be interchanged to allow more or less wind through, and rotated to deflect it in the desired direction, Figure 10. The inner layer of the double-skin façade would be operable: close, to act as a conventional ventilated facade; open to enhance the indoor spaces' ventilation.

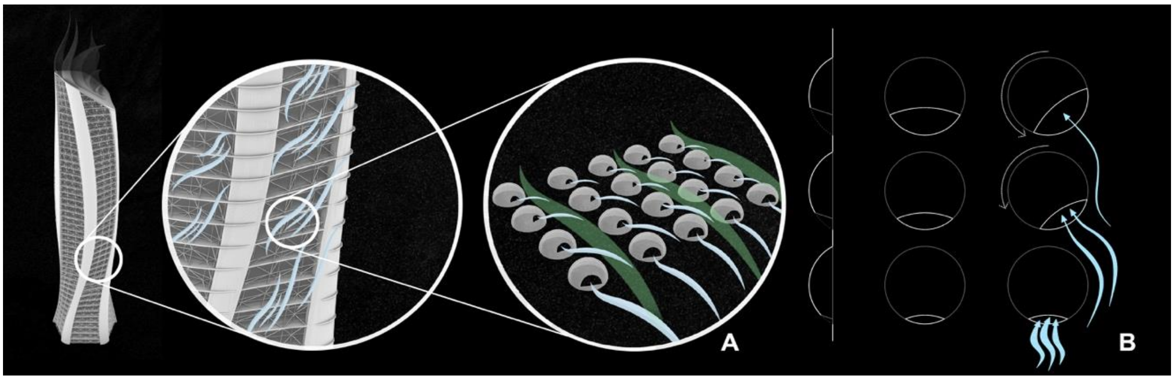


Figure 10. Conceptual development of the parametric-designed façade, with its modular pockets (A) that collect more or less wind and channel it in the necessary direction (B).

- Development of the dwelling/office units inside the building. As previous research has highlighted [13, 14], the indoor typological and morphological layout influences significantly the air flow in the given space. With more detailed CFD analyses, the study will analyze the contribution of different units' layout (single-story, duplex, triplex, etc.) in enhancing the natural ventilation and passive cooling allowed by the above-mentioned parametric modelling processes Figure 11.

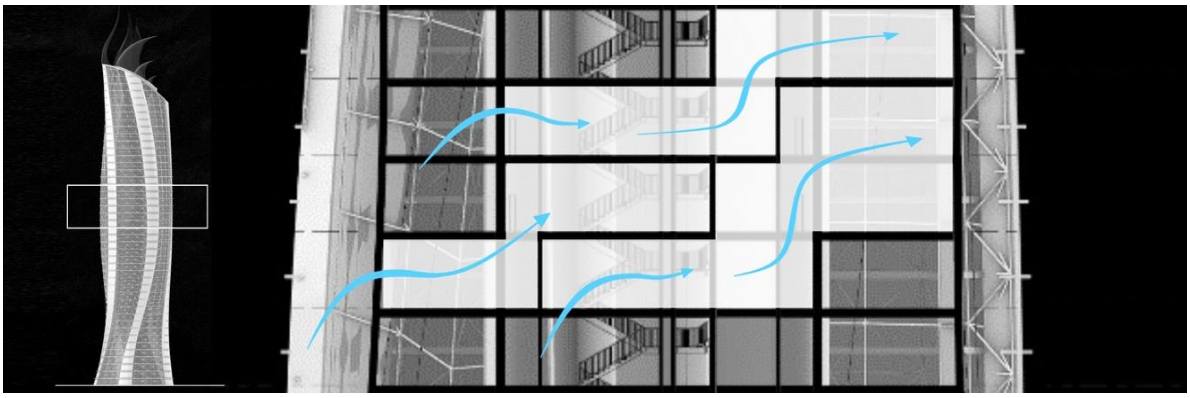


Figure 11. Conceptual development on indoor dwelling/office units: single-story, duplex, and triplex layout will be tested to verify to most suitable to further enhance the indoor natural ventilation.

Author Contributions: The conceptualization and methodology of the research was by N.A., S.S., V.B. and M.H.; the investigation, software, and formal analysis were carried out by N.A. and S.S.; visualizations were done by N.A. and V.B.; the original writing was done by N.A., S.S., and V.B., the revision and final editing to the writing was done by M.H.; the overall supervision and validation were done by V.B. and M.H.

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Session 2:

Climate Change and Urban Resilience

Resilient Urban Forms: Impact of Urban Morphology Descriptors on the Building Energy Use

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Abstract: In this era of climate change, cities are paying more attention to the building energy use and carbon footprint for attaining sustainability. Recalling upon UN-Habitat's initiative for 'resilient cities', it is imperative to explore the concept of 'resilient urban forms' in terms of the flexibility offered by the city's physical form towards energy use reduction. Currently, the two main areas of debate within the field of energy driven urban design include - the effectiveness of urban morphology and the impact of densification on building energy use. Even so, scholars are still questioning the effectiveness of the physical form of cities in energy use reduction when compared to other energy dependent factors (construction materials, heating, ventilation, HVAC systems). Adding to this knowledge gap, studies have attempted to quantify and understand the relation between measures of density and building energy use. Comprehensive research reviews suggest that densification may exhibit positive, negative, or complex relations with the heating or cooling energy demands. However, scholars have failed to reach any consensus due to the conflicting nature of the research findings within this field. This may be attributed to the fact that, energy use within a city fabric varies as a function of the geographic context, climatic conditions, economies, scale and culture. Besides density, other urban morphology descriptors may also have strong correlations with the energy use. Unfortunately, the impacts of densification on total heating or cooling energy uses still present no dominant conclusions. Reflecting on the current studies in this field, we hypothesize that "form-energy relations are meaningful only when the combined influence of independent form-based descriptors on energy use are addressed". Hence, the study proposes a methodological assessment framework using empirical and statistical approach to achieve energy efficient urban transformations within a city's 'neighborhood planning unit', an area corresponding to a standard superblock in a hot urban desert context. This goal is achieved by answering the three main questions: (1) What is the relation between urban form descriptors and building cooling energy demand at the neighborhood planning scale?; (2) Which is(are) the most significant energy driven urban form descriptor (s) that strongly associates with reduced cooling energy demand?; (3) Which is the most appropriate assessment (method) approach informing the practical experimental exploration of physical form of cities for energy-oriented planning?. Finally, the argumentative discussion of the study addresses their practical implication by implementing the framework for outlining planning and design strategies for achieving more energy efficient building systems at different scales.

Keywords: Urban morphology; Energy efficiency; UAE superblocks; Energy use intensity; UMI

1. Introduction

The Increase in global population and enhanced living standards have intensified urbanization, significantly leading to a rise in global energy consumption and CO_2 emissions. These increased population densities, along with the demands of the urban environment, further, intensify the global issue of human induced climatic changes (National Geographic, 2015). Energy consumed by the building sector consisting of both residential and commercial end uses, accounts for 20.1% of the global energy consumption (U.S. Energy Information Administration [USEIA], 2016). Without doubt, it is vital for the residential buildings and associated urban forms to be planned efficiently, as this transformation of the building sector foresees a great potential to reduce energy consumption. In response to this critical challenge affecting the dense urban areas, one of the widely accepted solution includes planning for sustainable energy efficient urban forms through urban resilience (Yang, 2015; UN Habitat, 2018; Sharifi & Yamagata, 2018,2019; Mangan et al., 2021).

Resilient urban form is defined as the adaptability offered by a city's physical structure towards survival of adversities at different spatial scales. Sharifi & Yamagata (2018) suggests that the "Physical design of cities can support maintaining urban integrity and functionality under constantly changing conditions and can influence capacity of cities to plan and prepare for adapting to shocks and adverse events". Furthermore, an experimental study conducted by Ratti et al. (2005) demonstrates that urban forms serve as one of the most important factors influencing a building's overall energy consumption, possibly accounting for more than 10% of its energy consumption (Curra et al., 2018). Accordingly, urban form can be translated as the physical and spatial representation of activities involving interactions between socio-economic, technological, and environmental factors. Hence, the study argues that, "Developing 'resilient urban forms' through interventions in the physical form of cities proves highly significant for building energy use reduction".

Considering the energy efficient urban form assessments, a wide range of studies have attempted to understand and evaluate the form-energy relation through multiple urban form attributes (density descriptors) and conceptual definitions (Perera et al.,2021; Javanroodi et al, 2018). As highlighted by Silva et al. (2016), these interactions among the descriptors of urban form lack clarity and pose difficulties in evaluating alternative building configurations and urban geometries for energy efficiency. Despite the systematic use of form descriptors to analyze form - energy use reduction, urban planning processes have not yet attained corresponding gains in efficiency (Mangan et al., 2021). This may be attributed to the fact that the desirability of urban configurations depends on various factors such as geographic context, type of disturbance, and purpose of assessment. It is critical to understand and plan the physical form of cities in a way that facilitates flexibility to reduce energy use with minimal need for interventions. Hence, given the complex and dynamic structure of urban forms, attaining better energy performance requires decision making mechanisms along with appropriate site/urban context specific solutions.

The ever-rising risk of thermal extremes turns out to be highly significant in the hot desert climatic zones, given the existing temperature extremes (hot and dry), high sun exposure and urban induced heating. The urban areas falling within the BWh (B:ard, W: desert, and h:hot) climatic subtype of the Koppen-Geiger climate classification system (Koppen-Geiger, 1928), are attributed as 'hot dry desert' environments. Within these cities, morphological and geometric configurations of the buildings, result in intra urban thermal variability constraining the factors that control localized cooling energy demands (Pal & Eltahir, 2015). Furthermore, recent research reviews highlight the limited number of studies addressing the impact of urban form descriptors on the cooling energy demand in the hot desert regions (AlKhaled et al., 2020). As these cities are highly vulnerable, city planning officials require a careful consideration of the urban form related tradeoffs for attaining cooling energy efficiency.

Considered as an important regional hub within the Gulf Cooperation Council (GCC), studies are being conducted in the United Arab Emirates (UAE) towards attaining cooling energy efficiency at the neighborhood planning scale (meso scale) (Ahmed & Alipour, 2019). Statistical analysis of residential energy models in the UAE (city of Dubai), showed that a 0.5% - 8.5% increase in energy demand was accounted by a 0.45% - 4.6% increase in the peak electricity demand per degree rise of temperature (Santamouris et al., 2015). Additionally, energy consumption of the residential sector is predicted to grow by 1.9% per year from 2012 to 2040 in the Middle East (USEIA, 2016). Like other cities of the UAE, Abu Dhabi's urban planning strategies represents the city fabric through an array of superblocks: "a framework of evenly spaced arterial avenues delineating large parcels of rectangular land approximating to 900 x 600m" (Scoppa et al., 2018). With adequate planning interventions, the superblocks may provide a paradigm shift towards a residential energy efficient urban form through physical interventions (passive approaches). Hence, the study calls for the need to understand form - energy use relation within Abu Dhabi's 'neighborhood planning unit (NPU)', an area corresponding to a standard superblock in the context of the United Arab Emirates (UAE).

The paper is structured into four sections. Section 2 defines resilient urban forms and relates it to the study context. The concepts of urban morphology and energy use in the urban systems and the significant urban form (density descriptors) and energy use descriptors (cooling demand) from literature are discussed within subsections of section 2. The discussions arrive at "Spacemate" as the most efficient energy driven urban form descriptor to comprehensively represent form-energy relations. The following section 3 proposes a methodological assessment framework inclusive of the form assumptions and building energy dependent properties for form-energy analysis within a sample superblock. Finally, section 4 concludes with the lessons learnt and future research outlook.

2. Theoretical Background

2.1 Resilient Urban Forms

Urban resilience is defined as the "measurable" ability of any urban system to adapt, transform and sustain, while responding to any adverse uncertainties, shocks, or stressors (UN Habitat, 2018). Although, resilience reflects upon 'adaptability' and 'flexibility', there is less clarity in defining the concept of 'urban resilience' and the underlying principles. Considered as a context sensitive property of urban systems, the defining attributes of urban form may vary as a function of the purpose of intervention, the spatial scale or risk being addressed (Sharifi & Yamagata,2016). To facilitate a better academic and scientific understanding of the concept of 'resilience', it is necessary to answer the three basic questions as undertaken by previous studies - "Resilience of what?", "Resilience to what?", and "Resilience for whom?". Considering the above answers, this study deals with the resilience of the urban form (physical dimensions) of a city towards the increased energy driven demands due to ever-rising risk of temperature changes for the incident community (Figure 1a). Prior to embarking on this field of study, the diversity of spatial and temporal scales within urban form analysis demands answers to a few additional questions as well. These questions on the resilience of urban forms such as "Resilience in what context?", "Resilience at what Geographic scale?", "Resilience during what stage?" and "Resilience for what?" are further considered significant in unpacking the potential of 'urban forms' in energy use reduction (Figure 1b). Accordingly, the study intends to understand the practicability of reducing building energy use within a 'Neighborhood Planning Unit'(Superblock) located in the hot urban desert climatic context at the planning stage. Hence, authors believe that exploring and understanding the urban morphology (physical measures) - energy use descriptor relations, will enable in optimizing the resilience of urban form towards building energy use.

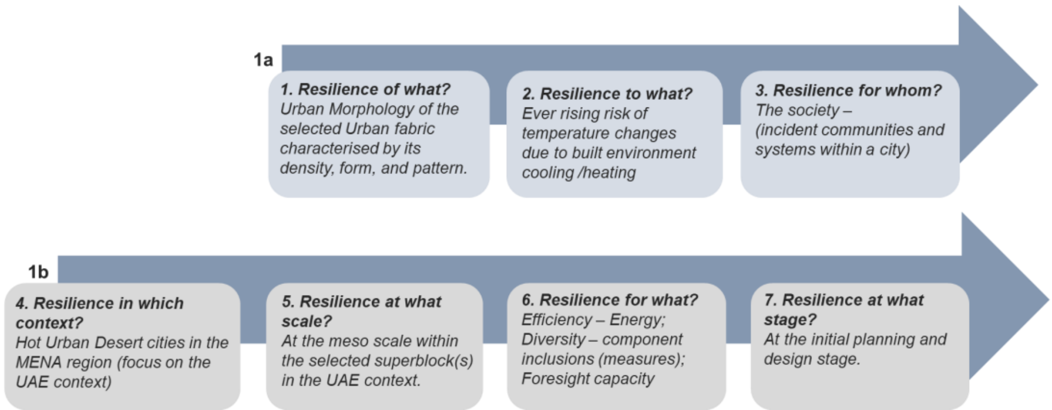


Figure 1. Defining the resilience of urban form (physical dimension) towards reduced building energy use.

2.2. Urban morphology & building energy use

Urban morphology attributes and the associated descriptors play an important role in influencing climate resilience and energy efficiency. Due to the interconnected urban structures, a complexity is observed in defining and identifying the main urban morphology attributes and the associated energy driven descriptors. Pioneer studies define urban morphology within a conceptual theory of physical elements of the city comprising of two main aspects – urban form elements and the associated processes transforming them over time (Solá-Morales, 1997). These urban form elements include plots, buildings, streets, and the infrastructure, whereas the processes include use, performance, or mechanisms that transform these identified urban elements. Hence, the definition of urban morphology depends to a great extent on the scale being addressed - macro, meso and micro scales. The macro scale urban morphology is characterized by the structure of the city and its predicted development in relation to network of other cities (Sharifi & Yamagata, 2016). At a lower scale, relative dynamic interactions exist between the spatial components along with spatial overlaps. For instance, the meso scale includes properties related to site layout, building orientation, or placement of buildings in the plot, those of which more likely represent the local micro scale. Even though meso and micro scales are interdependent, the former address's urban structure of the district or neighborhood, while the later address's the block configurations, urban canyons, or intensity with which the plots are built (group of buildings in the site). Even though, no clear boundaries exist between the different spatial scales, it is imperative to understand the interplay of the morphology descriptors at a lower hierarchy.

Although diverse spatial scales exist, the meso scale mimics the city morphology by representing the neighborhood or district structure inclusive of buildings/ plots/blocks. Overall neighborhood structure is characterized by the density and diversity of "block types, open and green spaces, site layouts, design (networks)" and the intensity at which plots are built (Sharifi & Yamagata,2016; Wheeler, 2015). Similarly, Oliveira (2016) refers to urban morphology as the skeletal structural system of the city constituting blocks, plots, and buildings connected by street networks. Furthermore, Shi et al. (2017), extends the idea of urban morphology as a domain defining the tangible physical form of the city endlessly influenced by its associated factors (people and processes). While the above studies consider urban morphology to include associated dimensions of building forms, Javaroodi et al. (2018), in contrast, sub categorized this concept to encompass forms, patterns and density as separate entities in experimentation and analysis. Considered as a comprehensive attribute, "urban density" determines the layout, plan, and height of the unit of analysis. "Urban form" represents the building shape or volumetric footprint including "L", "U" or "Y" configurations, while "urban patterns" represent the characteristics of the interconnecting street networks within the urban area or canyons. Hence, most of the scholars agree on urban morphology attributes to constitute the urban form (building shape, plots, blocks, building height, compaction, intensity of built environment) and urban pattern (street networks) in dense urban areas.

The concept of "energy driven urban design" introduced by Shi et al. (2017), binds the relationship between urban form and building energy use. This concept provides a foresight to considering the implications of the impact of urban city configurations on energy efficient urban planning. At the meso scale, 'energy use' of a building structure constitutes both embodied energy and operational energy. Embodied energy (EE) deals with the energy required for processing, manufacture and delivery of building materials to the site. On the other hand, operational energy (OE) is defined as the energy required during the occupancy stage of the building life cycle for carrying out services such as space heating/cooling, lighting, ventilating systems and operating building appliances (Tuladhar & Yin, 2019). OE constitutes 80%–90% of the total building energy demands and is highly dependent on the climate, building configuration, function and occupancy characteristics (Azari, 2019).

In practice, operational energy use is quantified using two main descriptors: energy use and energy use intensity (EUI). The former descriptor deals with thermal aspects of the urban environment, while the latter deals with the optimized operational energy of the building throughout a designated period (annually, monthly, weekly). Previous studies recognize EUI as the unified and most efficient descriptor for recording building heating, cooling or overall energy use (Figure 2). Since, the hot desert climates are characterized by urban lands of extreme heat, arid conditions with intense sunshine; this study addresses the significance of urban form descriptors on the operational cooling energy demand (operating ventilation systems, HVAC systems etc.).

While considering the research efforts connecting the two domains, previous studies have connected urban form with the building energy performance (Ratti et al., 2003; Ratti et al., 2005; Salat et al., 2007; Rode et al., 2014; Sanaieian et al., 2014; Caruso & Kämpf, 2015; Cajot et al., 2016). These base studies acknowledge the link mainly affecting energy performance through the manipulation of the geometries at the meso building scales for achieving low operational cooling energy demand.

2.3. Urban form-based energy driven density descriptors

Studies indicate that density descriptors predominantly influence the building energy use in terms of the heating and cooling energy demands (Perera et al., 2021; Mangan et al., 2021; Leng et al.,2020; Song et al., 2020; Salvati et al., 2020; Javanroodi et al., 2020;2018; Vartholomaios, 2017). Quan & Li (2021) identifies four categories of energy driven attributes for urban scale evaluation – density-based, geometry-based, land use/land type- based and network typology-based. The density-based attributes include design descriptors assessing the building morphology and intensity at which plots are developed. The most common density descriptors used are floor space index (FSI), ground space index (GSI), building height (BH), building density index (BDI), block density (BD), block coverage (BC), lot size (LS), and interbuilding spacing (Perera et al., 2021; Mangan et al., 2021; Leng et al.,2020; Song et al., 2020; Quan & Li, 2021). The second category includes descriptors that take account of the environmental factors (such as UHI effect, solar access, ventilation potential, infrared radiation exchange) influencing the building exterior surfaces according to the urban geometry. These descriptors assess the geometric properties related to the building, while influenced by external environmental factors for understanding the form-energy relations. In this regard, scholars have used descriptors such as surface – volume ratio (S/V), form Factor (FF), size factor (SF), lot geometry (building orientation), window to wall ratio (Wi/W) and aspect ratio (building height-to-street width ratio - H/W) (Perera et al., 2021; Mangan et al., 2021; Song et al.,2020; Huang et al.,2020; Javanroodi et al.,2020, 2018; Slavat et al.,2020; Faroughi et al., 2020). The third category includes design descriptors covering the complexity offered by the microclimatic, building geometry and temporal influences (time) on the energy use. Although, these descriptors are not often used, studies assessing both the spatial and temporal influences consider spatial distribution index (SDI), green area ratio (GAR), green area geometry (GAG) and water body index (WBI) (Leng et al., 2020; Faroughi et al., 2020; Ahmed & Alipour, 2019; Huang et al., 2017). As the name suggests, the last category of network typology-based descriptors evaluate the influence of typology and geometry of the streets connecting the building plots. The most widely used descriptors in this category are route type (RT), street width (SW), street orientation (SO), and street density (SD). Above discussion suggests that studies consider either a single category or a combination of more than one category for optimized urban scale form-energy relation.

Among the four categories of energy driven urban attribute descriptors, the density and geometric-based descriptors are highly cited and widely used (Curra et al., 2018). However, the direct use of geometry-based descriptors renders the calculation of the site (building) and climate (environmental) specific factors more difficult, and inaccurate leading to prolonged analysis. Conversely, the density-based attribute informs the form-energy relation using basic spatial design descriptors that are effective at evaluating the energy performance of urban areas at the meso scale. Suitably, these descriptors (including FSI, GSI, BH, BDI, LS and IBS) provide simple, accessible and accurate data with ease of use and calculations without any expert knowledge (Curra et al., 2018). Consequently, the classic density-based descriptors have been adopted as a standard attribute of form-energy evaluation in several studies (Trepci et al., 2021; Ahmed & Alipour, 2019; Javanroodi et al., 2018; Huang et al., 2017). Among these, the most significant density-based descriptors for cooling energy use reduction are floor space index (FSI), ground space index (GSI), building height (BH), and Interbuilding spacing (IBS). The FSI, GSI, and BH shows negative correlation, whereas IBS shows a positive correlation with cooling energy use. The relationship between urban form and cooling energy use has been widely discussed as detailed below (Trepci et al., 2021; Javanroodi et al., 2018; Salvati et al., 2020; Khaled & Alipour, 2019).

Experimental studies by Javanroodi et al. (2018) investigated the impact of surrounding urban configurations on a target office building in Tehran and concluded that higher FSI, GSI and taller buildings were the most cooling energy efficient. Similarly, Trepci et al. (2021) showed that building height (BH), lot size (LS) and inter building spacing (IBS) of an idealized mixed-use sample in Dallas (warm temperate climate) exhibited significant relations with the cooling energy demand. Energy model analysis revealed that higher cooling energy performance was obtained by the combined effect of reduced interbuilding spacing and increased building height. Yet, the lot size/geometry showed inconsistent relation based on the orientation of the buildings towards or against the solar gain direction (0o or 90o). Thus, a combination of descriptors showed higher form-energy efficiency when compared to the influence of a single descriptor. Moreover, the parametric variations of the study samples revealed that all the three descriptors (BH, LS, IBS) were significant for residential typology, however, only the building height was significant for commercial typology. Hence, the functional typology of the buildings influences the selection and significance of density descriptors used for assessment.

Apart from the dependence of density descriptors on functional typology (Trepci et al., 2021), the micro climatic variables serve as major predictors of cooling energy use. These micro climatic variables include urban heat island (UHI), solar obstruction /access, wind resistance (ventilation potential) and infrared radiation exchange. The low solar obstructions and higher heat gains within these contexts, render the effect of UHI on form-energy relation insignificant. In the hot urban desert climatic contexts, only building heights showed significant influence on the cooling energy demands (Mangan et al., 2021; Salvati et al., 2020; Javanroodi et al., 2018). By running simulations on the real urban samples in Chile, Salvati et al. (2020) pointed out the negative correlation between building height and cooling energy demand. Similarly, using Building Modular Cells (BMC) technique along with statistical analysis, Javanroodi et al. (2018), summarized that the most ideal urban form resulted in not only 10% decrease in cooling load, but also a15% increase in ventilation potential. Therefore, the study pointed out that micro climatic variations (due to UHI) influenced the cooling energy demand as well. It is noteworthy to highlight that; taller buildings prove to be more energy efficient under the influence of micro climatic variables.

In hot urban desert contexts, a higher urban density results in reduced cooling energy use. Khaled & Alipour (2019) studied the effect of compact urban forms on the cooling energy demand through a comparative study of traditional and compact housing neighborhoods in the United Arab Emirates (UAE). Authors identified an inconsistent relationship between FSI and the cooling EUIs in all the samples. However, by introducing individual experiments with additional descriptors, conclusions suggested that higher FSI, higher GSI, and reduced lot sizes significantly contributed to cooling energy efficiency (except the climate zones). In addition to the isolated individual influences, results show the potential of combined FSI, GSI, and lot sizes in building cooling load reduction within a compact neighborhood. Conversely, higher urban densities lead to higher peak energy demands when compared to lower urban densities

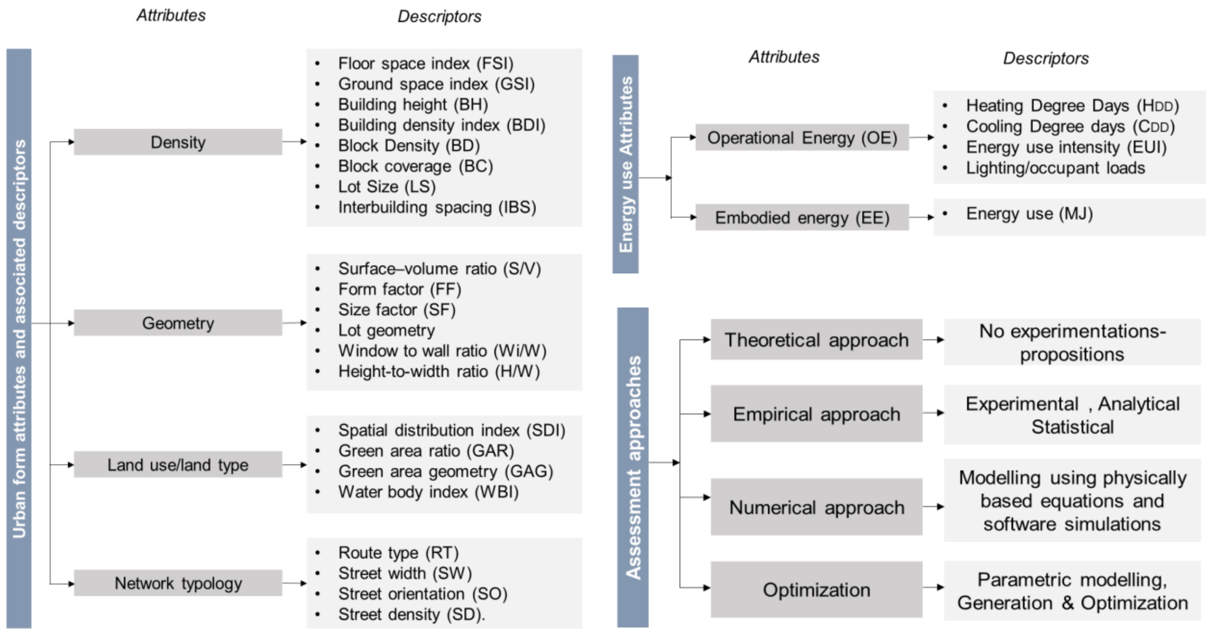


Figure 2. Urban form descriptors (4 categories), energy use descriptors and assessment approaches from literature (Author, 2021)

Apart from the selection of significant descriptors for the study, the form-energy relation is also influenced by the unit of building energy use. One such attempt made by Trepci et al. (2020), showed that the energy use intensity per unit of the area increased with density, however, energy use intensity per dwelling unit decreased with density for the same unit of analysis (residential TODs). The simulation results revealed that density descriptors proved efficient or detrimental in assessing cooling energy demand based on the unit of measurement. Hence, the study failed to obtain an understanding of the combined influence of the different density descriptors on cooling energy use. Despite these interesting findings, the study highlights the importance of considering a unified urban form metric not affected by energy use intensity measurement units (per unit area or per dwelling unit) so as to enable the isolation of individual as well as combined descriptor influences on energy consumption. Reflecting on the current studies in this field, it is beyond doubt that form-energy relations are meaningful only when the combined influence of independent density-based descriptors on energy use are addressed.

Within this context, it is important to retrace the argument put forth by Pont & Haupt (2005) in the uncertainty offered by a single descriptor in assessing urban form. Appropriately, the authors proposed a unified metric composed of four interdependent density-based descriptors to evaluate urban form more discretely. The sensitivity of the unified metric is achieved by visually representing the urban forms through four descriptors using a tool named - the 'Space mate' (Figure 3). Furthermore, Zhao (2011) added the concept of degree of dispersion (based on building perimeter and gross floor area), to develop a correlation between the space mate and average building energy consumption. Hence, the need for a unified metric for energy efficient urban form planning has increasingly become urgent (Figure 4).

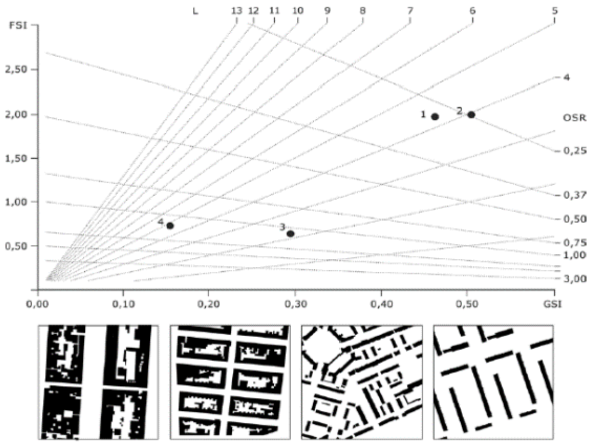


Figure 3. Visual representation of the base and derived urban density descriptors constituting space mate (Pont & Haupt, 2009)

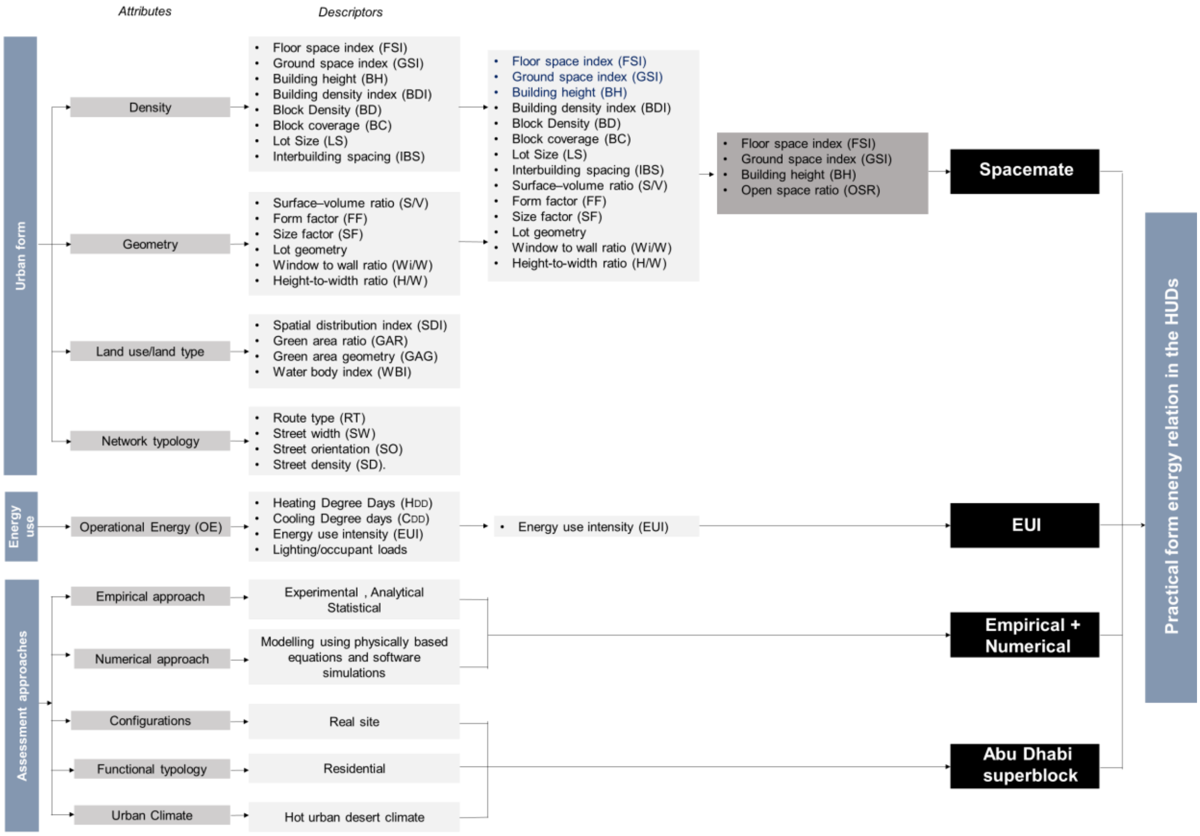


Figure 4. The form-energy urban evaluation framework for experimental research in HUDs (Author, 2021)

3. Proposed Methodological Framework

Previous studies discuss the urban form-energy relationship through different research design approaches – theoretical, empirical, numerical simulation, optimization, or mixed methods. The theoretical studies mainly outline propositions on the energy relevant urban descriptors or measures without experimentations (Silva et al, 2017), while empirical studies report results based on experimental building energy data, that are analytically approached using statistical models (Li, 2019). Here, the scholars are from diverse fields of study with more practical interest in energy efficient land uses. However, the most widely adopted numerical simulation methods report form-energy relations by modelling building energy use data using physically based equations and software simulations (Trepci et al., 2021). Generally, scholars in this field discuss the study as an extension of building form and energy in the urban scale. In addition, recent studies are directed towards finding optimized solutions through parametric computer experiments (generation methods) and algorithms (optimization engines) (Zhongming, 2020). Clearly, these new patterns of development render the theoretical or traditional intuitive methods less efficient due to the interdependencies between urban form and energy uses. Additionally, validation of the descriptors used, and their relations using statistical measures is a necessity to justify the findings of any study. Hence, a computationally simulated energy model together with statistical validation is the most efficient approach to study form-energy relations.

As highlighted by Leng et al. (2020), the use of real urban form and energy data ensures not only the practicability of the results, but also computes the direct impact of urban form on energy consumption. Also, the accuracy of statistical analysis while employing limited samples is effectively improved by using this method. Using a comprehensive research method, authors explore the quantitative relation between urban form and building energy use by simulating real urban forms and employing statistical analysis to assess the individual and combined impact of form factors on energy use (Vartholomaios, 2017; Leng et al., 2020). The proposed assessment approach consists of four steps as follows (Figure):

1. Selection of the study sample – Khalifa City superblock in AbuDhabi (UAE);
2. Defining the building energy model design parameters;
3. Calculation of unified form-energy descriptors and visual representation; and
4. Statistical analysis.

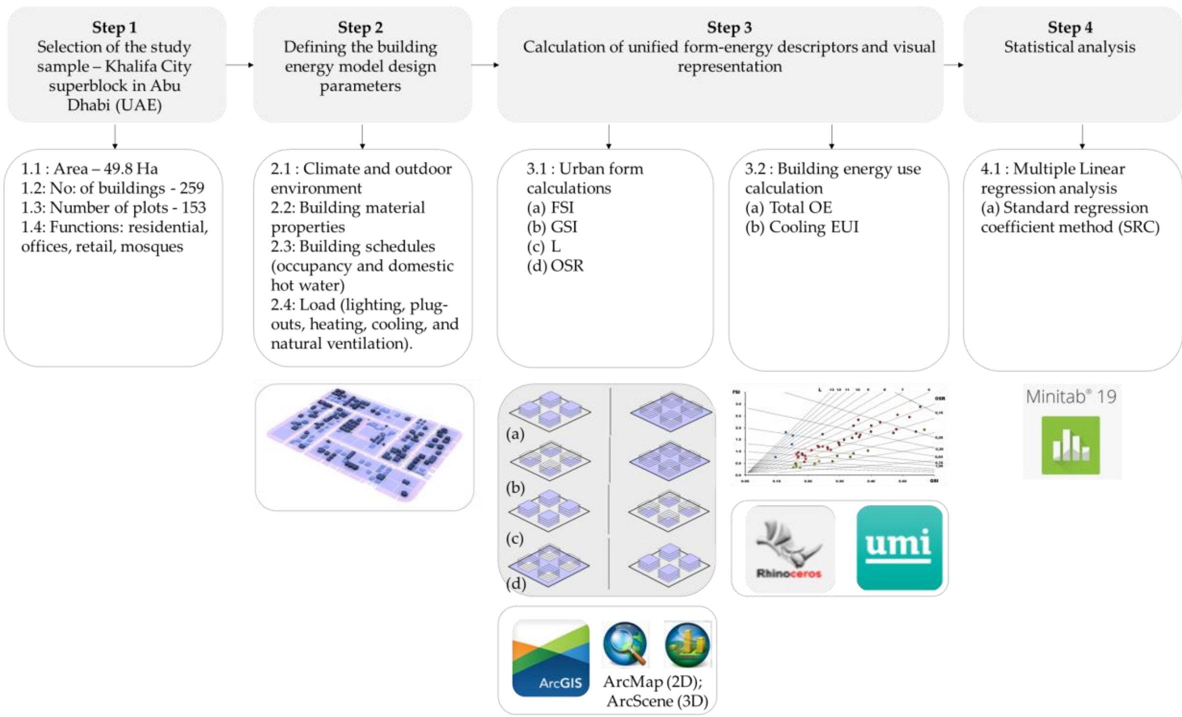


Figure 5. The proposed methodological assessment framework

3.1. Selection of the study sample – Khalifa City superblock in AbuDhabi (UAE)

The main aim of this step is to select the building type for the study and generate energy performance predictions. The results of these predictions will serve as a practical benchmark for the form-energy relation before introducing any alternatives or proposal for better performance. Since, the study aims to understand the form and cooling energy reduction relation in the hot urban deserts, other variables affecting energy performance must be controlled in the sample buildings of the superblock. For this study, a sample superblock of 49.8 Ha (sector-14) within the Khalifa city (KC) located in the Abu Dhabi island is selected and standardized to a size of 820m by 600m. Sector-14 superblock constitutes 259 buildings with residential, commercial (offices), retail, mosque and other subsidiary functions (Figure). The area of the KC superblock constitutes 7 internal blocks subdivided into 153 plots, either occupied or vacant with the following dimensions – 60.9m x 60.9 m; 46m x30m; 62 x 49 m.

Figure 6. The study sample – Khalifa City sector 14 superblock in Abu Dhabi Island, UAE.

Previous studies suggest that, a single small block shows negligible influence of micro climatic and occupant density conditions, while large blocks may be beyond their scope of influence. Further, limitations in terms of the analytical variability due to irregular building façade geometries overrides the priority for retention of the original physical form representativeness of the buildings. To ensure the practicality of the results, the modelling method considers assumptions and values related to heat loss, energy efficiency and thermo-physics of the building envelope based on the architectural principles and the minimum standard classifications for Abu Dhabi. Hence, buildings exhibiting similar physical properties are preferred for the comprehensive simulation study. Therefore, for the purpose of comparative computation of the buildings at the level of the plots, the buildings are categorized into 'point type' and 'slab type' archetype hypothetical buildings. Accordingly, each of the form descriptors are calculated for individual building plots within identified blocks. This is carried out to ensure the rationality of the spatial scale and comparability of each plot samples as discussed in the later sections.

3.2. Defining the building energy model design parameters

Generation of the energy models necessitates defining the following design parameters:

1. Climate and outdoor environment,
2. Construction materials, and
3. Building schedules (occupancy and domestic hot water) and load (lighting, plug-outs, heating, cooling, and natural ventilation).

3.2.1. Climate & outdoor environment

The climate data including the outdoor temperature, humidity, solar radiation, and wind provided by Energyplus in .epw format offers meteorological year data (TMY). Additionally, the outdoor environment parameters such as sky luminance distribution, sun position, ground reflectance, dimensions, and reflectance of external obstacles are defined by the energy simulation software based on the location. Although, variation sin the set-point internal temperatures in AbuDhabi oriented studies have been observed (20°C, 22°C, 26°C), the indoor air temperature during the cooling periods (heating avoiding in the UAE context) is set at average of 24°C for maximum occupancy with minimum fresh air per area as 0.0003 $m^3/s/m^2$. Additionally, to understand the impact of natural ventilation during the heating period, a minimum infiltration rate of 0.21 arch, as observed in previous studies in Abu Dhabi is considered.

3.2.2. Occupancy

Occupant related design parameters are based on the general living and thermal comfort conditions as shown in Table 1. Although, the data are customized based on the building functional typology, the details not available were assumed as follows : Occupant density - 0.04 m^2/person; activity level - 110 W/person and clothing type - 0.5 clo (Bande et al., 2019).

Table 1. KC superblock building schedules for load calculations.

Function	**Occupancy schedule**		
Residential Apartments	Occupancy density (p/m2)	0.025	All year round[3] WD[1] – 8:00 (0.7); 9:00-17:00 (0.3), 18:00 (0.7); 19:00-7:00 (1) WE[2] - 11:00-15:00 (0.7); 16:00-19:00 (0.3), 20:00-23:00 (0.7); 23:00-10:00 (1)
	Equipment power density (W/m2)	4	
	Lighting power density (W/m2)	7	
	Illuminance (lux)	200	
Offices	Occupancy density (p/m2)	0.055	All year round[3] WD[1] – 5:00-7:00 (0.8); 8:00 (0.2); 9:00-11:00 (0.6), 12:00-13:00 (0.5); 14:00-15:00 (0.6); 16:00-17:00 (0.2); 18:00-19:00 (0.8); 20:00 - 4:00 (0) WE[2] – 5:00-7:00 (0.6); 8:00-9:00 (0.2); 10:00-11:00 (0.4), 12:00-13:00 (0.3); 14:00-17:00 (0.2); 18:00-19:00 (0.8); 20:00 (0.1); 21:00 - 4:00 (0)
	Equipment power density (W/m2)	8	
	Lighting power density (W/m2)	12	
	Illuminance (lux)	500	
Retail	Occupancy density (p/m2)	0.1	All year round[3] WD[1] - 9:00 (0.2); 8:00 (0.4); 11:00 (0.6); 12:00-17:00 (0.8), 18:00-19:00 (0.6); 20:00-24:00 (0.4); 1:00-8:00 (0) WE[2] - 4:00-10:00 (0.2), 11:00-12:00 (0.4); 13:00-17:00 (0.5); 18:00 (0.4); 19:00-21:00 (0.2); 22:00-24:00 (0.1); 1:00-3:00 (0)
	Equipment power density (W/m2)	6	
	Lighting power density (W/m2)	16	
	Illuminance (lux)	300	
Mosques	Occupancy density (p/m2)	0.055	All year round[3] WD[1] -1:00-2:00 (0); 3:00 (0.2); 4:00 (1); 5:00 (0.2); 6:00-10:00(0); 11:00 (0.2); 12:00 (1); 13:00 (0.2); 14:00 (0); 15:00 (0.2); 16:00 (1); 17:00 (0.2); 18:00 (0.2); 19:00 (1); 20:00 (0.2); 21:00 (1); 22:00 (0.2); 23:00 - 24:00 (0) WE[2] (including Friday) -1:00-2:00 (0); 3:00 (0.2); 4:00 (1); 5:00 (0.2); 6:00-10:00(0); 11:00 (0.2); 12:00 (1); 13:00 (1); 14:00 (0.2); 15:00 (0.2); 16:00 (1); 17:00 (0.2); 18:00 (0.2); 19:00 (1); 20:00 (0.2); 21:00 (1); 22:00 (0.2); 23:00 - 24:00 (0).
	Equipment power density (W/m2)	8	
	Lighting power density (W/m2)	12	
	Illuminance (lux)	500	

[1] Week Days; [2] Week Ends; [3] Occupancy rate is based on the retail shops, office work time specific to the superblock, whereas assumptions are made accordingly for the unknown data.

3.2.3. Building material properties

To further explore the relation between building form and thermal behaviour, layered details of both opaque and transparent components are specified in accordance with the existing visual surveys and Abu Dhabi International Building Codes (ADIBC). The construction material properties are depicted based on the UPC (Urban Planning Council) study of typical Abu Dhabi buildings in Table 2. The study assumed a low airtightness of the building envelope with the natural ventilation air changes per hour of 0.21 (Bande at al., 2019). The transparency rate of the facades varies based on the building functions as enumerated: residential (30%), Offices (35%), retail (15%) and mosques (15%) (Table 3).

Table 2. KC superblock building material properties and construction details

Construction			Materials layers (from outside to inside)
Exterior Floor			0.01m Ceramic Tile + 0.02m Cement Mortar + 0.01m XPS Board + 0.15m Concrete RC Dense
Facade	Residential[1] Retail Offices	*Base*	0.02m Cement Mortar + 0.20m Concrete Block + 0.02m Cement Mortar
		Facade	0.02m Cement Mortar + 0.20m Concrete Block + 0.05m XPS Board + 0.03m Air Wall + 0.20m Concrete Block + 0.02m Cement Mortar
	Apartments Mosque	*Base*	0.02m Cement Mortar + 0.20m Concrete Block + 0.02m Cement Mortar
		Façade	0.02m Cement Mortar + 0.20m Concrete Block + 0.05m XPS Board + 0.03m Air Wall + 0.20m Concrete Block + 0.02m Cement Mortar + 0.02m Gypsum Board
Ground Floor			0.01m Ceramic Tile + 0.03m Cement Mortar + 0.02m XPS Board + 0.15m Concrete RC Dense + 0.05m Concrete MC Light
Interior Floor	Residential[1] Offices		0.01m Ceramic Tile + 0.03m Cement Mortar + 0.01m XPS Board + 0.15m Concrete RC Dense + 0.05m Concrete MC Light + 0.02m Cement Mortar
	Apartments Mosque Retail		0.01m Ceramic Tile + 0.03m Cement Mortar + 0.01m XPS Board + 0.15m Concrete RC Dense + 0.05m Concrete MC Light + 0.02m Cement Mortar + 0.60m Air Floor + 0.02m Gypsum Plaster
Partition			0.02m Cement Mortar + 0.20m Concrete Block + 0.02m Cement Mortar
Roof	Residential[1] Offices		0.01m Ceramic Tile + 0.03m Cement Mortar + 0.15m Concrete MC Light + 0.05m XPS Board + 0.15m Fiber Glass Batts + 0.15m Concrete RC Dense + 0.02m Cement Mortar
	Apartments		0.01m Ceramic Tile + 0.03m Cement Mortar + 0.01m XPS Board + 0.02m Roof Screed + 0.15m Fiber Glass Batts + 0.12m Concrete RC Dense + 0.02m Roof Screed + 0.02m Cement Mortar
	Mosque Retail		0.01m Ceramic Tile + 0.03m Cement Mortar + 0.02m Roof Screed + 0.01m XPS Board + 0.15m Glass Wool + 0.20m Concrete RC Dense + 0.02m Roof Screed + 0.02m Cement Mortar
Thermal mass			0.02m Cement Mortar + 0.20m Concrete Block + 0.02m Cement Mortar
Windows			0.003m Clear Glass + 0.006m Air + 0.003m Clear Glass
Structure			Concrete RC Dense (Normal Ratio = High Load Ratio = 330Kg/m2)

[1] Residential represents Villas of levels 1-3.

Table 3. KC superblock building template – thermophysical properties.

Function	Partition Ratio (PR)	Floor-to-Floor Height (FFH)	Window-to-wall Ratio (WWR)
Residential	0.30	3.0	0.20
Apartments	0.30	3.0	0.20
Offices	0.35	3.0	0.40
Mosques	0.15	3.0	0.40
Retail	0.15	3.0	0.40

3.2.4. Conditioning

The active building sub-systems include an electric cooling system with a performance coefficient of 2.6 CoP with heat rejection pump and fan system of value 24.4 (Bande et al., 2019). Using a three-step control system, an illuminance of 200 lux (res), 300 lux (retail), and 500 (Offices) are considered for the lighting systems (Table 4). Also, it may be inferred that the buildings heat transfer coefficients are similar due to the standard values considered while designing the buildings. Clearly, the same building typologies within different plots are comparable because of the same architectural physical characteristics.

Table 4. Zone information details – Conditioning, ventilation, Domestic hot water

Zone information	Residential/ Apartments	Offices	Mosques	Retail
	Conditioning			
Cooling setpoint (°C)	24	24	24	24
CoP	3	3	3	3
Min. fresh air/area (m3/s/m2)	0.0003	0.0003	0.0003	0.0003
Min. fresh air/area (m3/s/p)	0.0025	0.0025	0.0025	0.0025
Heat recovery efficiency (Latent)	0.65	0.65	0.65	0.65
Heat recovery efficiency (Sensible)	0.70	0.70	0.70	0.70
	Ventilation			
Infiltration rate (ACH)	0.21	0.21	0.21	0.21
	Domestic hot water			
Supply temperature (°C)	60	60	65	60
Inlet temperature (°C)	20	20	20	20
Flow rate (m3/h/m2)	0.00049	0.00021	0.00049	0.00006
	Windows			
Operable area (%)	0.8	0.8	0.8	0.8

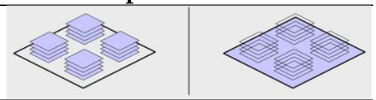
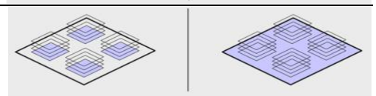
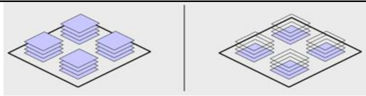
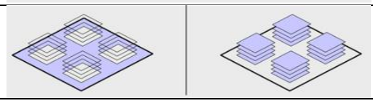
3.3. Calculation of unified form-energy descriptors and visual representation

3.3.1. Urban form calculations

The aim of this step is to systematically determine the urban form descriptor values of the generated superblock energy model with the purpose of estimating their independent and combined influence on energy performance. Previous studies discussed above shows the evidence of altered physical form of buildings in reducing the cooling energy use intensity. Accordingly, the construction intensity of the plots is quantified using a unified metric – space mate. The space mate density descriptors include the floor space index (FSI) - representing the intensity of development, ground space index (GSI)-representing the building ground footprint area, number of floors (L) – representing the height (layers) of the building, and open space ratio (OSR) – representing the pressure on the unbuilt plot area (Figure 3b). By using this tool, a one-on-one relation between form-energy use can be computed. Therefore, four urban form descriptors are calculated to evaluate the impacts on building energy consumption: FSI, GSI, L and OSR.

The geometric and spatial data of the buildings, including geographic location, building contour, building footprint area, plot area, height, building function and open space data of the KC superblock are obtained and calculated using ArcGIS10.0 software. Based on this 2D digital data, the urban form of each building is quantitatively computed based on the calculation formula as shown in the Table 5. Using the ArcGIS 3D Analyst extension, the building GIS data are visualized in a 3D context. This 3D viewer – ArcScene, transforms the 2D features into 3D using the height information from feature geometry, feature attributes, or layer properties. With the adaptability and ease of integration with geoprocessing environments, the resultant .sxd file is exported to the urban modelling interface (UMI) bundle for energy modelling.

Table 5. Urban form descriptors of the study area

Form descriptor	Definition and calculation formulae	Diagrammatic representation
Floor Space Index (FSI)	The ratio of the sum of all the building floors to the total sample plot area ***FSI*** *= Total floor area/total sample plot area*	
Ground Space Index (GSI)	The ratio of the built footprint area (ground) to the total sample plot area ***GSI*** *= Ground footprint area/ total sample plot area*	
Layers (L)	The average height of all the buildings in the sample plot ***L****= (Footprint area x height)/total footprint area*	
Open Space Ratio (OSR)	The ratio of the open space to the total gross floor sample plot area ***OSR*** *= Open space / total floor area*	

3.3.2. Building energy use calculation

The UMI bundle is a Rhinoceros (Robert McNeel & Associates, Seattle, WA, USA) based environmental building energy predictor with respect to operational energy, embodied energy, daylight simulation design, walkability, and model optimization. The actual energy consumption of each building within a particular plot is calculated in terms of the theoretical energy consumption and external influence energy consumption. Based on the developed building energy models with customized building template library as shown in the previous steps (Table 1,2,3,4), simulations are run to compute the overall OE, and lighting, heating, cooling, and ventilation potentials separately. It is noteworthy that the physical features such as partition ratio, window to wall ratio and heat transfer coefficients of building envelopes are included in the energy calculations. For this purpose, the summer cooling period is set from 4th of July to 31st of August. Therefore, the cooling EUI, represented as KWh/m2/y is considered as the efficient measure of building energy consumption in this study.

Finally, the visualized OE and cooling energy consumption in the UMI interface is downloaded as a .csv file and combined with the ArcGIS 10.0 software attributes for the KC superblock using the custom generated object/building IDs. Consequently, the form and energy descriptors of the buildings are plotted individually (FSI vs EUI, GSI vs EUI, L vs EUI and OSR vs EUI) as well as within the space matrix tool (FSI, GSI, L and OSR vs EUI). Hence, the spatial distribution of the building energy consumption and corresponding urban for descriptors is validated for acceptable form-energy relation using statistical analysis.

3.4. Statistical ananlyses

The aim of this step is data analysis by developing multiple linear regression models to determine if the influence of space mate descriptors individually and as a unified form metric on the total OE and cooling EUI are statistically significant. Using the Standard regression coefficient method (SRC), the strength of the correlation between FSI, GSI, L and OSR on total OE and cooling EUI based on the p-value and percentage of contribution. Although SRC is the most used method to check the sensitivity and statistical significance of individual independent variables on the dependent variable. To understand the combined influence of the independent variables (form descriptors), interaction plots are generated in the data analysis software – Minitab 19.0. Further, the reliance of this method is based on the R2 value, the lower values of which result in the use of Standardized Rank Regression Coefficient (SRRC) method instead. As the work progresses, the upcoming sessions, graphs for the monthly, yearly OE and cooling EUI will be presented to quantify the potential energy savings and explain the diversity in energy consumption of KC superblock buildings. Further, the results are validated by the box and whisker plot diagrams, while shedding light on the model sensitivity towards using space mate descriptors.

4. Discussion and implications for future work

In this era of climate change, cities are paying more attention to the building energy use and carbon footprint for attaining sustainability. Cities are dynamic systems with the capacity to manage, adapt or survive adversities at different scales. Recalling upon UN-Habitat's initiative for 'resilient cities', it is imperative to explore the concept of 'resilient urban forms' in terms of the flexibility offered by the city's physical form towards energy use reduction. Resilient urban form is defined as the adaptability offered by a city's physical structure towards survival of adversities at different spatial scales.

Base studies acknowledge the link mainly affecting energy performance through the manipulation of the geometries at the meso building scales for achieving low operational cooling energy demand. Overall, an unsolved debate exists, where the fundamental proposition of "density equals energy efficiency" (Steemers, 2003) by a school of scholars is condoned by many others (Holden, 2004; Mindali, 2004). The energy efficient urban form assessments understand and evaluate the form-energy relation through multiple urban form attributes (density descriptors) and conceptual definitions (Perera et al.,2021; Javanroodi et al, 2018). Despite the systematic use of form descriptors to analyse form - energy use reduction, urban planning processes have not yet attained corresponding gains in efficiency (Mangan et al., 2021). This may be attributed to the fact that the desirability of urban configurations depends on various factors such as geographic context, type of disturbance, and purpose of assessment. It is warned against approaching the 'one size fits all' model in attempting to develop resilient urban forms. Hence, the present study explores the potential of urban form descriptors in facilitating a more comprehensive evaluation of the impact of urban form on cooling energy demand in the hot dry desert climates.

Despite these significant studies characterizing the relationship between physical dimensions of the city and energy demand, it is agreed that the following important limitations motivate the need for an experimental study in the hot dry desert climates. These include: (1) Partial discussions on comprehending the diversity of physical dimensions, definitions, and quantifying measures in urban energy analysis; (2) Narrow scope in identifying energy use descriptors based on passive sources of energy generation (heating or cooling intensities); and (3) Limited consideration of success variability due to diversity of conceptual definitions, research design approaches, and urban scales on energy use reduction. Furthermore, it is difficult to isolate the variance of a single urban density descriptor on energy use due to shared variances or other interference effects.

Authors introduce the use of Space mate composed of four interdependent density descriptors to quantify urban form more discretely related to energy use. These include: floor space index (FSI, ground space index (GSI), number of floors (L), and open space ratio (OSR). By using this tool, a one-on-one relation between form energy use can be computed. The study proposes a methodological framework and approach to carryout experimental simulation studies deciphering the form-energy relations with the proposed density descriptors (Spacemate). Using this framework, researchers can evaluate the influence of density-based descriptors (FSI, GSI, L and OSR) on energy consumption and how the different representative urban forms (NPUs) contribute to building energy use in any climatic context. Using space mate descriptors, the following trade-offs are avoided: (1) difficulty in isolating the urban form descriptors from other energy driven attributes; (2) success variability due to undefined degree of interaction or interdependence between different urban density descriptors, and (3) diversity of urban concepts, research design approaches, contexts, and climates within this field. Accordingly, the use of "space mate" achieves three aspects simultaneously: (1) Form-energy relation at the lowest hierarchy obtained by comparing unified form metric with building energy use (Spacemate & EUI); (2) Strength of form-energy associations of independent descriptors: FSI, GSI, L and OSR with EUI; and (3) Influence of a given urban form (neighborhood/Block), characterized by the combined effect of FSI, GSI, L, OSR density descriptors on energy use. The study also seeks to assist the planners and policy makers in identifying key density descriptors for developing an optimal energy efficient planning strategy in the early design stages of the NPU in hot desert climates.

By considering only the density-based descriptors for urban scale energy evaluation, the present framework omits the influence of the other three categories of urban form descriptors (geometric, land use/land type and network typology). To improve this glaring challenge, the scope of urban form descriptors should be extended to include the influence of geometric properties of the buildings and influence of micro climatic variables for different urban elements (buildings, and street networks). While determining the energy use of hot dry desert climates, the energy demand is restricted towards understanding operational cooling energy demands only. Other promising direction includes understanding the significant urban from descriptors while considering the heating and overall operational energy demand under varied climatic contexts (tropical, temperate, continental, and polar). Future research could explore the impact of urban form on operational energy use (heating, cooling or overall) through experimental studies considering other categories of form-based descriptors, as well as varying climate change scenarios. The study analysis and results could be used to integrate strategic and practical information into the development of energy efficient solutions based on the physical (basic) analysis of the urban areas.

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New Type of Disaster Prevention / Regional Information Transmission System

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Abstract: In the Great East Japan Earthquake that occurred on March 11, 2011, it was found that the living environment of the evacuees who gave up returning home due to traffic stoppage was bad because information was not available around the large station due to this earthquake.(1) Also, at this time, there was no system to notify disaster prevention information yet. In order to do that, first, we examined the Urban Renaissance Safety Security Plan which was prepared by the government to address the problem of evacuees that could not go home. As a result, it was found that there is more content that can be transmitted in the area where the local government is involved in the transmission of information. Based on this tendency, we conducted a second survey. It turned out that the bottleneck of the introduction of information gathering and dissemination means is cost. It was also found that the cost is the bottleneck that the introduction of emergency power generation equipment and information equipment at evacuation center has not progressed. Based on these results, we actually set up the local information dissemination system for Shinjuku Station, which we call, the D-ZEV Shinjuku version. Shinjuku is one area listed on the Plan. In the demonstration, we collected thermal information using D-ZEV Shinjuku version. The thermal environment survey around Shinjuku Station, included a thermal environment survey inside the building, and a regional energy survey. In the demonstration, we conducted a questionnaire survey based on the explanation of the D-ZEV System. As a result, the overall system rating was 97% good, and in addition most disaster information was rated good.

Keywords: Local information dissemination system, Disaster prevention, Evacuation center, Evacuee, Energy,

1. Introduction

Around large railway station areas, after a disaster or other emergency, it is important to quickly collect damage information around the station and to properly guide the many people who are staying in the area. It is additionally considered that the construction of a system that collects that information and transmits it is necessary. Furthermore, the quality of the lighting and air conditioning of the access point environments in evacuation shelters and emergency sheltering facilities decreases owing to their malfunction during power outages, and thus, improvements are deemed necessary.

The present study develops a system that rapidly and accurately collects real-time information and transmits it at the time of emergency, and this information is transmitted to regions where such a system is not present as a pre-existing tool during normal times. Furthermore, this year, conducted surveys on the current status of the energy and thermal environments in buildings designated as emergency sheltering facilities for the objective of improving the latter, and built an environmental/disaster-prevention information system that incorporates these surveys.

2. D-ZEV system

At disaster prevention centres (such as evacuation shelters and emergency shelters) in the event of a disaster, collecting and transmitting disaster information, admission of local residents and travellers who have difficulty returning home, and emergency rescue are important issues. Therefore, built an information transmission system based on the "disaster-resistant zero-energy vehicle" (D-ZEV). Figure 1 shows the current information system. In this system, there are issues such as communication of local information and lack of energy in evacuation shelters. Therefore, by incorporating the D-ZEV system shown in Fig. 2, The system shown in Figure 3 is proposed. By incorporating this system, this system will promptly reach the local disaster prevention centre in the event of a disaster, and will endeavour to respond to disasters while providing information transmission, minimum necessary energy supply, and emergencies. In addition, Fig. 4 shows the information content of the 2011 Japanese disaster information app. In Japan, where there are many disasters, we need a system that can acquire all kinds of information. Currently, disaster apps in Japan are becoming more useful, but blocking information due to communication failures has not been improved.

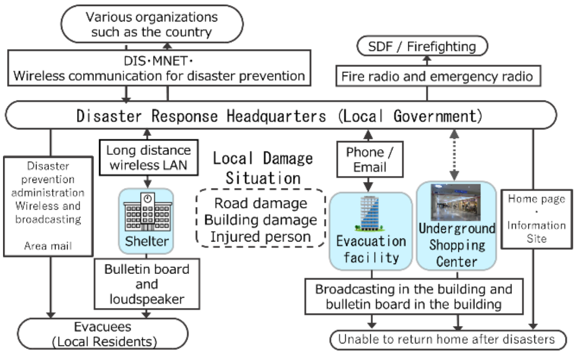


Figure 1. Current information transmission system

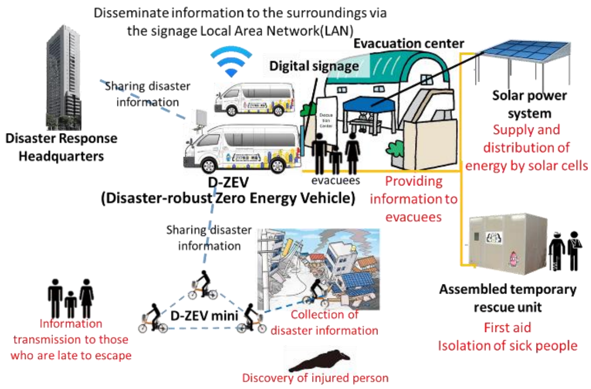


Figure 2. D-ZEV system

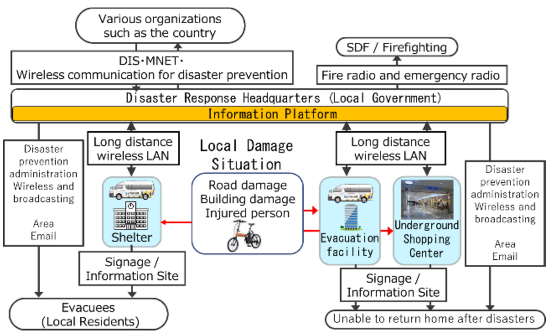


Figure 3. Environmental and disaster prevention information system including D-ZEV system

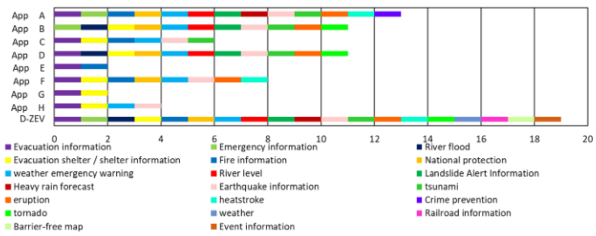


Figure 4. Comparison with existing apps system

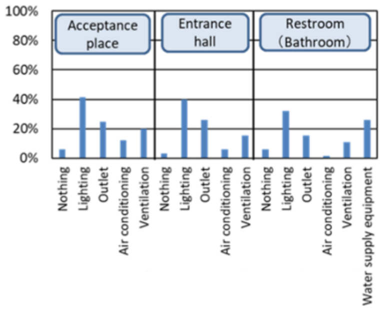
3. Urban Renaissance Safety Security Plan and its implementation by the Local Governments

25 local governments developing the Urban Renaissance Safety Security Plans. This plan is requested by the government to be created in the area around the station, which is presumed to have many evacuees those who have given up on returning home. Questionnaire surveys were conducted to understand the current status of plan implementation. In the questionnaire conducted in 2019, we confirmed the implementation status of the plan, the means of collecting and transmitting information during power outages and non-power outages, and simple information on the facilities that accept evacuees. The 2020 survey conducted a detailed survey, especially on information, energy and infectious disease control. As a result, the introduction of information transmission means to

residents around stations has not progressed during power outages and non-power outages. In addition, the reason why these plans are not progressing is that the seven areas have the highest cost obstacles.

4. Current Status of Energy And Information Transmission Means for Evacuation Facilities

We conducted a survey of local governments for building managers who have agreed to an urban renaissance security plan. Of the 263 copies, 83 were answered. As a result, it was found that many facilities have emergency generators installed in the basement and lower floors, and few facilities distribute surplus energy to other facilities in the event of a power outage. Figure 5 shows where the emergency generator distributes power in the event of a power outage. In addition, Fig. 6 shows the means of communicating information to residents in the evacuation centre. From this result, it was found that it is difficult for vulnerable people to obtain information, and that even healthy people have no means to convey information quickly. In addition, Fig. 7 shows that there are issues when opening an evacuation shelter and when operating an evacuation shelter. From this result, it is considered that there will be insufficient evacuation shelters due to damage in the event of a disaster.



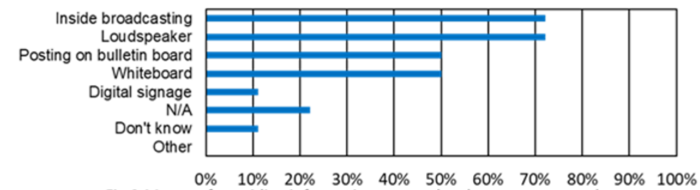


Fig6. Means of providing information to people who cannot return home

Figure 6. Means of providing information to people who cannot return home

Figure 5. Percentage of equipment that can be used during a power outage

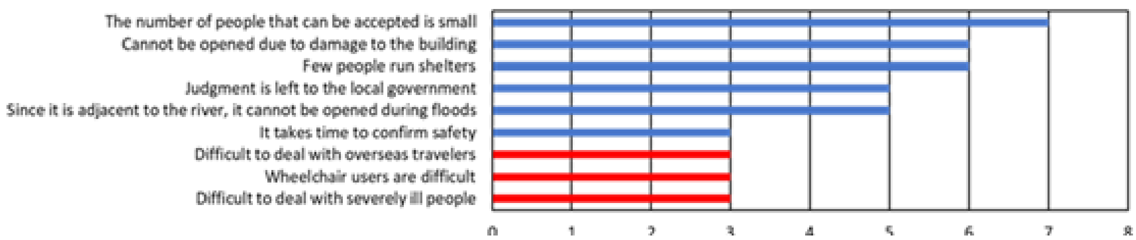


Figure 7. Concerns about accepting people who are unable to return home

5.Various Surveys around Shinjuku Station

About energy, given the current scenario where municipalities do not know the capacity of emergency generators in each emergency shelter, it may be important to understand the energy sources available in the event of a disaster. Therefore, referring to the data from the Tokyo Fire Department, we mapped the emergency generator near Shinjuku Station and the storage battery equipment (not under the jurisdiction of the Fire Service Act). Many buildings without emergency generators were also exhibited. It is shown in Fig. 8.

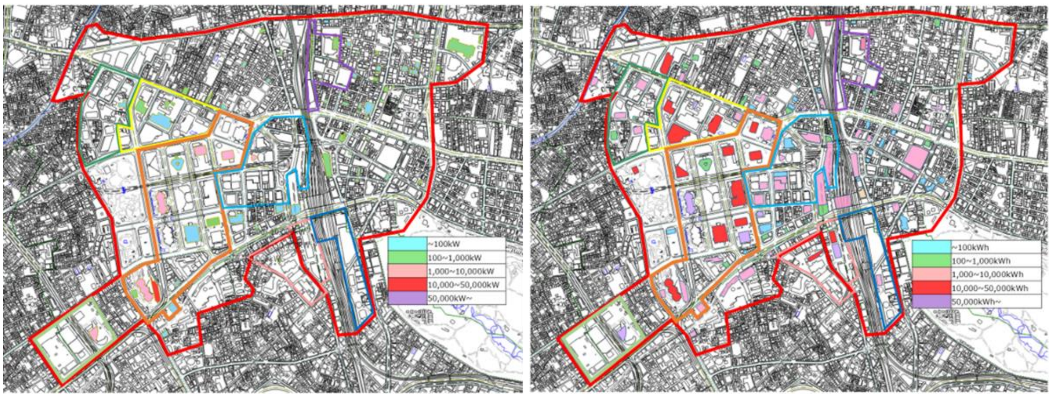


Figure 8. Emergency generator and storage battery equipment

Regarding the visualization of the summer thermal environment, the local government is conducting evacuation guidance without knowing the air conditioning equipment, and information on the summer outdoor thermal environment is indispensable. Regarding the thermal environment in the immediate vicinity of the building designated as an emergency evacuation facility in the event of a disaster, the indoor and outdoor measurement results at 1:00 pm show that the air conditioning temperature fluctuates depending on the building. Despite the air conditioning, there is not much difference in temperature between indoors and outdoors.

Figure 9. Thermal environment map at 13:00 on August 7,2019

6. Demonstration Survey of D-ZEV System

In November 2019, a demonstration survey on D-ZEV systems was conducted. The contents of the questionnaire were the evaluation of the "disaster information page", the evaluation of system equipment, the information required in the event of a disaster, etc. In the overall D-ZEV system, more than 90% of the positive. In the free description, many voices demanded the "immediateness and accuracy of information", and voices such as "damage information such as power outages at the time of disaster" and “Worrying that you may not be able to operate in a situation where there are few operators” were also mentioned.

Figure 10. Demonstration scenery

7. Conclusion

From the results of this survey, it is clear that many evacuation facilities lack energies such as air conditioning in the event of a power outage and lighting of power receiving devices, and an information system for promptly transmitting information on evacuation facilities has not been established. became. The results of the thermal environment survey around Shinjuku Station also confirmed that there are differences in air conditioning temperature depending on the facility. A questionnaire on the D-ZEV system confirmed the need. In the future, we plan to conduct an interview survey on the contents of the "D-ZEV system" of local governments and make further improvements.

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Conflicts of Interest: The authors declare no conflict of interest.

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1. Ministry of Internal Affairs and Communications / Issues and prospects for information transmission in the event of a disaster
2. Tokyo Fire Department, emergency generator / storage equipment database, (Can be viewed after applying to the Tokyo Fire Department and approving)

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A Meta-Analysis of Contaminant Removal from Urban Stormwater by Permeable Pavements

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Abstract: Pollution resulting from urban stormwater runoff has become a major problem for cities. The use of permeable pavements that allows stormwater infiltration into soil layers underneath the pavement system is considered a paradigm shift from conventional use of impervious pavements. In addition to reducing the runoff load on stormwater drainage systems, it contributes to the reduction of contaminant loads in the infiltrated water which would have otherwise ended in water streams and potentially cause environmental problems (such as deteriorated fish habitats). Recent research has expanded on the investigation of permeable pavements to include its impact on water quality in addition to the typical analysis pertaining to its mechanical strength and durability. In this study, a meta-analysis of the impact of permeable pavements on the infiltrated stormwater quality is conducted. The analysis focused on recent research (2010-2020) that has specifically investigated the reduction of certain contaminant concentrations in stormwater infiltrating through permeable pavements. Results were classified based on the type of contaminant investigated (heavy metals, nutrients, and organic content) considering the difference in composition and properties (e.g., pore volume) of tested permeable pavement systems. It was observed that lab and field studies investigating stormwater contaminant removal were mainly conducted for pervious concrete and porous asphalt. The analysis closed with insights into limitations and knowledge gaps that need to be addressed to better understand the effective use of permeable pavements in stormwater quality management.

Keywords: Permeable pavement systems; Pervious concrete; Porous asphalt; Urban stormwater management; water quality; Contaminant removal; Removal efficiency

1. Introduction

Permeable pavement, a low impact development (LID) technology, is an attractive alternative to conventional impervious surfaces in many urban cities and towns and has been actively used [1,2]. The porous space within the aggregate structure of permeable pavement enables it to function as a filter medium; in addition it helps in providing a short-term water holding capacity, increasing infiltration, reducing surface runoff, and enhancing the quality of infiltrated stormwater by reducing contaminants [1,2].

Total suspended solids (TSS), nutrients, heavy metals, chemical oxygen demand (COD), and hydrocarbons are commonly recognized as the primary constituents of concern frequently found in urban stormwater runoff [3,4]. Permeable pavements were found to significantly minimize the net export of particulates on site by up to 80% and are capable of significantly reducing the concentrations of heavy metals and hydrocarbons in stormwater runoff [2,5–8]. According to the Stormwater Best Management Practice Reports, permeable pavement removal efficiencies for total suspended solids (TSS), total nitrogen (TN), and metals such as lead (Pb) ranged from 65 to 100% [9]. Also, appreciable reductions in zinc and hydrocarbons concentrations were observed in a permeable pavement runoff when compared to runoff from a neighboring conventional impervious asphalt [8,10]. Another study, assessed the runoff quality from asphalt, permeable pavement, and crushed stone driveways, concluded that the asphalt runoff has the highest concentrations of total suspended solids, lead, zinc, and nitrate among other pavements [11]. Permeable asphalt, in particular, except for chloride and total nitrogen, has been found to have a high removal efficiency of heavy metals as well as the ability to reduce oil, COD, BOD, ammonia, and total phosphorus [12].

Permeable pavement systems (PPS) are made up of porous media pavement layers that have a high infiltration potential, allowing surface stormwater runoff to flow freely into a reservoir for storing before being harvested or slowly released into the subsoil, receiving water bodies, or drainage channels [13]. Contaminant removal could occur throughout PPS by several mechanisms such as mechanical filtration, adsorption, nutrient transformation, or through biodegradation by microorganisms [14,15]. The first layer of PPS is the permeable surface such as porous asphalt (PA), pervious concrete (PC), permeable interlocking concrete pavers (PICPs), and permeable reactive concrete (PRC). Underneath the permeable surface lies layers of graded gravel that support the permeable surface and allow for the infiltration and temporary storage of stormwater. The efficiency of PPS in contaminant removal is determined by the interaction of various layers of the system. Despite the good performance of PPS in reducing stormwater runoff contaminants, there is still a lack of knowledge about the impacts of different components on the performance, since different combinations may produce similar findings [16]. Several studies developed lab-scale PPSs to examine their influence on the concentration of typical contaminants in runoff [3,12,14,16]. However, despite the promising benefits of using PPS to improve the quality of infiltrated stormwater, there are no studies in the literature that consistently relate the efficiency of contaminant removal by PPS to the components and properties of PPS.

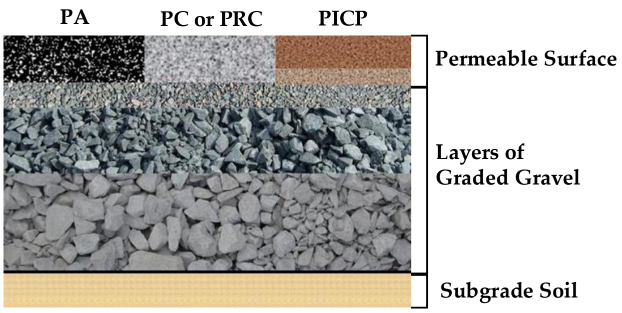

Figure 1. Typical structure of PPS

Therefore, the objective of this study is to provide a meta-analysis of the impact of the properties and design parameters (e.g., gravel gradation) of PPS on the infiltrated stormwater quality. Four main variations in the design of PPS were selected to investigate their influence on contaminant removal efficiency. These variations are type of permeable surface, pore volume of permeable surface, gradation of gravel layer and thickness of gravel layer of the PPS.

2. Methods

The meta-analysis of the contaminant removal by PPS was conducted in four steps:

1. Search for recent (2010-2020) relevant literature in high quality peer reviewed journals in known databases (ScienceDirect and Google Scholar). The search used keywords such as: permeable pavement systems, porous asphalt, pervious concrete, stormwater quality, and contaminant removal efficiency. The search resulted in 34 papers.
2. Qualitative review of the papers resulting from the search focused on screening for studies that included water quality analysis to demonstrate the improvement in stormwater quality infiltrated through PPS. Only 10 research papers from the 34 research papers on PPS published in scientific literature were selected based on their pertinence and significance for the subject under consideration and were directly used in the meta-analysis.
3. Extraction of data from the selected literature to a spreadsheet database in Microsoft Excel.
4. Data classification for the four variations in the design of PPS.
5. Qualitative and quantitative analysis of data from selected research articles to extract evidence of a relation, or absence of a relation, between the four variations in PPS and

contaminant removal efficiency. Data analysis includes scatter plots and summarizing column charts to delineate the impact of different factors on the contaminants' removal efficiencies

Results are presented for the four variations: type of permeable surface, pore volume of permeable surface, gradation of gravel layer, and thickness of gravel layer.

3. Results

3.1. Impact of type of permeable surface on contaminant removal

Several studies analyzed the removal efficiency of typical stormwater contaminants infiltrating through different types of permeable surfaces [17–21]. However, comparing the results of these studies is difficult because of the variations in the setup, gravel gradation, and thickness of gravel layer. **Table 1** shows the results of contaminant removal from four different studies that used four typical types of permeable pavement surface materials. The results of the selected studies (**Table 1**) revealed that the type of surface material has a slight impact on the removal efficiency of contaminants. All four types effectively removed total suspended solids (TSS), total phosphorous (TP) and some heavy metals (copper (Cu) and lead (Pb)) with 70% or higher removal efficiency. The effective removal of TSS and heavy metals suggests that the primary removal processes are physical (adsorption and mechanical filtration). Conversely, total nitrogen (TN) removal rates were low which suggests that TN removal can be governed by different mechanisms (e.g., biological processes), which may be affected by climatic conditions such as pavement temperature. Further research on the function of biofilm within pavements and its various forms is recommended to better understand the mechanisms governing TN removal [22]. Furthermore, **Table 1** demonstrates that the chemical oxygen demand (COD) and the biochemical oxygen demand (BOD) levels were significantly reduced after the runoff was infiltrated through PA, which can be similarly attributed to the adsorption and interception processes occurring within the PA [12].

Table 1 Contaminant removal efficiency (%) from runoff infiltrating through different types of permeable surfaces

Permeable surface	Removal efficiency (rate)%											Reference
	TSS	TP	TN	NH_4-N	Cu	Pb	Zn	Cr	Cl	COD	BOD	
PA	94	78	32	-	72	87	39	-	-	-	-	[22]
PC	90	81	30	-	70	81	34	-	-	-	-	
PICP	92	80	3	-	69	77	33	-	-	-	-	
PA	99.9	42	-	-	-	-	99.9	-	-	-	-	[23]
PA	87.2	5	-2.9	35.2	16.7	97.7	89.1	44.4	6.6	50	55	[12]
PC	-	-	-	-	-	87	90	-	-	-	-	[24]

(-) denotes data not available

3.2. Impact of the pore volume of permeable surface on contaminant removal

The effect of porosity of different surface materials of PPS on the removal efficiencies of stormwater contaminants has not been explicitly investigated. However, one study carried out by Li et al. (2017) used the pore volume number (PV) [17]. The study quantified the removal rates of some contaminants based on the pore volume of the surface material. Their results indicated that there was no proof of a relationship between the COD removal efficiency and the increase in pore volume of PA and PC. COD reductions (up to 35.7% @ PV = 1) can be attributed to interception and adsorption in PA and PC [12]. As for the removal of ammonia nitrogen (NH_4-N), a high removal rate was initially observed at low PV (58% @ PV= 0.5) whereas higher PV resulted in lower removal (14% to 20% @ PV= 30); this same removal pattern was observed for both PA and PC. In terms of TP removal, it was similarly observed that increasing PV decreases TP removal in both PA and PC (80% @ PV= 1, decreased to 26.7% @ PV = 30). Since the adsorption mechanism and chemical precipitation reaction are normally responsible for the removal of TP, it was argued that the high pore volume resulted in less adsorption sites, which reduces the TP removal rate [17].

3.3. Impact of the gradation of gravel layer on contaminant removal

The impact of the gradation of gravel on contaminant removal efficiency was discussed in literature. However, the quantitative evaluation of the effect of gravel gradation on the removal efficiency was only reported in one study [15]. Liu et al. (2019) investigated the effect of gravel gradation on the removal of a wide range of contaminants in stormwater runoff (**Figure 2**).

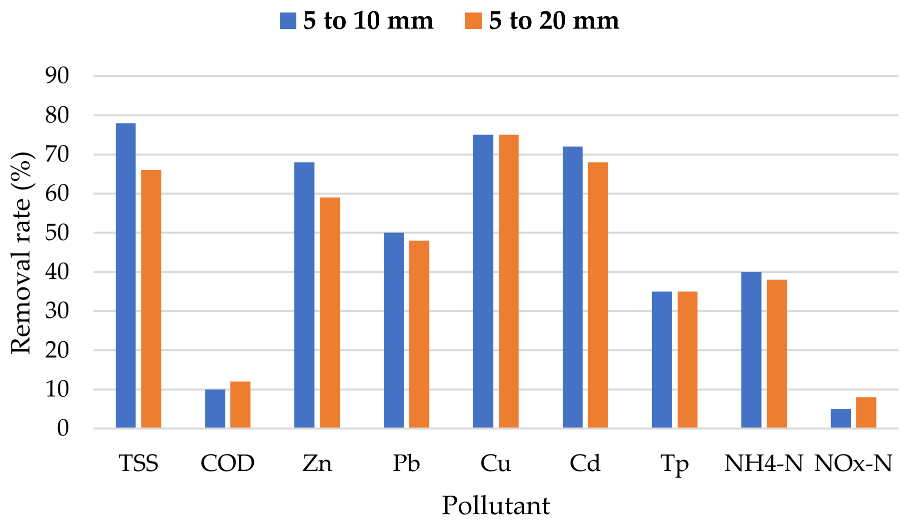

Figure 2. Removal rate of the selected contaminants for two gravel gradation (adapted from Liu et al. (2019) [16])

Figure 2 indicates that TSS removal rates decreased as gradation increased. This finding is expected, since the higher percentage of smaller gravels creates interlock [25]and increases the surface area available for contaminant adsorption and other physical processes. It is also useful for removing certain specific contaminants that can be bound to the TSS [5] , such as NH_4-N and heavy metals, as they are deposited on the surface of the gravel. On the other hand, removal rates of NOx-N and COD were not affected by gravel gradation which indicates that their removal mechanism are not related to the surface area inside the gravel layer [3].

3.4. Impact of the thickness of gravel layer on contaminant removal

Many studies have demonstrated the significance of the thickness of the gravel layer in the removal of contaminants [3,26–29]. This is commonly attributed to its direct relation to the storage capacity and increasing surface area available for contaminant removal [26]. Nevertheless, few studies have quantitatively assessed its impact on the removal of contaminants. In this meta-analysis three studies were reviewed with respect to the gravel layer thickness [3,16,30]. Although The three studies evaluated the removal rates of various contaminants, TSS and TP were the most commonly investigated contaminants. The findings were compiled in a single figure (**Figure 3**) to compare the results and elucidate the removal rates trend.

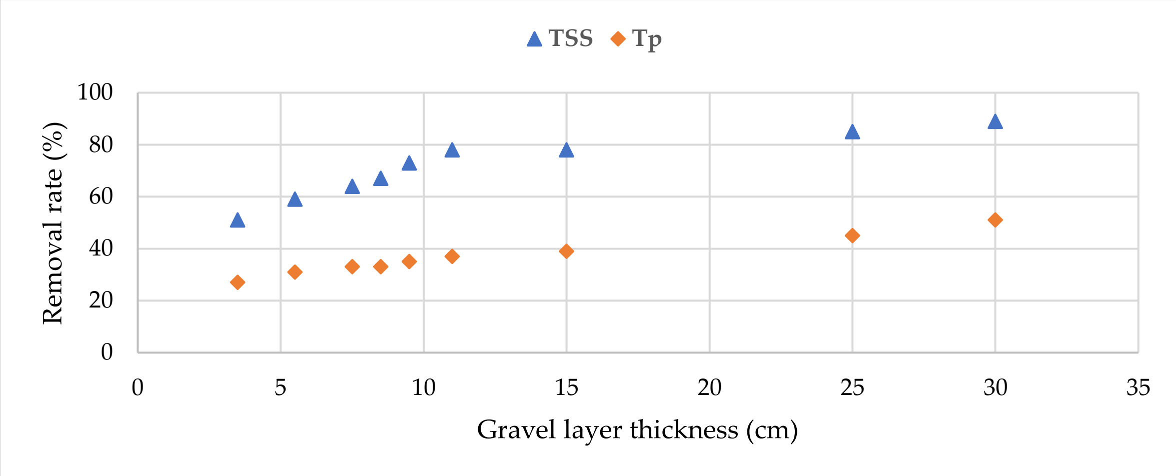

Figure 3. Removal rate of TSS and TP for various gravel layer thickness

As shown in **Figure 3**, the removal rates of TSS and TP increase with the increase in the thickness of the gravel layer for a given gravel size. It is theorized that increasing the thickness of the gravel layer improved the removal efficiency of contaminants removed by physical processes, such as TSS, rather than biological or chemical processes, such as NOx-N, TN, or COD [3,16,19,31]. Moreover, as the thickness of the gravel layer increases, stormwater can pass through a longer pathway, resulting in further adsorption and removal of the contaminant [29].

4. Conclusions

The results of this meta-analysis confirm the suitability of PPS for contaminant control in stormwater. However, the challenge of comparing results from different studies remains due to the various experimental conditions appearing in the literature. It is thus recommended that future investigations of PPS should focus on the repeatability of results under the same experimental conditions and the potential relations between contaminant removal efficiency and the various properties of PPS. The following are some insights into limitations and knowledge gaps:

- Although porosity of surface materials of PPS has been investigated from the perspective of the permeability and strength of the permeable pavement in several studies [32–34], further investigation of the relationship between the porosity and contaminant removal should be performed.
- The majority of the reviewed studies only tested a few water quality parameters; therefore, it is recommended that future investigations examine the removal efficiency of all common stormwater contaminants.
- The gravel layer configuration (thicknesses and gravel gradation) significantly affects contaminant removal efficiency of PPS. In general, A thicker gravel layer is desirable for the engineering design of PPS to enhance stormwater runoff quality, as the increase in layer thickness contributes to an increase in contaminant removal. Optimal gradation of the gravel layer should be investigated using a multi-objective study with permeability, bearing, and contaminant removal efficiency as potentially conflicting objectives.

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Re-envisioning Indian Informal Market Places towards Resilient and Sustainable Development-A Case of Durgadbail Hubballi, India

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Abstract: Many traditional Indian market places have been resilient to the changing times, addressing the priority of the prosperity of people. The smart city mission envisages the development in these market places as an architectural intervention of aesthetic sense as an image marker of the city. The significance of these places addressing the concerns of household traders and customers is often shadowed in highly ambitious projects taken up by Urban Local Bodies. The paper aims to discuss on the issues related in the traditional market places due to new interventions by smart city mission. The paper intends to describe the importance of an informal sector in traditional market places towards making them sustainable. The study area identified is Durgad bail, Hubballi, which has one of the oldest formal and informal market spaces that has been a representative of market areas of similar scales across India. The scope of the study is limited to built market spaces and opens public spaces of Durgad bail where informal commercial activities occur. The understanding of the current situation in Durgad bail is done through primary and secondary data. The analysis of the market place is done through literature review. The paper compares the proposal for the other two traditional market places of Hubli to anticipate a similar development for Durgad Bail. The paper concludes with an argument towards including sustainable approaches in making these places inclusive and resilient development in an urban context.

Keywords: Indian market places; informal sector; resilient; sustainable approaches

1. Introduction

As per the 2030 Agenda for Sustainable Development goals, the emphasis is to make cities and human settlements inclusive, safe, resilient, and sustainable.[1] Resilient Cities are those that can survive the changing economies, natural resources, governments, and environments. It is the components of the cities that develop capacities to absorb the stresses to its social, economic, and spatial systems and infrastructures to maintain essentially still the same functions, structures, systems, and identity. [2] Cities comprise various physical and functional components. Indian Cities, to some extent, have the capacity to absorb stresses due to their overlay of social, economic, and spatial systems. The historic core with traditional markets places has been the physical and functional center, holding the other components of the city. In most Indian cities, these traditional markets are often characterized by formal and informal commercial activities. These traditional market places have continued to survive to today's times of threat from Mall culture. They have maintained the identity in the city due to its diverse functions and physical form. These market places have evolved over a long time and, in line with economic, technical, cultural and social changes, have human-scaled urban solutions modified gradually as human society progressed.

Most Indian villages depend on these regional market places nearby for trading/selling their agricultural produce. The open spaces associated with these markets have supported informal commercial activities. The study analysis the issues related to the informal sector in making these places sustainable. It also examines the informal sector's opportunities in these market places towards making the cities more humane and vibrant.

The economy of Hubli Dharwad district is predominantly agricultural in nature, though the twin cities of Hubli-Dharwad -constitute one of the major industrial centers in the state of Karnataka. They have been a commercial center for all the nearby villages of the region for the trade of their agricultural produce. The market places have been for people of different cultural, ethnic and class backgrounds and have never lost their significance.

This paper helps to understand the type of interventions happening in traditional market place through smart city mission and the effects on the informal sector. The interventions by smart city missions usually end up with the design of built form. These buildings are designed as an image marker, the qualities of the relationship between formal and informal space in such intervention are at stake. These architectural interventions are approached as piecemeal projects and lack coherence with the context. The comparison of proposals by Hubballi Dharwad Smart City limited for two market places in Hubli will provide an understanding about the kind of development undertaken by the competent authorities. It will give the insight to envisage the development for Mahatma Gandhi market and public open place in Durgad bail. The sustainable strategies are to be reframed and adapted considering the social, cultural, and economic context of the area, including the informal sector. At the same time, qualities of the relationship between formal and informal spaces should become the basis of design interventions in making these places more resilient.

2. Understanding Traditional Market Places

A marketplace is, in general, a location where people gather for the purchase and sale of provisions, groceries, and other goods. The traditional marketplace is defined as a marketplace which has naturally formed before the 80s and includes both permanent and periodical markets. It is a place where goods were exchanged, and communities emerged from the construction of culture and history. The marketplace in India is an aspect of the everyday life of the people. It is part of every Indian's weekend routine. Linda J. Seligmann has this to say about the Mercado in Cuzco, Peru – "Walking through the markets of Cuzco, one finds oneself in the core of the city, surrounded by agitated movement, a cacophony of sounds, smells and stinks, human beasts of burden bearing hundreds of pounds on their backs, tricyclists carrying large women and their produce on wheeled platforms before them, huge rumbling lorries, beckoning and wheedling vendors, and the lurking presence of pickpockets. It is almost impossible not to delight in the remarkable variety of merchandise… Traditional open-air markets that date from colonial times meet with visions of modernity and postmodern mass media images in odd ways here". It mirrors the scenario of the Indian marketplaces of the present day – the traditional meeting modernity, as a transition from the old ways to the new on display for the world to see. [3]

3 Introduction to Durgad bail

Reason for selecting Durgad Bail, Hubli for the study is because Hubli is a city with its identity rooted in commerce and trade. The Durgad Bail market area is an old market area of the city that is representative of market areas in cities across India. A study of this market could provide one with a glimpse into the transformations in markets of similar scales across India in making the city resilient. The scale that we are dealing with is restricted to the city level, whereas some of the famous markets of India extend beyond the cities that they belong to the historic core of the new town. To understand or get a glimpse of its origins, especially an origin linked to trade and commerce, one has to look at the historic core of the city. In the case of many historic Indian cities, the old core is usually the city's market places.

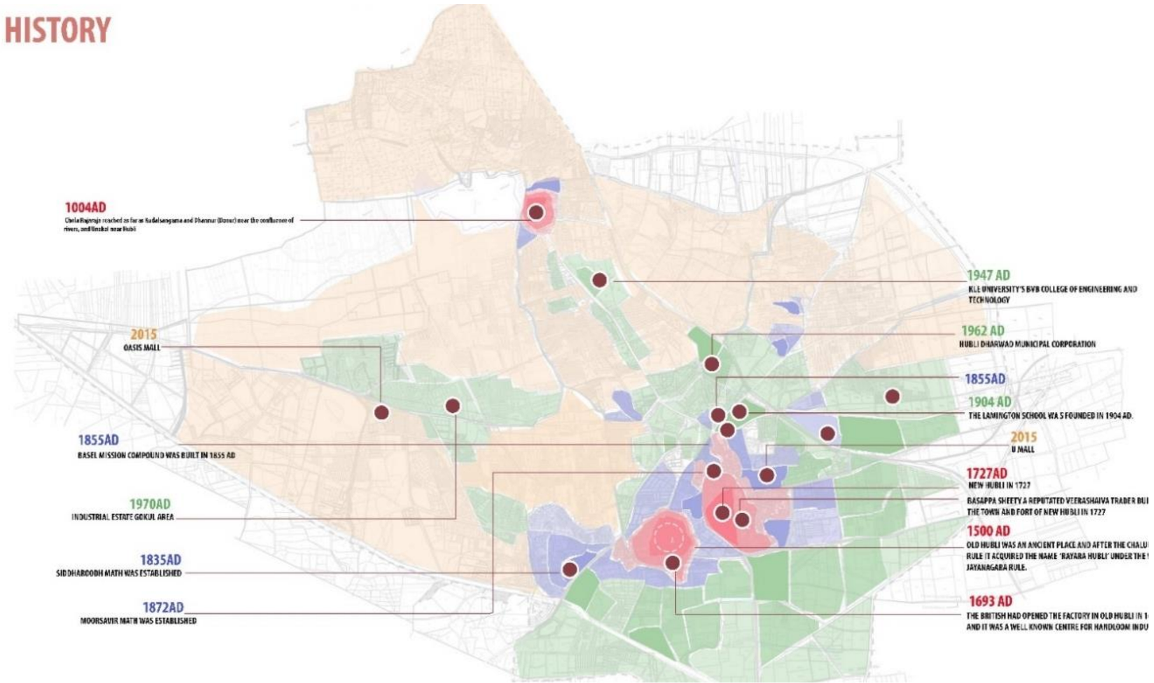

Figure1. Map showing the evolution of Hubballi
Source: VII semester Urban Design Studio. School of Architecture, KLETU, Hubballi August 2016

History suggests that the oldest parts of the city of Hubli could be traced back to at least the 11th century, when it came under the Vijayanagara Rayas. At the time, the city was called Rayara Huballi. This part of Hubli continues to exist as the Old-Hubli region of the city. The new town developed much later around the Hubli Fort that was constructed in 1727 by a local trader Basappa Shettaru with the help of Nawab Majid Khan of Savanur. This fort happens to have been situated in what is known as the Durgad Bail area. The fort was subsequently destroyed during a drought period but Durgad Bail is still known as the fort-maidan to this day. The new town started developing around Durgad Bail and hence it reveals that the area is essentially the historic core of the new town. In the years that followed, Hubli was conquered and reconquered by the Marathas and the town was under the administration of the Sangli Patwardhan of the Peshwas. By the year 1820, both the new and old town were handed over to the British colonizers, who started a Railway workshop in the city and transformed it into an important industrial center. [4]

3.1 Analysis of the existing situation of Durgad Bail

3.1.1 Urban identity

Durgad Bail, its market areas, and the urban fabric that has developed around it have become an integral part of Hubli's identity. It is a living and thriving testimony of the past, of the more juvenile days of the city. The place possesses the character of a sacred site to the people as it provokes nostalgia and helps root people to the area – it generates a strong sense of belonging. [5]

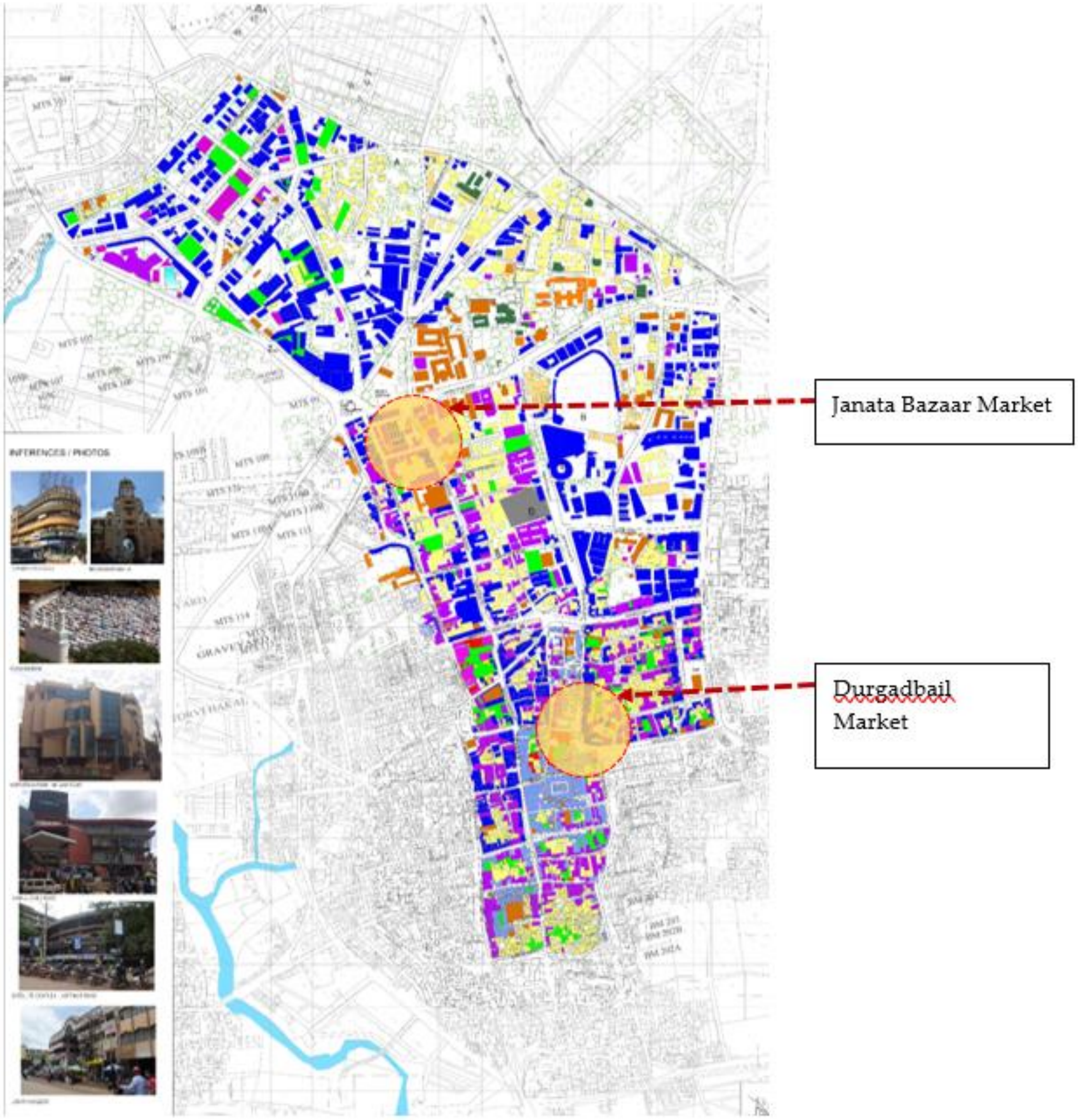

Figure2. Base map of Hubballi showing the study area of Durgadbail market
Source: VII semester Urban Design Studio. School of Architecture, KLETU, Hubballi August 2016

3.1.2The thriving marketplace

Most of the people in the city associate their experience of Durgad Bail with its marketplace. It is one of the more vibrant parts of the city. Its streets are lined with shops that sell textile, clothing, jewelry, stationery, household ware, food and toys. The alleys between the older buildings are occupied by tarpaulin-covered informal wholesale stalls that sell groceries. Over several years, these informal stores have assumed a semi-permanent and some even permanent character. The place gets extremely crowded throughout the day and makes the vehicular movement extremely difficult, at times impossible. The place sees a larger inflow of civilians during festivities. Particularly during the days leading up to Cultural festivals, when Durgadbail assumes a different social character - people throng the area with their families, new informal temporary stalls are set up, and these often stay open past midnight. [6]

3.1.3 Integration of the vulnerable classes

The marketplace, with its several big and small businesses, contributes to a major portion of the trade retail of the city and hence is responsible for generating direct and indirect employment (chartered accountants, tradesmen, delivery boys, rickshaw-pullers, tempo drivers and porters). Through this employment generation, it helps in integrating the "vulnerable" classes of the society. These include the immigrants, the elderly and in some cases even disadvantaged people. These vulnerable classes of the society are often rejected/ ignored and find it extremely hard to find employment elsewhere.

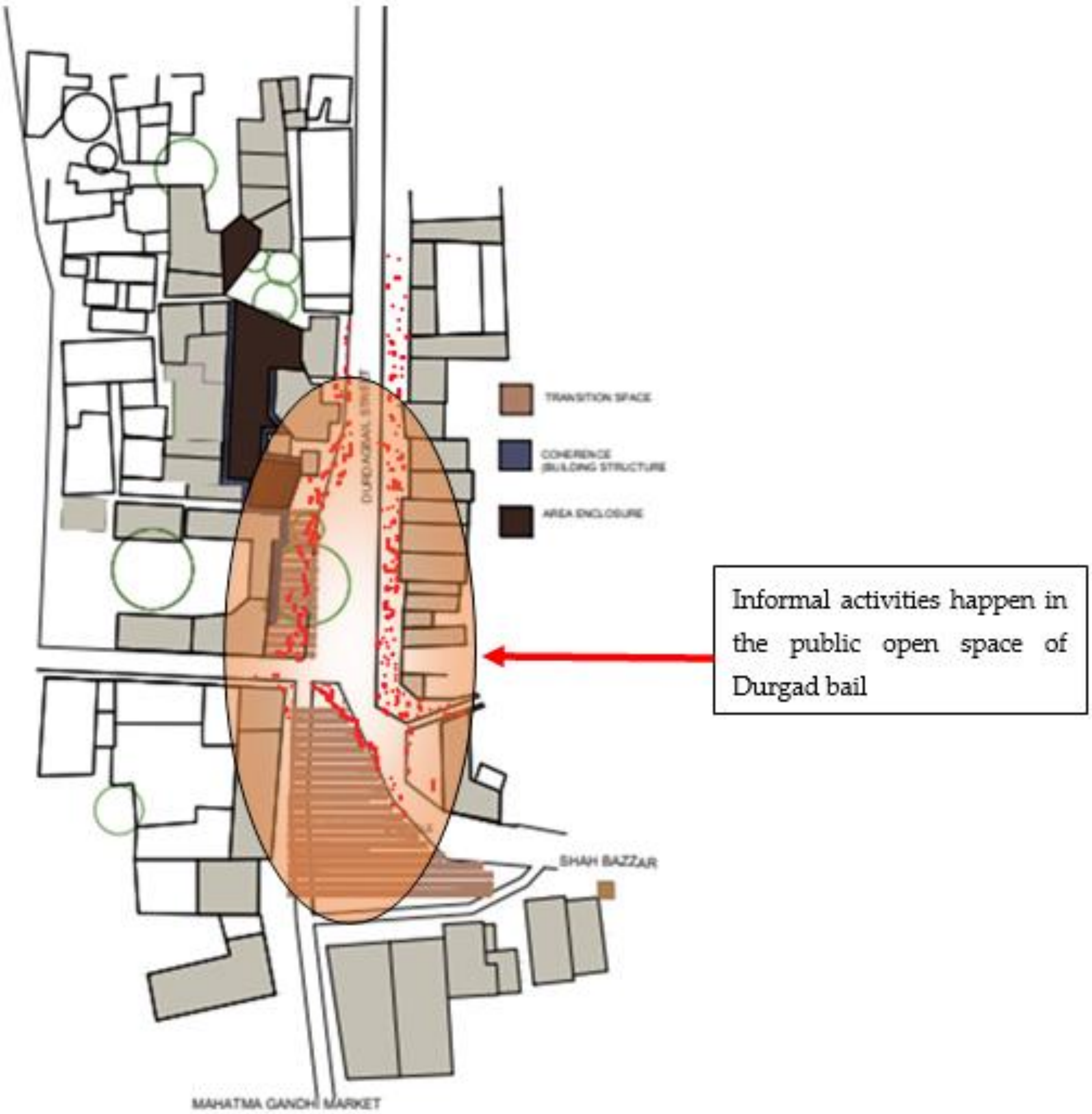

Figure3. Map of Durgadbail market place showing the informal activities
Source: VII semester Urban Design Studio. School of Architecture, KLETU, Hubballi August 2016

3.1.4 Informal economy

The number of informal businesses is equal to or more than those of the regular businesses in the area. As stated by Mamatha Prakash Dutta in the paper Old Markets, New Ideas "the main reason for this is that the informal businesses do not need to go through the expensive process of buying a store where real estate in prime locations is expensive. It is cheaper to open a stall at the edge of a street… These informal stalls also add to the strength of the market as it makes it possible for a large variety of goods of all costs available at a single location, making it attractive to shoppers." [7]

The informal stalls in the M.G. Market area are set up around the M.G. Market building built as a formal set up for the trade of goods. Some of the stalls are set up within the internal open-to-sky courtyard of the building.

Figure4. Images showing the informal activities in the Durgad bail
Source: Author. 2016

3.2 Factors contributing to the current situation:

3.2.1 Industrialization of the city

The city has witnessed industrialization ever since it became a significant junction after The Loco, Carriage, and Wagon workshop started maintenance and repairs in 1885 for the Southern Maratha Railways. It has become the busiest railway station in Karnataka after Bengaluru.

Table 1: A timeline of the South Western Railways in Hubli:

Year	Event
1885	Southern Maratha Railways The Loco, Carriage and Wagon workshop, Hubli started maintenance and repairs of Meter gauge locomotives, coaches and wagons
18 October 1886	The Madras and Southern Maratha Railway opened the 130.02 kilometers Hubli–Harihar rail line
1919	Madras & Southern Maratha Railway (MSMR) was formed and the workshop was brought under the jurisdiction of MSMR. The workshop continued with periodic overhauling activities of MG rolling stock.
5 November 1951	Hubli became one of Divisional headquarters of Southern Railway
1966	Become one of highest earning division and taken-over by South Central Railway
1987	Hubli workshop also manufactured wooden body
1999	Hubli diesel shed started for training and repair of diesel engines
1st April 2003	Hubli became headquarters for SWR with total employees 37350

Because of the mass transportation of goods made possible because of this, several large industrial areas sprung up in and around Hubli. It further brought in goods and commodities into the city and assisted in its rapid and explosive commercialization. It also helped in bringing in a large population of daily wage workers and other immigrants from nearby and farther away from towns and villages into the city, including a new demographic with different lifestyle preferences from bigger cities such as Mumbai and Bangalore, a young class of workers seeking employment in a very potential city. [4]

3.2.2 Consumption habits

Commerce is the factor that drives areas such as Durgad Bail, today. It affects the place in many ways, both positive and negative. Hence it is under constant exposure to the very volatile nature of consumer consumption habits. Though globalization has made it easier for developing countries to access the more advanced and improved lifestyles and the technology of the developed nations, traditional market places have thrived to sustain by catering to the need of local people. Cities across India have witnessed a recent invasion of supermarkets, shopping centers, and malls replacing the traditional marketplace. These commercial formats, run by people with finances, are attractive to the consumers because, apart from selling goods, they also sell the idea of luxury and modernity.[8]

3.2.3 Mixed land use

There is a still an evident mixed land use of residential and commercial functions seen in the vicinity of Durgad bail. Many older houses still exist, though some have fully converted to commercial spaces. Durgad Bail possesses a mixed-use character, evident from the number of residential buildings and the surrounding marketplace. Though there has been a thrust of getting converted to totally to commercial land use due increasing land value, the Durgad Bail area has been able to sustain its mixed land use. Over the last few decades, however, the area has become increasingly commercialized even though few malls have emerged in the city. [9]

3.2.4 Degradation of the physical environment

The advent of wholesale trade, the narrow winding streets, the congested main street, lack of parking facilities, lack of cleanliness, and poor maintenance and exploitation of the older buildings have led to deterioration of the physical environs of Durgad Bail. This has greatly reduced the quality of life that the area has to offer. One of the major reasons for this is the city agencies' lack of investment and strategy like the Municipal Corporation. Recently, the redevelopment of M.G.Market and Durgad Bail public space has been one of the initiatives by Smart city mission of Hubbalii Dharwad.

3.2.5 The public realm

A positive aspect of traditional marketplaces is that it is a very physical space for human interaction. People experience a strong sense of relation with the urban and architectural space surrounding them. The marketplace is a public space where relative strangers can interact, learn and grow from diverse contacts. Marketplaces are definitely under the threat of losing out on their social role in the city. The exchange of sensibilities is under threat, and sustaining traditional marketplaces such as Durgad Bail across developing countries can help maintain this exchange. Festivals and cultural events have made it possible to still maintain the public realm in Durgad Bail. [5]

3.2.6 Strong traditional methods of selling

Marketplaces like those of Durgad Bail follow a very traditional method of selling – there is very little marketing, advertising and merchandising of goods and products sold here. A typical attitude amongst store owners in traditional marketplaces is a strong sense of belief in the patronage of their customers, which is not a very reliable method of sustaining customers, especially since there is aggressive competition from other formats. [10]

3.3 Understanding the scenario-Case studies

3.3.1 Case study – Aminabad, Lucknow

At the historic core of Lucknow lies the traditional market district of Aminabad. This part of Lucknow is immersed in rich history and forms an essential part of the identity of its people. Some of the buildings in the region date back to the age of the Mughal kings. Many buildings in the district have strong Islamic architectural features. It is evident from the street facades that there was a strong urban design control. But these buildings are, at present, under the threat of deterioration from various factors, the most critical being "over-commercialization".

The traditional marketplace of Aminabad was designed to sell food grains. Over years, however, the character of the place shifted from retail to wholesale, and the place gradually fell into decay. The place is also flooded with a large number of informal stalls along the streets which has added to the strength of the economy of Aminabad. But commerce has slowly extended into the residential areas of Aminabad and has dramatically impacted the quality of life. The city's municipal bodies have also turned a blind eye, and the increased distances from the suburbs has further disadvantaged this region. The older residents of Aminabad have also moved out to the suburbs in pursuit of a better quality of life, and immigrants and daily wage workers now occupy the houses here. There is a change in the social subsect from high income to low income and hence the buildings in the area lie in disrepair. The poor condition of the buildings and the disorganized pattern of commercialization have led to an overall deterioration of Aminabad. [7]

Figure 5. Image of informal activities in Aminabad market, Lucknow.
Source: website: Formertourism.com (shopping in Lucknow)

3.3.2 Case study – Namdaemun market district, Seoul

The latter half of the 20th Century saw South Korea develop in one of the most rapid and drastic paces. This period is referred to as the Miracle on the river Han, and conglomerates such as Samsung, Hyundai, and LG are accredited. The situation that followed was that many of Seoul's traditional market places, which were the city's important public spheres, started losing out on importance as they were ill-equipped to adapt to this rapidly changing scenario. With fewer visitations every year, they started falling out of use. It has led to the city losing its existentialistic quality and a once-thriving public realm.

The Namdaemun market was the first permanently established marketplace in Korea. Despite its rich history of 600 years, it has been overlooked while the rest of the city witnessed growth. The traditional market showed a self-sustainable development without specific plans; thus its response and change to the transforming environment were relatively slow. [11]

Although a developing nation, India has the potential to witness rapid development in the not so far off future, perhaps like in South Korea. Durgad bail and its market areas, as of now, are ill-equipped to handle such significant transformations. Unlike Namdaemun, Durgad bail is still a significant public sphere in the city. Steps must be taken to safeguard the marketplace from losing out on its existentialistic qualities.

Figure 6. Image of informal activities in Namdaemun Market , Seoul
Source: website: www.ensquaredaired.com

4. Smart city development Initiatives

Hubballi Dharwad was listed under 100 smart cities. The major development activities under smart City focus on road development, traffic junction renovation, smart vehicle parking, Renovation of M.G market and Janata Bazaar, Affordable Housing, Nala Rehabilitation, Development of lake and gardens, etc. [12]. One of the objectives of key interventions is to encourage active high street retail in the area. But the proposal of Multiplex, restaurants and food courts in the M G Market building on the third floor challenges the sustainability of informal sector in the Durgad bail area.

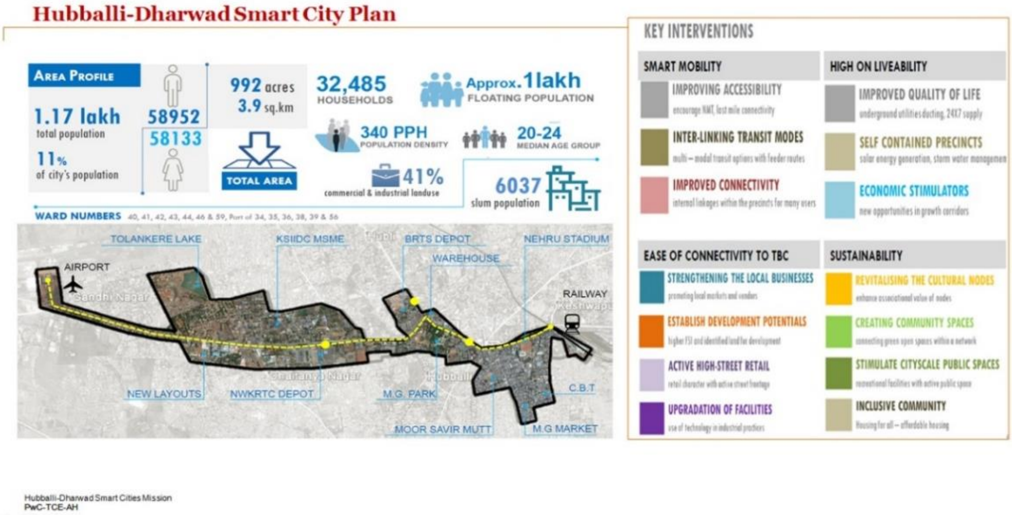

Figure 7. Hubballi Dharwad Smart City Plan.
Source: www.hubballidharwadsmartcity.com

Figure 8. Smart city development initiatives by Hubballi Dharwad Smart City Limited.
Source: website: www.hubballidharwadsmartcity.com/downloads

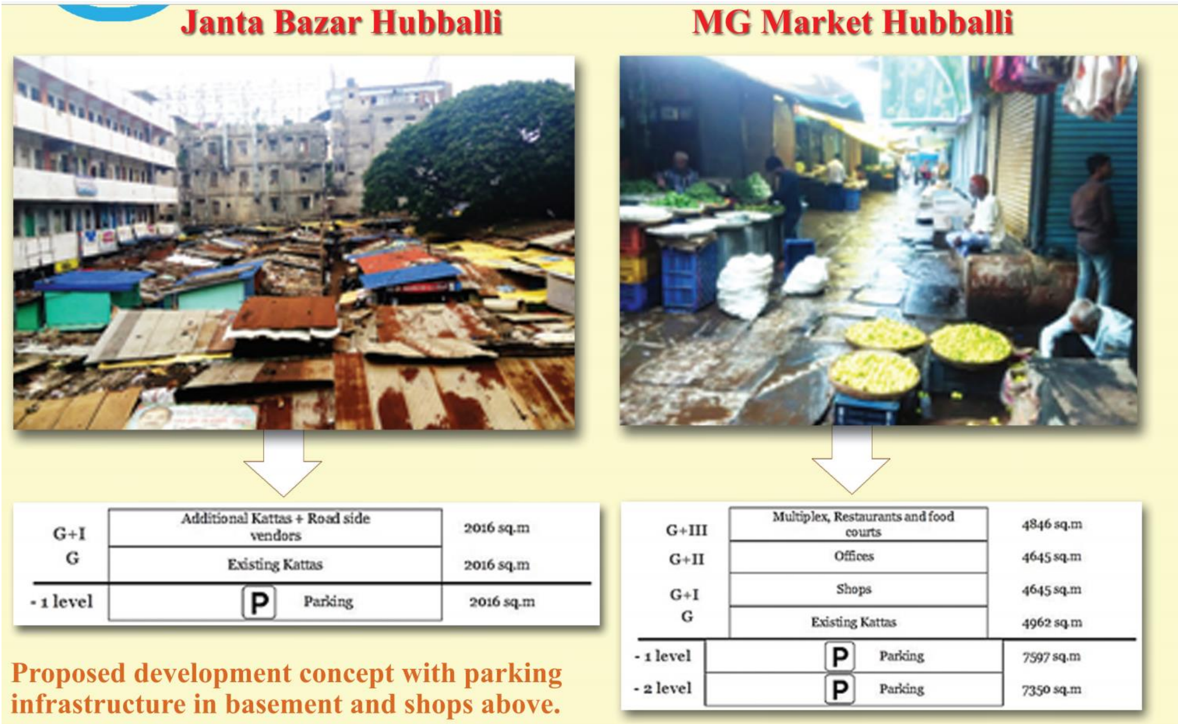

Figure 9. Proposed development concepts for Market places in Hubballi by Hubballi Dharwad Smart City Limited.
Source: website: www.hubballidharwadsmartcity.com/downloads

4.1.1 Old Hubli Market place

The old Hubli market place has been one of the major market places for the nearby farmers of old Hubli area to sell their agricultural produce. The main corner building of Shops form an enclosure to the semi covered vegetable market place. The informal shops are spread along the edge of the road.

Figure 10. Map showing the formal and informal activities in Old Hubli Market.
Source: Author

The new proposeal by Hubballi Dharwad Smart City Limited is designed for formal sector, without considering the role of informal sector in generating economy as well as making the place more inclusive to all.

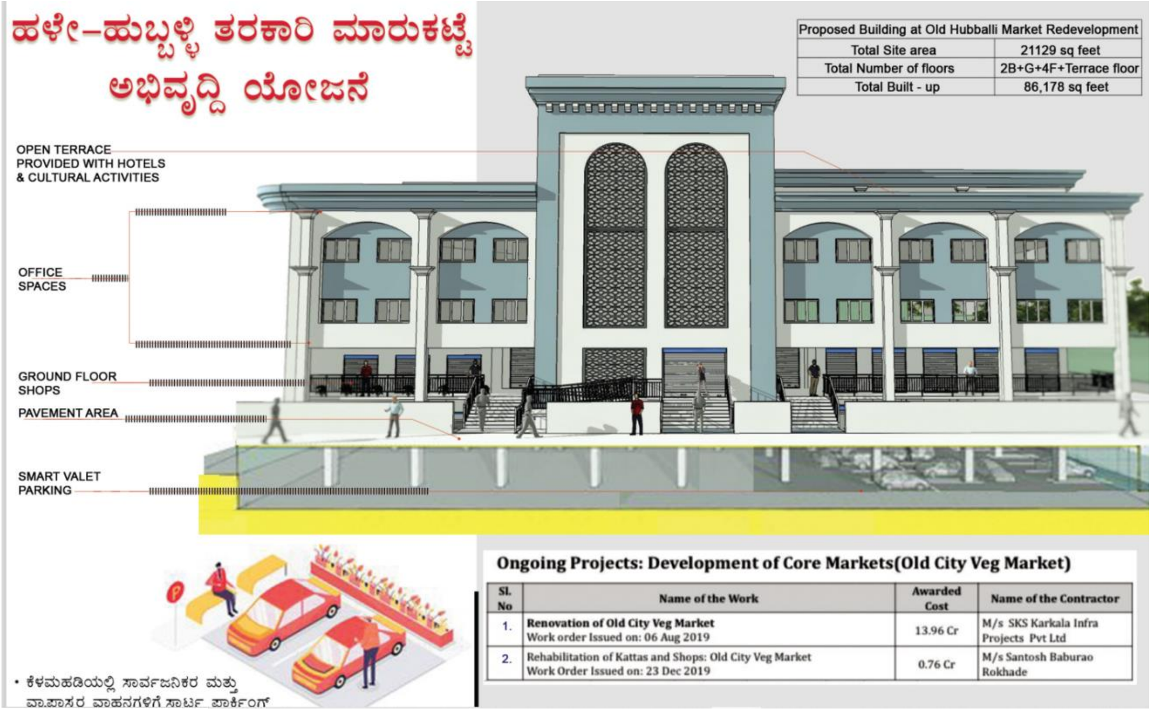

Figure 11. Proposed Building for Old Hubli Vegetable Market in Hubballi by Hubballi Dharwad Smart City Limited.
Source: www.hubballidharwadsmartcity.com/downloads

Figure 12. Image of Informal activities currently happening in front of Old Hubballi market area
Source: Author 2016

4.1.2 Janata Bazaar Market place

Janata bazaar has its proximity to the centre of Hubli City. The building abutting the main road has restaurants, shops and offices. The informal shops, vendors spread across the open spaces leading to the main vegetable market at the centre of the block.

Figure 13. View of informal vendors at Janata Bazaar during late evening
Source: Author, 2016

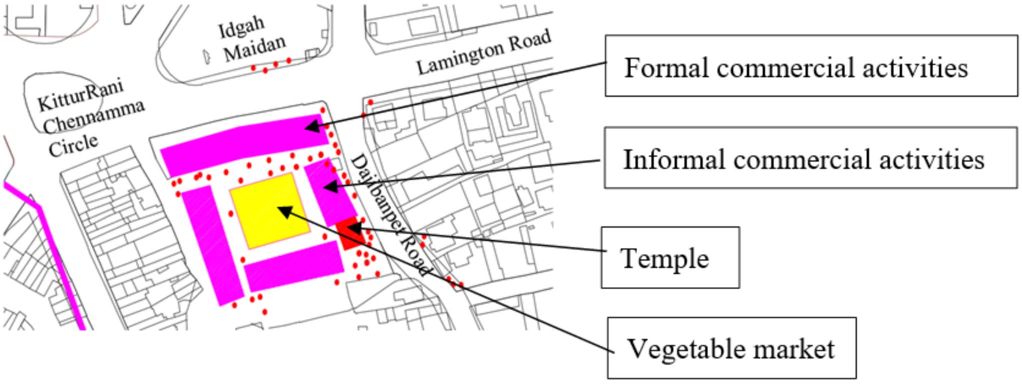

Figure14. Schematic existing Plan of Janata Bazaar market
Source: Author, 2021

The new proposed building is design to address the sustainability in terms of climate responsiveness and energy efficiency. The socio cultural aspects of the place have taken back seat.

Figure15. Proposed Building for Janata Bazaar Market place in Hubballi by Hubballi Dharwad Smart City Limited.
Source: website: www.hubballidharwadsmartcity.com/downloads

5. Discussions on Sustainability issues for the informal sector in market places

The informal sector is highly diverse, and the informal economy is not generally amenable to the same sort of policies as the formal economy. The informal economy is not large but growing and cannot be ignored. The informal sector displays enormous variation in environmental performance. There is a potential for engaging it constructively with the provision of spaces for informal activities. The informal sector is critical to many of the poorest households, with important implications for pursuing both social and environmental agendas. [13]

5.1 Spatial requirements

There is no policy or systematic efforts to accommodate the street vendors, informal sector by the government. They depend on the public open spaces for trading. They face the threat of eviction and uncertainty in the trading space. The informal industry can be strengthened in traditional market places by providing free kiosks and provides various choices of space or place of business for street vendors, namely shelters, tents, carts etc.

5.2 Dependence on Formal economic spaces

Most of the informal sector depends on the Formal sector. Urban Local Bodies have to apply the principles of inclusive urban planning for the urban informal sector. The informal sector needs to be recognized and incorporated in a manner that gives full recognition to the rights of the people who depend on this economy for their livelihoods. The informal traders are those who are learning to become traders. They can be encouraged to upgrade skills and increase the capacity they already have.[14]

5.3 Lack of Policy for Informal Sector

There is no policy to accommodate street vendors and traders by the government. The street vendor may or may not pay some nominal charges on daily basis for their trade. Their Nature of moving from one place to another might be the reason for lack in making attempts by the government to frame policies for informal sector. [14]

5.4 Smart City perceptions

There is no universally accepted definition for smart city. However in the approach to the Smart Cities Mission, the objective is to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and application of 'Smart' Solutions. The focus is on sustainable and inclusive development and the idea is to look at compact areas, create a replicable model which will act like a light house to other aspiring cities.

Smart cities proposal aims for reduction of anticipated complexities and expenses that accompany future urbanization. It focus is on the use of Information and communication technology in the entire proposal in various sectors viz, Environment, energy, Transportation, smart buildings, Governance and Social Infrastructure. The proposals under smart city mission include buildings that are sustainable in terms of the materials used and construction techniques employed, to reduce the overall carbon foot print. The local character of the place in terms of relationship between formal and informal sector gets ignored under such smart buildings. [15]

5.5 Social Sustainability

Social sustainability is achieved when physical realm is integrated with the social world , viz infrastructure to support social and cultural life, social amenities, systems for citizen engagement and space for people and places to evolve. Priority has been given to economic and environmental sustainability in the context of redevelopment proposals for market places. But the policy and investment focus on renewable resources, low carbon communities and encouraging pro-environmental behavior. The traditional market spaces with public open spaces allow for a high degree of social interaction between people. Therefore traditional markets' redeveloping strategies should aim to create a community spaces that are socially, along with economically and environmentally, sustainable. [16]

5.6 Intangible values

The cultural environment contributes to the sense of place in the traditional markets. The new interventions could fail to provide a broad-minded solution if they lack considerations to the culture of that particular market place. The place attachment, sense of place is significant is sustaining the market operations. The bonding between the local community and the cultural heritage value there contribute in retaining and strengthening the sense of place of markets. [17]

6. Conclusion

This paper has put forth some of the transformations happening in traditional market places and its impact on informal sector. Informal activities particularly in market places are essential and unavoidable sectors in the cities of developing countries. The features and status of urban informal sector is to be defined. The goods of the informal activities are originated mainly from the local area; they meet the local needs of the people. The Urban local bodies should plan, consider and manage spaces for informal markets. Basic infrastructure of open spaces at various urban nodes, intersections, existing market areas and other public places should be provided to accommodate the informal sector. The integration of spaces for informal sector into urban policy would help set supply standards and preserve local character and public spaces. This institutional intervention is important because government institutions have the authority and flexibility in overcoming the main problems of the informal sector in traditional markets. The new proposal of smart buildings should always add value to its context and this requires much more than simply fitting in. the new interventions should preserve the sense of place qualities that meets the needs of local informal sector and will sustain the local culture of the market.

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Fantasy of Real Estate Model and Consumption; the Case of Rawabi

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Abstract: The urban booming that the West bank and Gaza strip witnessed after the advent of the Palestinian authority in 1993 is considered a major factor in changing the Palestinian landscape and creating new living experiences in a midst of neoliberal market. This paper aims to discuss the production of fantasies throughout the new urban developments in Palestine, focusing on the new residential neighborhoods in Ramallah and Al Bireh governorate such as Al-Reehan neighborhood, Rawabi city, Al- Etihad neighborhood, Diplomatic housing complex, etc. The urban boom in Ramallah can't be alienated from the impacts of neoliberal market and new global realities, cultural fascinations and technological advances. Apparently new architectural forms and meanings appeared in response to these aspects, as the new. When exploring the new urban developments in Ramallah and Al Bireh, we can't ignore that the contemporary culture is led and powered by digital imaging technology, which has transformed the way we visualize and see the world. Architects are now equipped with enhanced tools of dreaming. As these imaging tools become more sophisticated, the line between the imaginary and the real are increasingly blurred [2]. Based on qualitative research, the residents' evaluation and perception of their flats and their relation to the city are discussed in order to understand this new readymade living experience from a user point of view and compare it to the investor vision. The study methodology is focusing on a literature review of the context, the hyper- reality and consumption, the concept of home and the everyday theory, followed by an analysis of the Case of Rawabi. The analysis addressed the project vision and associated lifestyle and a post occupancy evaluation based on observations and interviews with the residents to explore their perception of their residential units and connection to the city. Finally the paper is looking for a bottom up approach to understand the city of Rawabi that could be reflected in other developments and leads to rethink our dream of urbanized Palestine.

Keywords: Home; hyper-reality; Hyper-consumerist culture; every day: post- occupancy evaluation; Rawabi; Palestine.

1. Introduction

This research investigated the current urban condition in Palestine in the midst of major neoliberal urban restructuring and transformation during the past two decades. The research concentrated on the governorate of Ramallah and Al-Bireh yet will take Rawabi city as a detailed case study.

Middle Eastern cities are currently competing to attract international investments, businesses and tourism development. Currently, developments in Dubai in the United Arab Emirates, such as the world's two largest man-made islands (Palm Jumeirah and Palm Jebel Ali) and major skyscrapers and luxury resorts on Sheikh Zayed Street, are setting precedents and are becoming models for other cities of the region. This stands in stark contrast to, say, the 1960s, when the Arab world looked only to cities like Cairo or Beirut for cutting-edge urbanism [1] (p.275).

The urban boom in Ramallah and Al-Bireh governorate can't be alienated from the impacts of new global realities, cultural fascinations and technological advances. Apparently new architectural forms and meanings appeared in response to these aspects. Once investigating Ramallah and Al-Bireh governorate's new residential projects, we can't ignore that the contemporary culture is led and powered by digital imaging technology, which has transformed the way we perceive the world [2]. Impressively Ramallah and Al-Bireh represent interesting case of new ready consumed lifestyles; the new developments such as Al Reehan neighborhood, Diplomatic neighborhood and Rawabi city are evidently marketing a readymade lifestyle (Figure1, Figure2). These urban developments, reflect major political and ideological practices of power as controlled by neoliberal tropes and manifested through spatially- engineered realities that operating the digital imaging technologies. These emerging neoliberal transformations are expected to lead to inequality and exclusion as they exemplify a new urban lifestyle that reshapes the Palestinian dream of home/state and ignores the local cities and villages' spatial and architectural characters and social values.

Unfortunately, as a result of the cultural revolution and in searching for contemporaneity we disregarded our humanistic values, according to Fathi "what are we to do when we want to achieve contemporaneity in our modern architecture? What is our standard of reference for housing people? If we want our buildings to be contemporary, probably we have to make our buildings fit the latest findings of modern science. We have made great progress in the physical and mechanical sciences, but we have made much less in the human sciences, the science of the human being" [3] (p.13). In consequence, the notion of home is facing major challenges in surviving in an era of globalism and modernity. Heynen concluded that dwelling and modernity are opposed to each other, and confirmed that "dwelling is in the first instance associated with tradition, security, and harmony, with a life situation that guarantees connectedness and meaningfulness" [4](pp.18-18). Moreover Dovey illustrated the factors that eroded the sense of home as: rationalism and technology, commoditization, bureaucracy, scale and speed, the erosion of communal space and professionalism [5](pp.51-58). This paper is pointing to the new developments in Ramallah and Al-Bireh governorate with an explicit focus on Rawabi city in order to investigate the residents' evaluation for their living experience in Rawabi and their connections to the city.

The paper investigated the residents' perception of their flats and city in order to compare the investor vision to reality. Accordingly the interviews with the residents, the observations of their daily experience of space were very informative to show the gap between the fictional and the reality, and the residents' ambition to create their own space.

In the following sections a general overview of the urban developments of Ramallah and Al Bireh after Oslo agreement and the foundation of the Palestinian state. And an investigation of the impacts of neoliberal forces on the architectural representation. Rawabi city was taken as a case study; an empirical study based on a socio-spatial analysis focused on the residents' everyday life and perception through interviews and observations of physical and social space.

2. Study Methodology

The study methodology followed an analysis of the Case of Rawabi. Birzeit University undergraduate students from the Architecture in Palestine course and the Introduction to Graduation Project course have participated in collecting the data. The analysis addressed the nature of the real-estate and the project. And on the other hand the study presented and investigated the reality through the residents' everyday life and perception of their residences in the face of consumerist culture and its imposed urbanity.

In order to conduct a post occupancy evaluation that aims to obtain feedbacks on the city environment, public space and services and the residential buildings performance in use, this research followed a qualitative ethnographic approach based on a socio-spatial investigation. Accordingly the research applied several tools that included interviews, field observations, and spatial mapping. These tools were applied to collect data on the physical space and residents' experience of space as following:

2.1 Interviews

Open ended interviews were used to elicit general information including marital status and family size, education, and employment, and the residents' evaluation of the living experience in Rawabi including:

- The reasons behind the participants choose Rawabi to live.
- The residents' evaluation for the living experience in Rawabi including the services and public spaces.
- The residents' evaluation for their neighborhood and apartment design.
- The residents' experiences of coping and adapting to their flats design.

The interviews were done during the year 2019-2020; five main interviews were conducted; two of them were interactive interviews in the interviewees' apartments. The interviewees sample was diverse; the interviewees were selected based on their living experience in Rawabi, material status, gender and employment. Three of them were from the city first residents, four of them are owners One of interviewees was a female, three of them were married and living with their families in Rawabi, and only one works in Rawabi. Finally, the interviewees' initials were used to refer to them in the text.

2.2 Observations

Direct observations were carried out to investigate how residents practice their daily life and how they change their everyday space. The observations were conducted by the researcher and undergraduate students from Birzeit University. The observations started with conducting a general field survey of Rawabi. Observations further tackled two main areas: the residential neighbourhoods, focusing specifically on the residential buildings, open spaces and gardens, and the city centre or Q centre. The observations were conducted during the week Sunday- Friday, with different timing during the day considering morning, mid of the day and evening.

Observations revealed how residents are using the city spaces. Furthermore, by observing the residential buildings, streets and gardens it was possible to gather information of how residents are coping and adapting with the city design.

3. Context

Influential forces other than the Palestinian Authority (PA) have been sculpting the State of Palestine. As during Oslo's golden period, from 1995 to 1998, more construction took place in Ramallah than in the city's entire history, fueled by Palestinian investment mainly from the countryside, augmented by family funds from the diaspora. A second wave of construction engulfed the city after Palestinian returnees with their own ideas of urbanism opened new restaurants, cafés, and businesses. Then in 2003, the Palestine Investment Fund (PIF), a partnership between the PA and Palestinian investors, paved the way for public land to become available for private development by international investors, mainly from the Gulf [6,7,8].

However the Palestinian economy remains dependent on the charity of outsiders– in the form of donor aid – and on Israel, which controls water and electricity in the territories and periodically injects much-needed Palestinian tax revenues into the economy. Internal and external control left the state-to-be little room to grow except, as evidenced by the skyline of Ramallah, skyward. New malls, housing developments, and a transnational landscape of spanking new high-rise buildings give the appearance and shopping opportunities of a flourishing consumer economy [7]. Ramallah has become a gilded, neoliberal ghetto, the neoliberal turn of the PA has been generally associated with the premiership of Salam Fayyad (2007–2013), aiming at establishing a state by September 2011. In that period, the PA programme rested on the assumption that 'institutional facts on the ground' would convince the world community that the Palestinian people had acquired sufficient maturity to be entrusted with a state. Subsequently, the government adopted neoliberalism as a model to demonstrate the facts on the ground [9]. By 2013, the PA and Palestinian investors working with the Portland Trust, are planning fifteen thousand new homes on the West Bank for people with monthly incomes between $800 and $1,500. This segment of the population can now avail themselves of affordable home mortgage schemes like those in the United States, before the subprime loan debacle set in [7].

The new housing developments such as, the Diplomatic housing complex, Al Reehan, and Rawabi are devoid of common architectural elements. Yazid Anani[1] in an interview with Emily Lawrence about his contribution to the Designing Civic Encounters art project in 2012, explained that "our housing projects used such public and common architectural elements. Now it's like containers standing next to each other where you squeeze people in. Architecture becomes a form of containment, reproducing the colonial strategies" [10]. As well, Lawrence explained that Shuruq Harb[2] described Rawabi as "a city modelled after a housing complex, like a settlement, so it's a really weird concept,". Harb added that "Rawabi clearly represents neoliberal policies … in a way it's like a privatized city" [10]. While these new housing developments represent a combination of reality and digital images that makes the mountainous landscape look evocative and artificial (Figure 1). Visual representation and images of the new developments implies a luxurious and glamorous new neighborhoods and cities. Ramallah city and the nearby regional streets are occupied with huge advertising boards, projecting a splendid future. The billboard articulately captures the power of the commoditized image. It sells not just a house or a flat but also a lifestyle. (Figure 2)

Figure 1. Al Reehan Neighborhood Under Construction (Resercher,2015)

Figure 2. Billboards in Birzeit Street-Ramallah (Researcher, 2015)

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[1] Palestinian architect, artist and academic.
[2] Palestinian visual artist and writer.

The following section is focusing on the case of Rawabi, the first purpose-built Palestinian city built by Palestinians, in order to explore the influences of neoliberal market creating a new home experience and lifestyle. And to compare the hyper reality created by the investor to the everyday life and the residents experience of the city. Rawabi was chosen for its unique situation as a new planned city that was initiated after the establishment of the Palestinian Authority, as well as the availability of data.

4. The Case of Rawabi

In such a hyper-consumerist culture, digital/synthetic landscapes are increasingly depicted as "total lifestyle experiences," ready to be consumed. Impressively Rawabi (Figure 3) represents ideal case of these new ready consumed lifestyles; the iconic mega projects such as Rawabi City, are evidently marketing a readymade lifestyle. On the other hand the everyday life of the residents is important to read the real city, de Certeau theories on spatial practices is very interesting to read the city from below and within[11]. That's why it was important to investigate the residents' daily experience within this neoliberal model in order to find a space for the ordinary within this hyper-reality.

Figure 3. General View of Rawabi. Source: Birzeit University undergraduate students (2019).

4.1. Project Background and Vision

According to Rawabi official website Rawabi city is located 9 km north of Ramallah and 3.5 km north of Birzeit, Rawabi lies 25 km north of Jerusalem and 25 km south of Nablus. Rawabi's municipal boundaries encompass 6,300,000 square meters of land, which will initially be home to 25,000 residents. Additional residential and commercial units slated for subsequent construction phases will ultimately serve a city with a population of more than 40,000. Rawabi city aims at establishing "a new community for Palestinian families that will provide opportunities for affordable home ownership, employment, education, leisure and an attractive environment in which to live, work and grow" [12].

According to residents of the surrounding villages Rawabi land was bought from the villagers of Atara, Abwain and Ajoul for 1000 -3000 JD each Donum (1000 m2), and the rest of land was bought using the Palestinian acquisition law, which organizes the use of private land for the public use. Accordingly parts of these aforementioned villages will be included in the city land borders (Figure 3).

The city consists of about 5,000 housing units spread across 23 neighborhoods, and a city center that offers a retail business district with hotels, cinemas and a convention center, Rawabi also features education and medical facilities, houses of worship, public green spaces and recreation facilities (Figure 3,4). Based on the official website of Rawabi, the city will expand the local economy's linkages to the global knowledge economy. It will introduce new technologies to the Palestinian construction sector and encourage international firms, particularly in the high-tech, health care and renewable energy sectors to take up a key role in bolstering current economic activities. Through attracting investors and technology suppliers; Rawabi plans to generate more than 5,000 permanent jobs, creating quality of life and making a long-term, sustainable contribution to national prosperity[12].

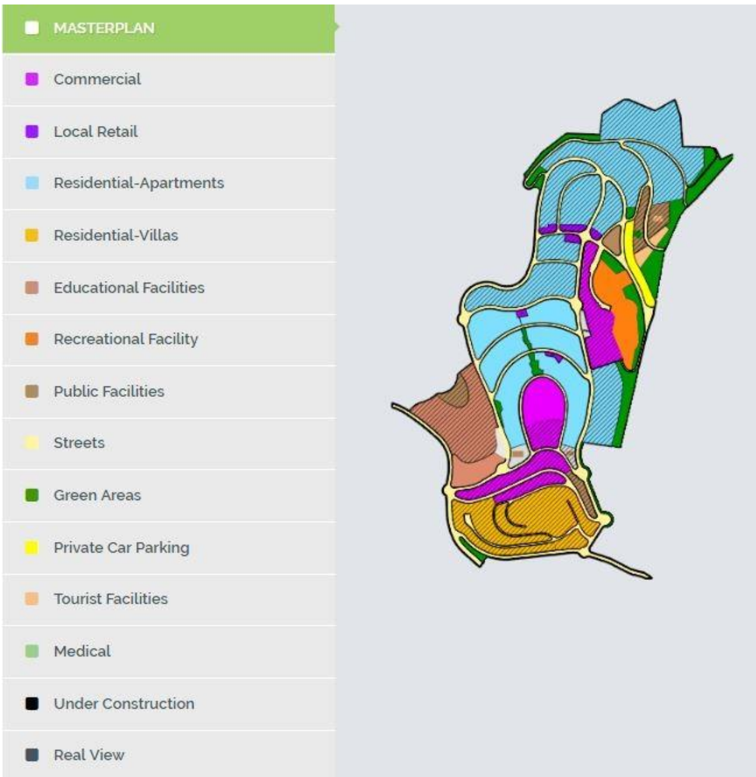

Figure 4. Rawabi Master plan (Source: Rawabi Official website)

Exploring Rawabi's new home experience is based on a post occupancy evaluation, that focuses on the residents' perception of their residential units and their connection to the city in addition to observations of the residents' behavior in space.

4.2 Living in Rawabi

The living in Rawabi was evaluated through open-ended interviews with the residents. The interviews were done during the year 2019-2020, 5 interviews were conducted, and 2 of them were interactive interviews in the interviewees' apartments. The residents were asked to evaluate their living experience in order to compare the reality to the developers' vision which is important to investigate Rawabi's real estate model and the fantasy branded by the developers. Here the evaluation will focus on, the city environment, services, public space, the residential unit spaces and design.

4.2.1 City Environment; Quietness, Cleanness and Safety.

Two of the first Rawabi's residents said "the best thing about Rawabi is the clean and the quiet environment". K. A. An urban planner who is also one of the first residents said "For me, it is better to live far away as much as possible from work. When I get out of work and arrive home, no one will call me to go back for anything". For S.T. who lives in the second neighborhood, she said that "I don't feel safe in Rawabi, as there is no people in the streets and not all of the city is lighted in night in addition to the low occupancy of her building and all of the city". She added "I try not to go back to my house late because the city is so scary at night and I feel like I enter a graveyard, not a city".

M. M. a professor at Birzeit university and one of the first residents of Rawabi, was met in his office, he was happy of his living experience in Rawabi, created a garden on his veranda trying to adapt to city life through practicing his passion in farming as someone originated from village.

4.2.2 Services

A.E. - one of the first residents- said" there's no hospital or pharmacy here, I am scared that If one day my son gets sick, It would take so much time to buy him medicine or take him to the hospital". However, other residents aren't satisfied, due to expensive expenditure they pay monthly for their flats and neighborhood services such as heating and internet costs, and the gardening cost, while not the entire city is lighted at night.

4.2.3 Public Space

When talking to a group of children playing in the street they said there are no proper playgrounds and they prefer to play in the street (Figure 5). Also Residents were not satisfied of the accessibility between different neighborhoods and the Q center, the stairs are not pedestrian friendly (Figure 6). A.D. described the way he adapted to walk from his flat to Q center where he works, through walking from building to another and using the elevator to reach the upper level of the street without any interaction with the public space. Residents were not satisfied with the public spaces, they need to pay 20 shekels for the car parking to visit *Wadina* area, which should be a public park for the residents.

Figure 5. Children Playing In the Dead End Street. Source: Birzeit University undergraduate students (2019)

Figure 6. Stairs Connecting the residential neighborhood to the Q Center. Source: Birzeit University undergraduate students (2019)

4.2.3 Residential Unit Design and Spaces.

A. D. a young man who live and work in Rawabi said the view from his apartment is blocked, and he isn't able to open his windows due to visual intersection with neighbors. He described the balcony in front of his room as dead place, as it is overlooking other flats, he doesn't feel comfortable to use it and he use it only for hanging clothes .

S. T.is dissatisfied of her flat, she said that "I offered my flat for selling, but can't sell it for more than two years". When she was asked about the reasons behind her feeling of dissatisfaction, she said "I have many problems in my flat, humidity, cracks and the finish quality is not worthy, for example the shower glass partition was broken for two times without knowing the reason, also there is always heat coming from the floor".

About her flat design, she explained that she was not free to design the interior space of the flat, she explained that there were three options for the bathrooms and kitchen design offered by the selling office and she was asked to choose between them.

4.3 Residents' Behavior in Space

The residents' behaviors in space were investigated through the observations. The observations were focusing on observing the space and users behaviors.

4.3.1 The Use of Open Spaces

The observations showed that the city open spaces were empty most of the time, most of the week. Figure 7 shows observations of the open spaces in different times during the week.

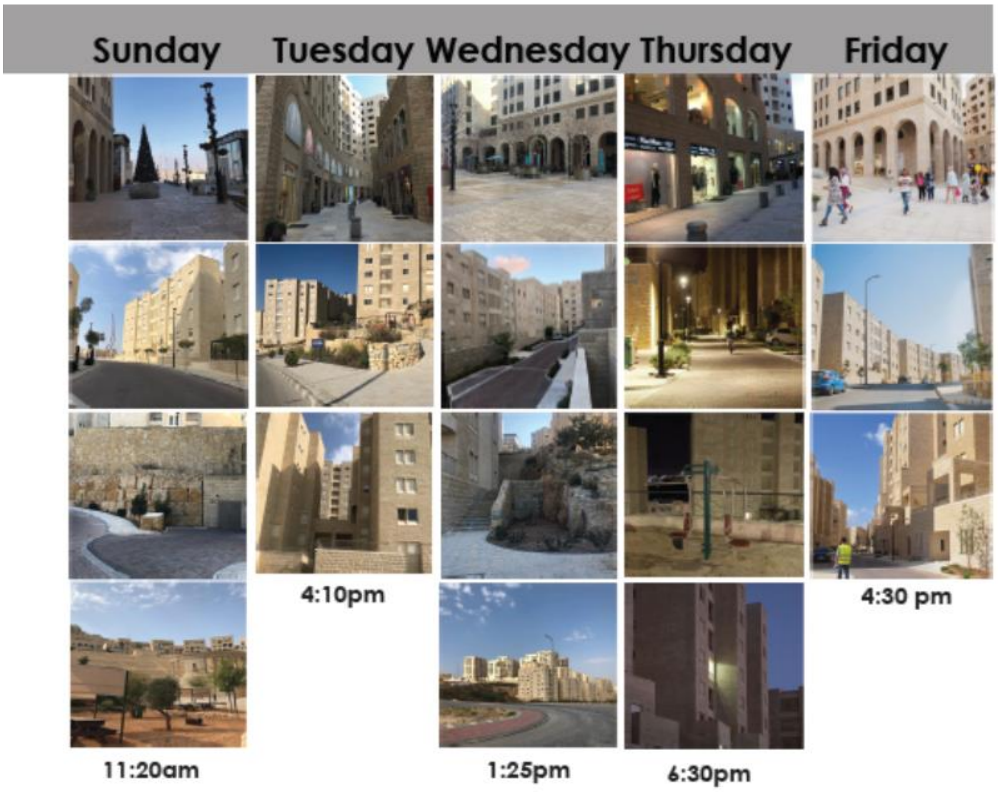

Figure 7. An Observation of the city public spaces during the week. Source: Birzeit University undergraduate students (2020)

4.3.2 Changes in the Residential Buildings

Knowing that physical changes are not allowed by Rawabi municipality and the city security are controlling any physical intervention by the residents. The Observations of the physical changes in the cities showed that the main changes are:

- Adding pergolas for privacy (Figure 8).
- Adding air conditions and hides them in balconies.
- Adding decorative features, for example changing the gate of private garden (Figure 9).

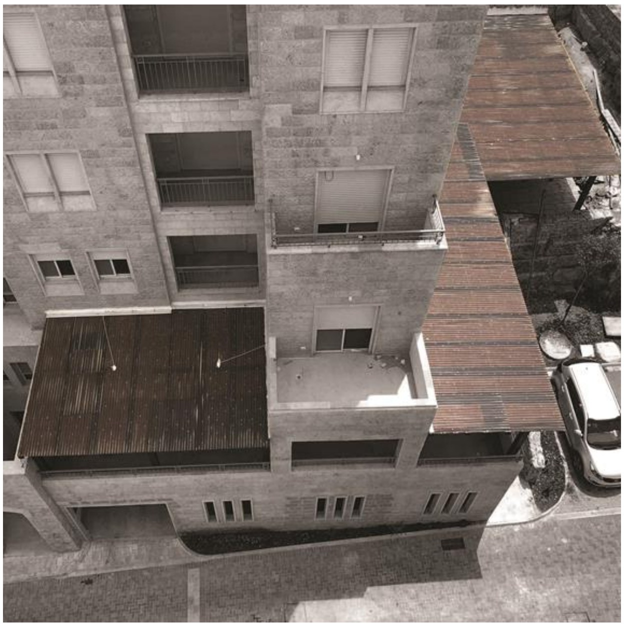

Figure 8. Newly added pergolas. Source: Birzeit University undergraduate students (2020)

Figure 9. One of the residents changed the gate of his garden (researcher ,2020).

5. Discussion and Reflection

Throughout investigating the new urban developments in Ramallah and Al-Bireh governorate, it is noticeable that the leading purpose of these developments is to produce the maximum revenue ignoring human values and the notion of dwelling. The users' needs and preferences are not the priority in designing new residential developments in contrary to what the developers are promoting. According to Willis while design schools continue to propagate Mies van der Rohe's famous dictum that "Form Follows Function", the reality in the world's great cities is that "Form Follows Finance" [13,14].

Through the formation of urban islands of excessive consumption and exclusive residential neighborhoods, the dream of state was transformed to a dream of a modern flat that equipped with all the modern appliances, luxurious live and richness. The new developments are reflecting a consumerist lifestyle which focuses on the individual needs without paying attention to the community or the specific situation of the Palestinian State which stuck in limbo between a colonial history and a post-colonial future. Buying architecture becomes similar to buying a product. Living in it becomes like acquiring any lifestyle you can afford.

From other side reviewing the new urban developments highlighted the impacts of urbanization or urban transformations (from rural to urban), which disregards the spatial qualities and values of the Palestinian settlements and communities. The new developments such as Rawabi represents an example of a non-original consumerist hyper-reality in which the experience of home is disregarded, residents are not satisfied of their flats design and their relation to the city in general.

Focusing on the case of Rawabi, the post occupancy study showed that the residents of Rawabi city are experiencing a gap between the ready- made life style they were offered by the investors and the reality they live. The interviews and the observations showed that Rawabi is lacking the main services that the residents of a city need like public schools, nurseries, grocery, pharmacy, and health car. Living in a flat in one of its apartment buildings means to be isolated from others, and from services. The city center-Q center- is not working as an active center for the city residents and public spaces are mostly empty.

Finally, studying the residents' evaluation of their own flats and experience in the city proved that there is an essential need to focus on the post occupancy study in relation to the city, its vision architecture and its branding. Rawabi is a specific case in which an intersection between the fantasy of investors and the reality created a reproduced city which is disconnected from its context. Thus a contextual approach of urban development is vital to unleash the potential of the local city and incorporate a new language in architecture that can reconnect urbanism to modern life with environmental specificity and culture, never ignore the colonial context of Palestine.

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Inflicting Self-Demolition of Home in East Jerusalem: The Violent Act of Colonial Domicide

A more violent form of domicide: Enforced self-demolition of home in East Jerusalem

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Abstract: The violence associated with Israeli colonial domicide – the intentional destruction of the home- has continued and accelerated in East Jerusalem since 1967, till the day. Home demolition implemented by the Israeli apparatus used strategic, political, administrative, legal, bureaucratic in addition to urban planning means to un-home the Palestinians of East Jerusalem. Demolition of homes in the last 10 years, has accelerated and had a devastating impact on Palestinian families. On top of that is the procedure of self-demolition of the home by the Palestinian owners themselves. Although home demolition has been implemented by Israeli bulldozers and explosives, enforced self-demolition of home by its Palestinian owners counted for one quarter of demolition cases. Using a handful of cases of self-demolition, the paper discusses how inflicting self-demolition presents another form of violent colonial domicide. This violence does not only impact the societal and spatial setting of the demolished home, but also effects the younger generations, the psychological internal anguish of self-demolishing their homes, and the economic aspect of enduring pauperization. The paper shows how colonial domicide acts opposes sustainable development but in fact produces de-development on the spatial, social, and economic levels. Despite of this, Palestinians still sustain steadfastness (*Sumud)* socially and personally

Keywords: domicide; Jerusalem; urban injustice, home, self-demolition, colonialism

1. Introduction

> I am 67 years old, I have never in my life witnessed moments more difficult than having to demolish the homes of my four children with my hand…I cannot describe it to you. There are no words. I mean, I say this is a difficult time. The most difficult moments in my life… (Wadi Hilweh Information Center (c)– Jerusalem, August 28, 2021).

Tens of cases of Palestinians self-demolition of their homes have been taking place in different neighborhoods in East Jerusalem and have increased over the years and spiked and doubled in 2020 (OCHA-OPT 2019; Land Research Center 2021). Self-Demolition of home or structure is when the owner is forced to demolish his/her home or structure by him/herself in silence. This form of demolition used to be done away from the media in the dark of night in reticent humiliation from divulging that the person destroyed his/her home or structure with his/her own hands (Land Research Center, 2021).

The Israeli control over East Jerusalem in the 1967 war included Israeli annexation of the city which is illegal under international law. Yet, Israeli policies over the past decades have increased Israeli illegal settlement construction in the city to increase the settler population. Over the years, the settlers have gained confidence in infringing on and violating Palestinian human rights to disrupt their daily lives, being backed by official Israeli policies and ministers and members of the Israeli parliament (Knesset).

This in conjunction with policies to socially engineer and reduce the Palestinian population of the city through various laws and regulations. The Israeli urban planning system including zoning, development of Master Plans, and legal procedures have created a complicated, long-term and very expensive procedure to acquire a building permit. This has left no other choice to many Palestinians in East Jerusalem but to build without permits, which is considered by the Israeli Authorities as a criminal offense. Thus, the increasing number of home demolition was through "legalized" demolition orders. The increase in demolition orders is consistent with the Jerusalem municipal plan, Jerusalem 2020, that has guided municipal policies to reduce the Palestinian population of the city from 40% to 30% by 2020 (Samman 2013, 104-105, 145).

The Israeli policies follow-up the house demolitions of such Palestinian structures with fines as well as billing the Palestinian families for the costs of the whole demolition process. These include, the costs of closing of the area around the house to be demolished, the costs of deploying the police forces, and the costs of bringing in the bulldozers to demolish the structure and the demolition itself. The purpose of this has been to impoverish the Palestinians who have withstood Israeli policies to make them leave the city.

Despite the threat of being subjected to multiple and high amounts of fines and still possible demolition, Palestinians continue to build homes as part of their survival as the Israeli colonial apparatus flaunts its responsibility to provide the Palestinians with the basic needs including housing. Despite of being subjected to "domicide": the demolition of the home, Palestinians believe that building without permits is part of their steadfastness and resilience against unjust colonial practices, to manifest their right to exist in their city.

The objectives of this research are:

- To contribute to the theory, interpretation and implementations of domicide while showing how by constraining social sustainability it jeopardizes development
- To show how the Israeli colonial case forms an advanced form of colonial oppression on the colonized and jeopardizes development

The questions that are posed are:

- How self-demolishing became a new form of imposed Israeli colonial policy? Why people are forced to self-demolish their homes? How does self-demolishing impact the resources, effort and time of the victims? How does this constrain social sustainability?
- How self-demolition has an even more devastating impact on the colonized? How does it jeopardize development?

The paper argues that the increased form of self-demolition of homes of Palestinians in Jerusalem due to the advanced colonial policies inflicted on the Palestinians, form a new more violent form of domicide. This is an advanced form of injustice on the social economic, psychological well-being of the people. Self-demolishing is devastating as it is a state of dispossession and loss in its most painful way. It constrains social sustainability as domicide entails erasing the meaning of one's life, erasing one's own dream, erasing memories, erasing life and dwelling, killing the everydayness of life in one's own home, forced to be implemented by one's own hands. Thus development is jeopardized, if not curtailed.

2. Materials and Methods

The theoretical framing is based on the concept of "domicide" which was developed by Porteous and Smith in 2001. It is defined as:

> the destruction of a place of attachment and refuge; loss of security and ownership; restrictions on freedom; partial loss of identity; and a radical decentering from place, family, and community. There may be a loss of historical connection; a weakening of roots; and partial erasure of the sources of memory, dreams, nostalgia, and ideas (Porteous & Smith, 2001, p. 63).

Domicide could occur from different forms of power, whether political, urban, or economic. It could be direct and at once or can take a period of time depending on the specific case and context. Wars are the most significant processes causing domicide on a large scale and inflicting disastrous results on the people. Urban policies and processes of gentrification also lead to domicide on a large scale and impose devastating changes on the lives of the inhabitants. Adam Elliott-Cooper discusses the results of gentrification and displacement as un-homing which violently severs the connection between people and place, thus undermining the right to dwell (Elliott-Cooper et al 2020: 494). Mark Davidson focuses on the displacement of home as part of the everyday life lived experiences of space. Attachment to home encompasses deeply embedded emotions on a personal, social, and political levels. Using several cases within an interdisciplinary approach Hannah Jones and Emma Jackson the meanings of belonging to a place (Jones and Jackson 2014). Owain Jones elaborates on the notion of loss of home and raises the question of whether the loss of home place/landscape can destabilize the self? (Jones 2015: 11). How much the loss of home affects the loss of sense of oneself and of identity? How does this affect the memories of the different age groups who built and lived in the home? How all these dynamics are elaborated when one is forced to demolish the home with his own hands? How do all these effects on persons affect social sustainability and how is impacts Palestinian development in the Occupied East Jerusalem?

In her article "Rethinking Domicide: Towards an Expanded Critical Geography of Home", Mel Nowicki identifies the different contexts in which the concept of domicide can be used to analyze critical home scholarship, and focuses on four areas to further explore the term. These are related to home unmaking, socio-symbolic domicide in geopolitical context, domicide and heteronormativity in post-disaster home loss; and agency and resistance to domicide through both political activism and banal resistances of the everyday (Nowicki 2014). However, none tackle the issue of enforced self-demolition as another form of domicide.

The methodology is based on qualitative analyses based on the concept of "domicide" and identifies a new form of it. The collection of data and information is based on different forms of media on a handful cases of self-demolition in East Jerusalem. This included information from various human rights reports, social media networks, news and documentaries on 11 specific cases (See Appendix A). The common internal dynamics of the process of self-demolition were identified. This entails the recognition and differentiation between the demolition implemented by the apparatus of the colonial regime and that enforced to be implemented by the inhabitants, the victims themselves, thus adding a new form of domicide.

3. Results

Based on analyses of data from different organizations as well as Israeli authorities, the number of annual home demolitions in East Jerusalem since 2000 till 2015, was within an average of about 85 per year (NRC 2017: 2). However, since 2019 there has been an increase in demolitions. In 2019, 104 housing units and another 117 other structures were demolished. Out of the 104 demolished housing units, 40 were self-demolished compared with 14 in 2018, and 11 in 2017 (Ir-Amim 2000: 2-3). While all these have jeopardized Palestinian development in the city affecting the large portion of Jerusalemites living in houses without Israeli building permits. Israeli authorities use the tactic of "forced self-demolition as a mean to avoid international pressure to stop house demolition in East Jerusalem"; Palestinian owners refusing to implement self-demolition incur aggravated fines and expenses when Israeli forces forcibly carry out the demolition (Al-Haq 2020).

Studying a handful cases of self-demolition of homes in 2020 and 2021 (See Appendix A), reveals that self-demolition of one's home when the victim is forced to be the implementor of the imposed injustice on the victim and the family is even more excruciating than what is normally attributed to meaning of domicide, Thus self-demolition, an aggravated version of domicide, not only jeopardizes development but activates de-development (see Roy 1995, 2007). It includes:

3.1. The dilema of an unresolved mystery for children and grandchildren.

Unresolved for children and grandchildren is why their home is being destroyed by their parents and grandparents. The painful effects of self-demolition upon the family are long-lasting. When the Israeli Authorities demolish the home, the family's emotional fabric remains strong and intact especially in the children, in face of the aggression. However, when the head of the family is the one who destroys the home, the home which has sheltered the family and which represent years of sacrifice in time, energy, and livelihood to build, he appears weak unable to protect them nor provide them with security and stability. These feelings reverberate within the family which then feels distorted and shaken. As a result, the children feel torn and frustrated as the trust in their family, in their community and in the future is broken (Land Research Center 2021).

Some of these aspects are reflected in cases, for example in case 5, where the head of the family watches his son who was to be married within weeks, having to drill down his future home, and his four-year old grandson tapping to concrete with a chisel, eyes wide in a fixed stare, trying to make sense of why his uncle and grandfather are destroying the part of the home which he was told was going to be for him in the future (Maydan Al-Quds, July 28, 2021). In case 11, the head of the family who had to self-demolish his four homes by order from the Jerusalem Municipality, says:

These houses that were destroyed belong to my children. Here I have two sons married with children --around 13 persons. This house is for my daughter, who has gone. She has had to go to Lid (Ludda inside the Green Line) to her father-in-law's house. She is my only daughter. And the house down there is for my (third) son and he has children; it was demolished completely … (Wadi Hilweh Information Center (c) – Jerusalem August 28, 2021).

3.2. Internal anguish and torment of those who are self-demolishing their homes.

By forcing the heads of Palestinian families to demolish their own homes, the Israeli Authorities enforce upon the whole family the torturous and traumatic procedure of having to watch and experience bringing down their own home. That the rooms that housed people's lives and daily routines gradually pile up into rubble, shredding the notion of home and its secure spaces, liquidate the familiarity of the place interwoven with the emotional well-being of the family. The family's personal belongings, its dreams and memories lay in the street.

This is the plight of Palestinians living in houses unable to get building permits either because of land re-parcellation difficulties when there are a large number of heirs to the plot of land, or because of the high costs of permit application which does not necessarily mean that a permit shall be granted. In fact, the success rate is quite low. Thus, a third of all Palestinian houses in East Jerusalem are built without an Israeli-issued building permit and over 100,000 Palestinians face the risk of being displaced (OCHA-OPT 2019). In case 5, the head of the family says:

> Only God knows how I was able to build this house. I have put everything I had in this house which has cost me around half a million Israeli shekels (150,000 USD)... (Maydan Al-Quds July 28, 2021).

The son says: "I have prepared myself for my wedding and now they (Israeli Authorities) have surprised us with this news (the demolition order). And so, they have destroyed our plans, and have turned upside down my happiness. I do not know what to say to you (the interviewer) (Maydan Al-Quds July 28, 2021). The head of the family of case 6 built the house for his son who is married but with no children yet. To see his son having to demolish his home was anguish itself (JMedia 2021). The head of family in case 8 said that: "When you toil and then come to demolish [your home] yourself, it is very difficult. This in and of itself is oppression." (Wadi Hilweh Information Center (a) – Jerusalem July 6, 2021). The quote from case 3 sums up all the above about this aspect of self-demolition: "We toil to build and then toil to demolish." (Wadi Hilweh Information Center (b) – Jerusalem June 2021)

3.3 Enduring pauperization policy

When it comes to building permits for Palestinians in Occupied East Jerusalem, the Municipality enforces regulations that extract exorbitant fees and fines over extended periods of time. Furthermore, families with building permit problems have to also hire lawyers to represent them in various courts and Israeli municipal and planning bodies. This means that even though the purpose of building a house in Jerusalem is to spare paying rent especially if one already has property or can expand on an existing structure, Palestinians end up paying monthly installments in fines and fees for many years with a minimal possibility of getting a building permit issued retroactively. There are no refunds, or halting of such payments even after the structure is demolished. For example, case 2 states that he has tried for years to get a building permit and paid large amounts in fines and to delay the demolitions (Al-Jazeera News 2021). Case 3 stated that:

> They let one live for 11 to 20 years as if you are paying rent [for your own home] even though one builds at one's own expense and hard work. Then they come and give you fines and end up paying monthly installments of 1800-2000NIS (USD 550-600) in addition to water, electricity and other (living expenses). And then in the end… they come and tell you to demolish your house because it is built without a license. …. We work hard to earn money and a living. A life full of hardship. This house has cost us around 200,000 shekels (USD 60,000), …. When you struggle to earn and save 200,000 shekels - only God knows what this means, and how difficult this is especially in Jerusalem (Wadi Hilweh Information Center (b) – Jerusalem June 2021).

Similarly, case 6 said that over the years he "paid 130,000 shekels (USD 40,000) in fines …and now there is a demolition order." His voice breaks in grief "…so I came today to demolish it myself so that I do not get another fine. On this basis, I destroy with my hands" (JMedia 2021). Also, case 7 has paid USD 13,000 in fines for building without a permit to the Municipality in addition to large fees to lawyers to defend the case in Israeli courts but to no avail (Maydan Al-Quds July 13, 2021). He was also, threatened by the Municipality that he would have to pay USD 60,000 coving costs of the demolition process if he did not demolish his home himself (Abu Mualla, Al-Quds Al-Arabi, 13 July, 2021). Case 9 has been paying enormous fines of their two homes since being built in 2013 (Ammouri, Anadolu Agency 2020).

Palestinians building without permits in Jerusalem become entrapped in an Israeli imposed system incurring a series of fines and fees hoping to protect their homes from demolition, most often without success. So, this system of monetary extraction by the Israeli Authorities can go on for many years and still end in demolition, with additional fines and imprisonment. All these measures only exacerbate the dire conditions of Palestinians who are already trying to sustain a bare, yet steadfast, existence in the city even if it pushes them into poverty and all that comes with it in social and economic hardship.

4. Discussion and Conclusion

Self-demolition is an unprecedented and most violent form of domicide. It encompasses a compound injustice that affects the physical existence and the well-being of the victims as a result of the home loss and the spirit and morale of the victims who are compelled to undo a life's work of sacrifice and savings. It signifies an advanced form of colonial practices in that it impacts the victims by depleting their fianancial resources and saving as well as their efforts over years of time. The financial aspect puts them in heavy debt after depleting their earnings and savings to build to live in Jerusalem. Their years of hard work are destroyed before their eyes with the added trauma of having been forced by Israeli authorities to self-demolish at the threat of incuring more debt and imprisonment. These factors whether separate or combined are detremental to the victims' prospects of sustaining their existence in the city. The objectives of the Israeli imposed self-demolition policy upon the Palestinians in Jerusalem are: to displace the Palestinians of Jerusalem in order to achieve a Jewish majority in the city, and for publicity to appear that Palestinians are demolishing their homes by themselves as an alleged "admission of guilt". Also, the Israeli Authorities can spin publicity to attempt to absolve them from the human rights violations against the Palestinians in Occupied East Jerusalem particularly displacement and house demolitions. Given that over 100,000 Jerusalemites – almost a quarter of the Palestinians in the city - are threatened with displacement from such colonial measures whether house demolition and self-demolition as a result of inability to obtain Israeli issued building permits, this jeoperdizes Palestinian social sustainability considerably.

On an operational level, Palestinians' demolition of their own homes saves the Israeli authorities from having to do it themselves with all that this entails during implementation. Furthermore, by generally delaying the self-demolition orders, the Israeli authorities are able to extract from the Palestinian families' revenue through fines in the tens of thousands of shekels from each family. Furthermore, the self-demolition policy leaves traumatic psychological effects on the targeted Palestinian families. In this sense, the Israeli Authorities seem to be applying Jones's notion, attempting to destroying the Palestinian self by having them destroy their own Palestinian homes, property, life-long dreams, and hopes.

Hence, the case of domicide in Jerusalem provides new meanings about severance of home as a place for dwelling. It is a double and compounded trauma because all what was sacrificed was laid to ruin in order to avoid additional economic dependency as a result of fines, and damaging other existing structures if the demolition is occurring in a multi-storey building. The whole process generates a chronic trauma as the victims and their families break up the sense of home security, stable continuity of as somewhat structured everyday life, being able to be oneself, of having privacy in a sheltered place – all of which provide a sense of home. Adding injury to this injury is the feeling of loss and uncertainty compounded by the unjust violent colonial actions of the Israeli state aimed at, to the extent possible and in various forms, bring down and remove Palestinian existence in Jerusalem, replacing them with settler colonizers. Thus, all this is suffered by Palestinians in Jerusalem in order to continue to live in the city and not to be succumbed to colonial practices but to salvage from demolition process by the Israeli apparatus which is normally rampant hazardous chaotic and sudden.

So, in self-demolition of homes in East Jerusalem therefore, the colonial practices become internalized by the victim so that the victim in turn goes through the torturous process of implementing these colonial policies through his or her own hands. On the individual and community levels, it destroys resources in the most unsustainable way whether on the spatial, social, psychological or economic levels. Social sustainablity of the victims is severly jeopadized. Development is slowed down and undercut as victims lose hard earned resources including financial, property and at times personal belongings. The time in several years the victims' spent trying to have a place to live in the city to fulfill Israeli regulations and all the energy to try to sustain such an existance, all these obstacles are set in the most painful ways. They not only severely jeopardize development, these measures and especially self-demoltion represents one of the many systematic ways of settler colonial de-development in a devastating way, making it extremely challenging for the Palestinian victims to recover morally and financially.

However, even though these colonial practices and policies are internalized so that the victim becomes an implementor, the dynamic of still showing and practicing steadfastness or Sumud to remain living in the city is outstanding. This, despite all the hardship that this systemic internalization of the colonial practice entails through domicide. This shall be further elaborated in an expanded paper.

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Appendix A

Selected cases of self-demolition of home in East Jerusalem, 2020-2021:

Case 1	Abu Rayyaleh family in Al-Esawiyyah neighborhood, March 2021.
Case 2	Hijazi family in Silwan, March 2021.
Case 3	Bashir family in Jabal Al-Mukabber, June 2021.
Case 4	Dajani family in Al-Tur neighborhood, July 2021.
Case 5	Abu Al-Hawa family in Al-Tur neighborhood, July 2021.
Case 6	Shqirat family in Salaa in Jabal Al-Mukabber neighborhood, July 2021.
Case 7	Nassar family in Wadi Qaddoum in Jabal Al-Mukabber, July 2021.
Case 8	Abu Ghannam family in Al-Tur neighborhood, July 2021.
Case 9	Abu Turki family in Jabal Al-Mukabber, July 2020.
Case 10	Khader family in Ashqariyah neighborhood in Beit Hanina, August 2021.
Case 11	Al-Dallal family in Beit Hanina August 2021.

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Indoor Air Quality Vulnerability Mapping of Urban Dwellings in Bangladesh

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Abstract: Unwanted summer, extreme heat waves and air pollution have created severe human health and well-being issues. For instance, in Bangladesh, these phenomena have been noticed, particularly between March to July. As opposed to the norm, the dwellings' indoor air quality (IAQ) tends to be unacceptable, resulting in a severe impact on human health. Current research identified that the number of heatstroke patients increases every year in the tropical region where the children and elderly are being affected severely. Besides the IAQ issue, local housing is responsible for the relatively high energy use through space cooling in the tropical region for ensuring indoor thermal comfort and air quality. IAQ enhancement in line with energy efficiency measures through passive design strategies is becoming a significant challenge in the housing sector. Thus, this study investigates the IAQ-related issues around typical urban apartment dwellings in Bangladesh's major cities as case studies. The transient data to monitor the levels of T_{VOC} (mg/m^3), $PM_{2.5}$ (µg/m^3), PM_{10} (µg/m^3), HCHO (mg/m^3), air temperature (ºC) as well as relative humidity (%) were collected using environmental data loggers. At the same time, a questionnaire survey related to occupants' socio-demographic profile, health and well-being was also conducted to grasp their living conditions. Finally, in line with the data analysis, a parametric simulation was conducted to develop a correlational vulnerability mapping between the collated IAQ results and the occupants' health and well-being circumstances.

Keywords: Indoor air quality; Heat stress vulnerability; dwelling; tropical climate

1. Introduction

Being one of the most challenging problems, air pollution has significant impacts on human health and well-being. Air pollution kills more than thousand people in Bangladesh each year. In recent times, Dhaka, one of the world's megacities, is facing a rapid growth of urban inhabitants [1]. Besides the extreme outdoor AT (summer: 32ºC<AT<42ºC), air pollution like carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), hydrocarbons (HC), ozone (O_3) and suspended particulate matter (SPM) in Dhaka city are testified as severely detrimental to the health and causes poor IEQ [1]. Previous studies have also identified that people living in polluted environments with foul air have a 23% increased risk of heart attack and a 40% increased risk of fatal heart attack [1] [2].

On the other hand, a survey report of Economist Intelligence Unit (EIU) associated with the UK-based weekly Economist shows that for the second consecutive time Dhaka has become 'the worst city to live in' [3-4]. In such a context, the impact of households IAQ on human health is becoming a crucial part of society. In Bangladesh, environmental pollution and excessive outdoor heat are causing severe hazards which are the most challenging nowadays [5]. The field monitoring also observed an adverse impact on most of dwellings in Dhaka, Bangladesh for extremely hot environments and poor IAQ without standard adaptive criteria. This study investigates the IAQ-related issues around the typical urban dwellings as case studies in the major cities of Bangladesh. Finally, in addition with the data analysis, a parametric simulation has been conducted to develop a correlation vulnerability mapping between the collated IAQ results and the occupants' health and well-being circumstances.

2. Study Methods

Environmental field monitoring of local urban dwellings by data loggers was conducted from June to December 2018 because of seasonal variation (summer to winter) based on the selections made against set criteria for IAQ evaluation. A comparison of environmental relationship was enabled between monitored and simulated data. Primarily, the field monitoring was conducted in middle portion of each floor of dwellings to record week-long IAQ data. Environmental Data loggers and Laser Non-Contact Thermometers were positioned at midpoint of two different heights which were between the floor's 750 mm (working plane height) to 3050 mm (minimum ceiling height). The indoor environment was monitored using a Temptop LKC-1000S+ Air Quality detector with $PM_{2.5}$/PM_{10}/AQI/Particles data logger. The outdoor temperature and humidity data were collected from the local weather station provided by the Met Office, Bangladesh. The approved index according to the Department of Environment (DoE), Bangladesh has been given below [6] (Table 1):

Table 1. Approved AQI for Bangladesh

Air quality index (AQI) Range	Category In English	Color
0-50	Good	Green
51-100	Moderate	Yellow Green
101-150	Caution	Yellow
151-200	Unhealthy	Orange
201-300	Very Unhealthy	Red
301-500	Extremely Unhealthy	Purple

Table 2. Description of surveyed dwelling typologies

Type	Floor	Construction Materials
Apartment 1	Six-storey	Brick walls and roof from the reinforced concrete slab
Apartment 2	Six-storey	Brick walls and roof from the reinforced concrete slab
Apartment 3	Ten-storey	Walls brick and glass combination and roof from the reinforced concrete slab
Apartment 4	Ten-storey	Walls brick and glass combination and roof from the reinforced concrete slab
Apartment 5	Twelve-storey	Walls brick and glass combination and roof from the reinforced concrete slab
Pucca	Three-storey	Brick walls and roof from the reinforced concrete slab
Semi Pucca	One-storey	Wall and roof constructed from temporary materials such as corrugated sheet, bamboo etc.

A better undesrstanding can be achieved through a qualitative approach that includes occupants' indoor environmental quality experiences in the residences. It can also be useful for developing a housing design guideline for better IAQ. A questionnaire survey was conducted among around 200 users based on their socio-demographic and health symptoms scenario in this approach. These questions (checklist) were developed on the topic of IAQ based on international guidelines, including 'closed' and 'open' questions [7]. For instance, closed queries comprised "*Do you have any health conditions or symptoms that may raise susceptibility to environmental problems?*" and open questions included "*In which room or rooms do these symptoms usually occur and why?*" Questions have also been asked to expand knowledge about the occupants' behavior, such as "*Do you frequently dry clean clothing or household furnishings?*" and "*Do home occupants have hobbies that create dust?*" Users were also asked about their economic status and income level, level of education, family member, monthly expenditure, age, gender, sex, etc. In these questionnaires, no one was required to mention their name or identity to provide information without hesitation.

In conclusion, occupants were allowed to suggest design or change strategies that would improve their dwelling conditions. The survey was conducted in Bengali among the focus groups. Also, notes were taken accordingly for coding and analysis. It may be noted that for data collection, any kind of influence was not formulated. User's age and sex also had a unique role in data collection. In that case, anyone under 18 years was not allowed to fill the question papers. Complete freedom has been given to all users for answering the questions. However, in particular cases, only a few ideas about the issues related to the households were given so that users could answer correctly. The question paper has been divided into two categories.

In the first part, the questions were raised about the socio-demographic scenario for household users. In this case, the questions of age, sex, marital status, employment, and workplace have been asked to the users. Later, users were asked to answer their educational qualifications, number of family members and monthly income. Since no one was required to write their names on the question paper, everyone could provide their information correctly without any hesitation. Even users have been asked about the current status of the house they live in, the house-changing information, the type of house, construction materials, the period of construction and how long they have been living in that house (Table 2). The lowest four answer typologies were given to the users as multiple choice in response to each question. So, everyone provided the appropriate answer to them. In this study, the middle and upper middle class income group were the priority. According to the socio-economic aspect of Bangladesh [8], household users of these income groups have been considered as a probable focus for buying a city-based apartment or staying in a rented houses.

In the second part of the questionnaire, the household users were asked about their health symptoms due to the environmental conditions of their dwellings. Example of the types of questions are described below.

The first question was about the type of health symptoms that have been occurred due to environmental reasons. Such as cold, weakness, hair loss, allergies, diabetes, respiratory problems, headache, blood pressure, eye problems, etc. If they face any of the issues mentioned above, they were usually asked 'which places', such as in the bedroom, drawing room, kitchen, etc. It was also asked the users where they typically stay for the longest period of the day in their houses. In the next part, the question was asked to find out about the location's surroundings or the building. Is there is any garbage or car parking area attached to the residence? Whether there is a pet in the house or if someone living in the house has some symptoms that can damage indoor environment. It has also been asked if any furniture has been changed in last three months in this living place. It has been asked which type of oven is being used in the kitchen area, how much cooking time is required and whether there is any system to release the indoor air from the kitchen to outside. If aerosol is often used in the house, what about ventilation system of the rooms and what is their locations. Also, it was asked if there is any environmental comfort feeling such as hot or cold in the house. In that case, ASHRAE 6 scale comfort code has been considered [9].

Moreover, they were also asked whether any odor is felt in their houses or if there is any leakage on the roof. Mold growth scenario has also been emphasized. Finally, they were asked about their preference for changes in their dwellings. All the things in this question paper might not be included, so their suggestions have been given priority.

3. Household Pattern in Bangladesh

Bangladesh is known as one of the most densely populated countries of the world. Although poverty is widespread and bottomless here, population growth has been reduced in recent years and improved health and education. According to the Bangladesh Bureau of Statistics (BBS), the per capita income in Bangladesh has risen from $1,190 to $1,314 in 2015 [10]. The literacy rate of Bangladesh has been raised. According to UNESCO Bangladesh, the adult literacy rate of Bangladesh is about 72.76% where the literacy rate for males is about 75.62%, and for females, it is 69.9%. About 44% of the country's urban population lives particularly in Dhaka city. In cities, they generally live in apartments. As per the Consumer Association of Bangladesh (CAB), the living cost for the residents of Dhaka city is continuously increasing since past ten years where around 35% to 50% or more of the total income of a person is spent to pay the house rent. Dhaka is the most populated city in Bangladesh and one of the most populated cities of the world. In 2016, The estimated population of Greater Dhaka was over 18 million, whereas the city itself has 8.5 million of people. It has been noted that about 44% of the total population of Bangladesh lives in the megacities due to having a vast range of work opportunities. According to the calculation, every day, about 3.5 million people move only to Dhaka city in any way for daily work. The middle-income group prefers to live in the typical apartments with average quality of standard.

Generally, the size of the urban families is getting smaller day by day. In such a family, there are 6-7 people including husband-wife with their parents and two children. This number is associated with the monthly income and expenditure of the family. However, in most cities, family members are no more than 4-5 nos. In addition, their residences contain one master bedroom, one childbed and one guest bed in the house they live.

The whole house is divided into three parts: Public, semi-public and private zones. One attached toilet with the master bedroom and a common bathroom genially serves their requirements. In many cases, they need to arrange a single bed temporarily in their drawing room's corner to solve the space problem. The kitchen is usually attached to the dining space.

Figure 1. Household activities in a typical apartment building

There is a window for air circulation on the west or east side of the kitchen. Shortage of daylight is often faced in the dining space. These types of houses are usually sized between 850-1250 square feet (area). According to the Consumer Association, Bangladesh (CAB) [11], these households have the highest monthly expenditure on food (about 47.69%) and the cost of living (house rent) which is approximately 12.43% of their total income. Except for health, clothing and medical care, about 10% of their total income is spent on home management and home-based activities. The estimated minimum cost for a middle-income family varies between 15,000-22,000 BDT. Therefore, they can't switch into an air-conditioning system or any other significant changes in their houses at any time.

4. Results and Discussions

4.1 Socio-Demographic analysis

This survey has been conducted among 200 households families, located in the urban areas of different cities in Bangladesh. Almost all the surveyed participants age between 25 and 40. The ratio of female and male participants in the survey was about 60% and 40%. It has been found that participants having an education up to college level, have a higher monthly income and expenditures (Fig. 1 and Fig. 2) which is more than others. In that case, their monthly income is up to 60,000-70,000 BDT and up to 85% of them live in an apartment in the city center. According to their information, they do not want any significant changes in their houses for a better indoor environment. About 55% of them have their apartments. Due to this reason, their monthly expenditure is lower than those who live in rented houses.

On the other hand, the survey shows that people with a monthly income range between 30,000-40,000BDT usually spend 20,000-25,000 BDT as their monthly expenditure. About 40% of them live in flats/apartments and the rest reside in detached and semi-detached houses in the city (Fig. 3). It has been identified that reduction of the monthly expenditure is the main reason for living there. On the other hand, 80% of the people with monthly income below 20,000 BDT live in an isolated house called `Chapra.' In that case, they are choosing to live outside the city rather than the main town. They prioritized the places with easy accessibility to the city's heart with minimum expenditure. The educational qualification of these families is up to school level. The survey identified that around 90% of the living homesteads are aged between 10-20 and the users has been living there for approximately 5-6 years. According to the survey, about 70% of the participants reported that their family members are 4-5.

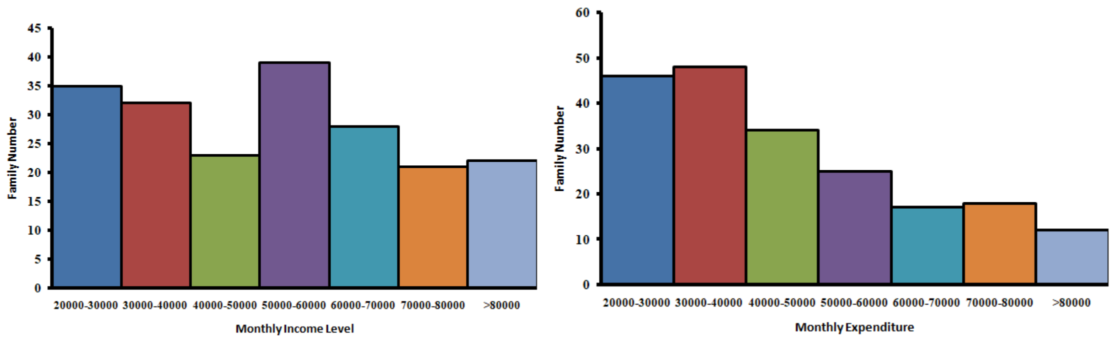


Figure 2. Comparison of monthly income and expenditure

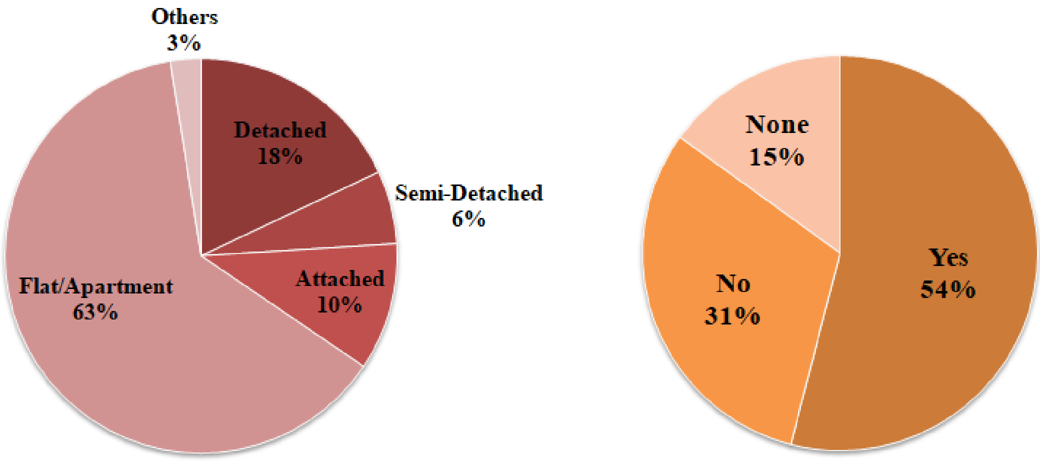


Figure 3. Comparison of building typologies and additional space requirement scenario

4.2 Health symptoms analysis

The survey found that 50 out of two hundred users suffer from nausea diseases, cold and cough (Fig. 4). The data suggest the major part of the population living in these houses suffer from eye irritation caused by lack of sunlight throughout the day. Weakness, headache, increased blood pressure and even hair loss are the frequent health symptoms for the dwellers. In most cases, these problems are act severe at night time. Of all the surveyed people, 36% mentioned that their health problems are usually more noticeable in the bedroom (Fig. 4). 26% of user data provided the information about their health problems in the kitchen.

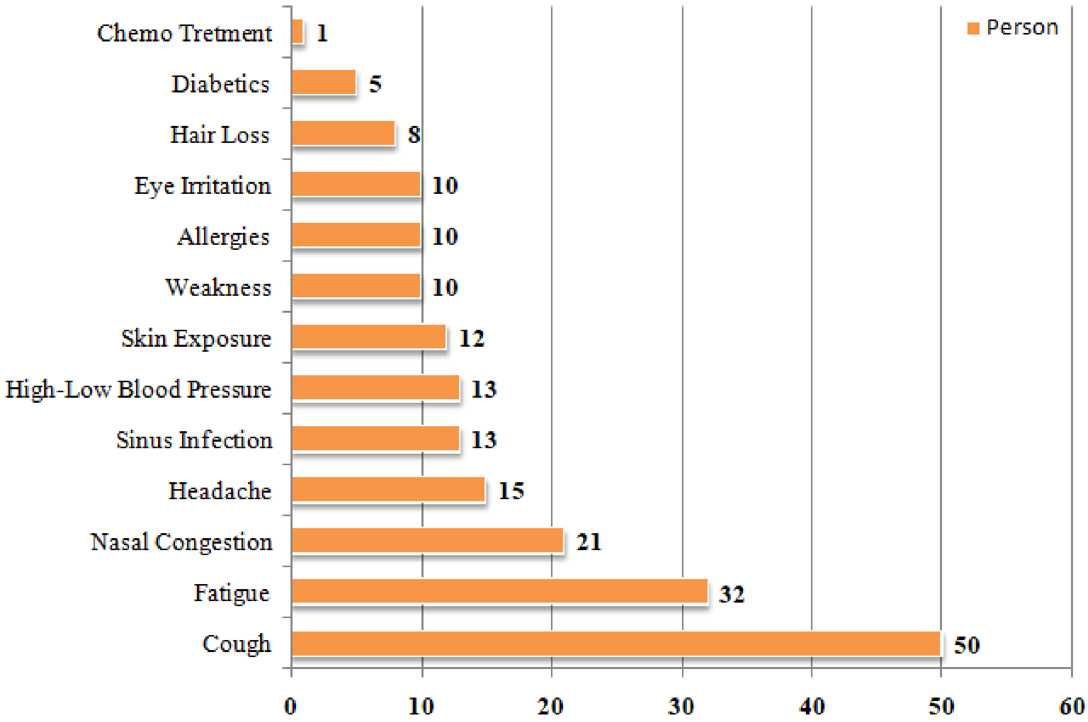
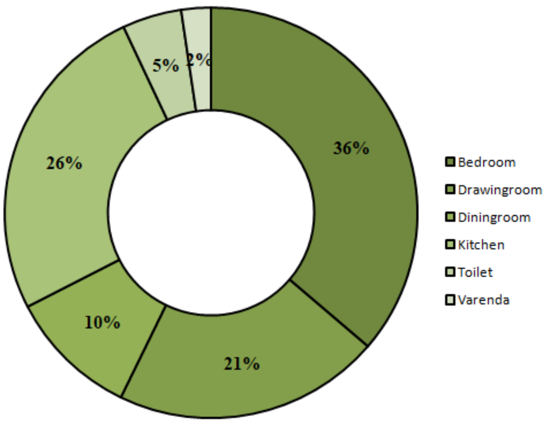


Figure 4. Health symptom scenario



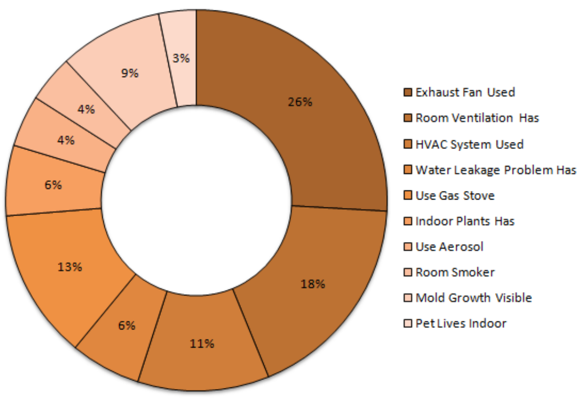


Figure 5. Health symptom occurs scenario

Figure 6. Comparison of indoor conditions

It was found that about 11% of the families use air-conditioning systems in their bedrooms to control the indoor air quality. About 26% of them use exhaust fans every day in their kitchen and 18% of the families have planned room ventilation. Those who use gas stoves for cooking (about 13%)

mentioned that they require adequate room ventilation during their cooking. Otherwise, the house gets covered with smoke that causes difficulty in breathing (Fig. 5-6).

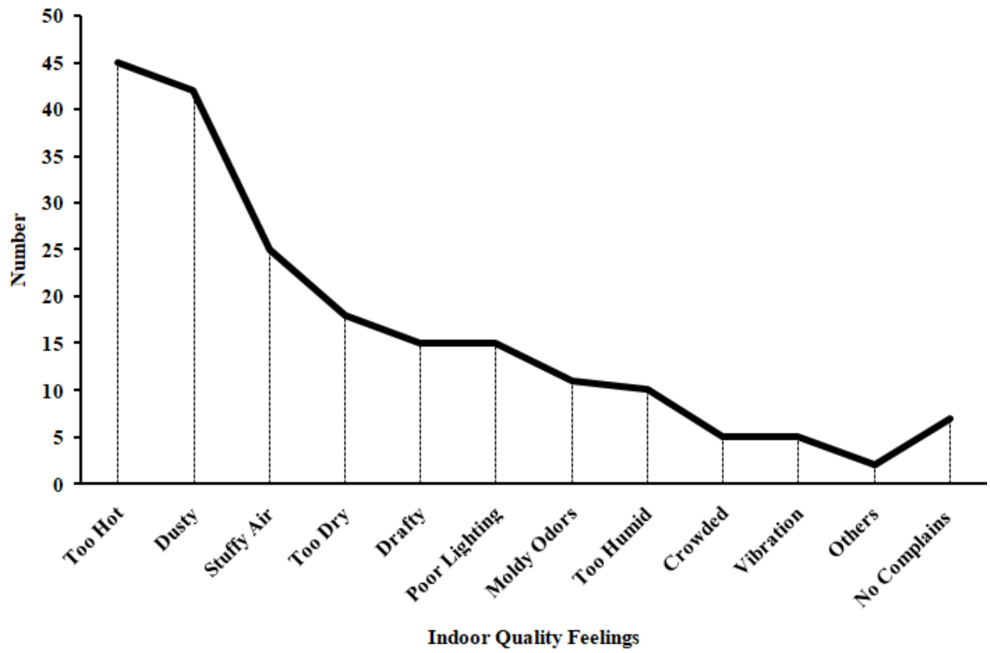


Figure 7. Comparison of indoor quality feelings of dwellers

Common phenomenon observed from the questionnaire survey are dusty and stuffy air, dryness and low daylight, which most users know (Fig. 7). About 40-45% of users informed that it is hot and dusty inside their houses. According to their information, those who smoke in the room, dry clean or have pets tend to suffer more due to allergic problems. In this case, about 12% of users mentioned about their skin problems throughout the year. But in their opinion, they have different kinds of health issues during the summer season in their houses.

5. Monitored Indoor Air Quality

In this study, TEMTOP LKC-1000S+ air quality detector has been used for measuring $PM_{2.5}/PM_{10}$ as well as air quality index (AQI). Through the data monitoring of a single-family urban dwelling for a week, it was observed that AQI fractions on average indoor are considerably higher (almost 3-4 times) than the usual range as per the Department of Environment (DoE), Bangladesh (Fig. 8).

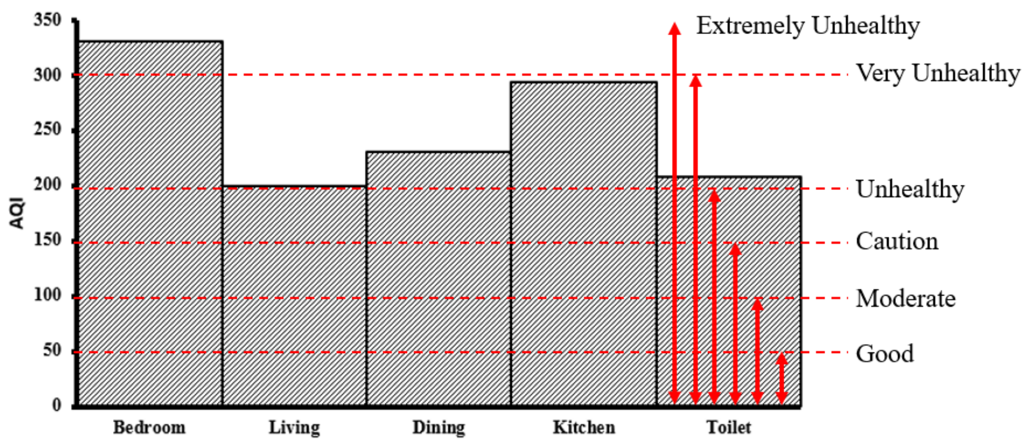


Figure 8. AQI comparison of different spaces

This analysis has monitored the highest IAQ range for the bedroom, about AQI>330, which indicated 'Extremely Unhealthy' condition for the dwellers. In that case, respiratory illness can be caused to the people with continued exposure. The effect can be severely distinct among the people with a lung condition or heart disease. It was also observed that while cooking, the indoor air quality in the kitchen noticeably decreased within 15-20 min. The data monitoring average range observed for the cooking period AQI>250 showed a 'Very Unhealthy' environment for the occupants. It can result into several health impacts such as discomfort in breathing on extended exposure and distress in heart disease. As the dining space was attached to the kitchen, AQI>200 was found which may cause discomfort in breathing. People with asthma, lung and heart disease, children and older adults are likely to be affected more.

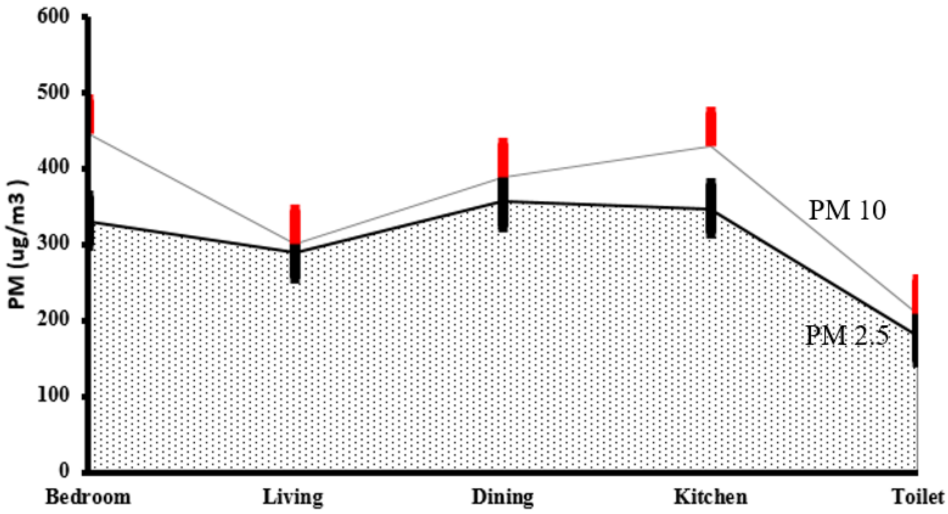


Figure 9. PM comparison of different spaces

The findings from the air particle (PM) that has been collected from diverse locations of the particular dwelling, shows that (Fig. 9) around 60-75% of the $PM_{2.5}$ and PM_{10} mass (based on house location) remained considerably higher than the Bangladesh National Ambient Air Quality Standard (BNAAQS). The Bangladesh National Ambient Air Quality Standard (BNAAQS) for annual average $PM_{2.5}$ is 15 μg/m^3 whereas the 24 hr standard is65μg/m^{3}and from the data monitor found max 350μg/m^3. On the other hand, PM_{10} is 50 μg/m^3 where the 24 hr standard was min 150μg/m^3 and found max 430μg/m^3 from the monitoring. Both $PM_{2.5}$ and PM_{10} fractions are observed to be significantly higher (almost 3-4 times) than the BNAAQS values [12] due to outside dust, kitchen smoke, lack of proper ventilation, indoor materials, etc.

6. Whole Year Prediction

EnergyPlus (Version 8.1.0), a dynamic computer simulation program developed by the U.S. Department of Energy [13]. for the whole year parametric study, integrated with Google Sketch-Up (version 8), the Open Studio Plug-in 1.3.0 have been used. For further accuracy, the simulated energy model of the dwelling is modeled as per one of the surveyed dwellings. The simulated result could be easily compared to the existing condition prior to the predicted simulations.

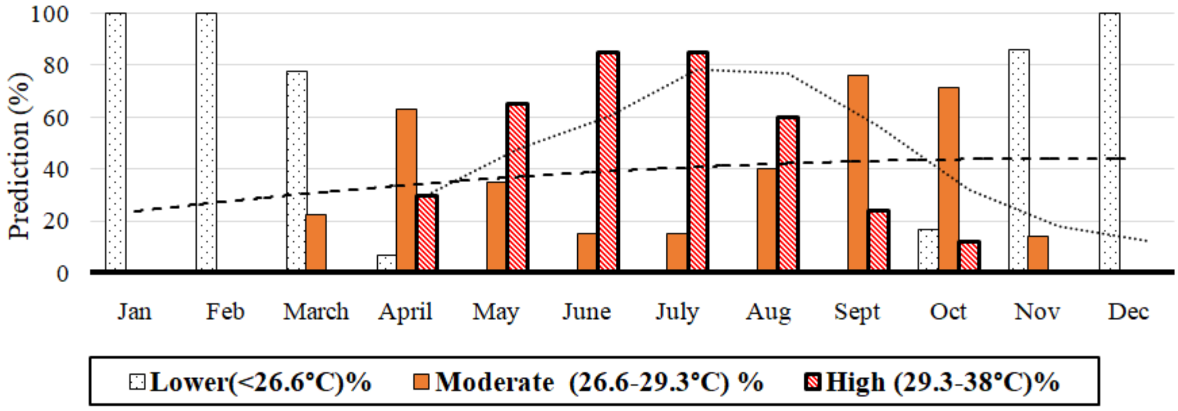


Figure 10. Whole year prediction of IAQ

From the analysis and annual simulations of indoor AT (°C) along with the risk factor criteria, the observed high risk value remained around 80% in higher conditions. The riskiest indoor environment was observed during the summer (June-July) with an average of 34-36°C where the lower level was approximately 18°C in December-February (winter). From the prediction, it has also been discovered that an average of 35-40% indoor times became extremely high during April to July (nearly 38°C), leading to a very high-risk factor level for the dwellers. Moreover, from the annual analysis, nearly 36-40% condition appeared as the moderate state and minimum 22-25% condition was characterized as very high-risk level for dwellers in the particular dwelling (Fig. 10).

7. Design Requirement

At the end of the survey, it was asked what modifications they required to improve their houses with a better IEQ. According to their data (Fig. 11), about 85% of people think proper cross-ventilation in houses may solve most problems. It will ensure continuous air circulation that will help the houses to remain cool and fresh.

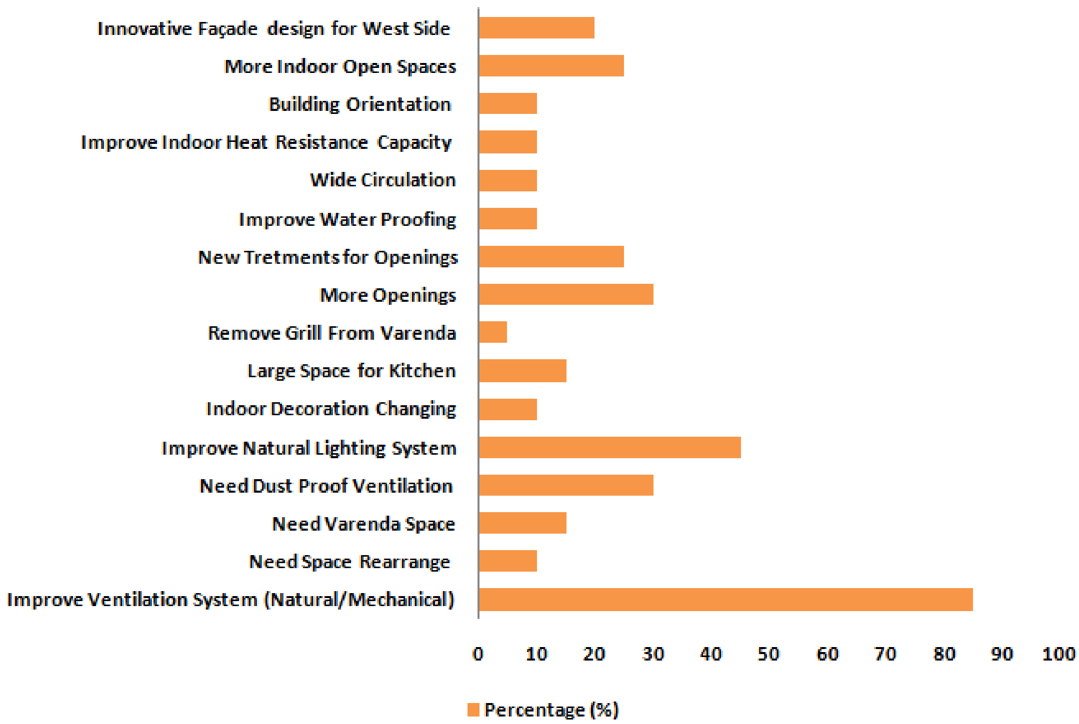


Figure 11. Design requirement comparison

Natural ventilation may be the best option to get. If it is impossible to get ventilation by natural means, it can be done in artificial ways. About 35% of people think about dust-proof natural ventilation systems where the external dust cannot come in. In addition, 48% of users believe that proper daylight is essential for good IEQ. About 30-40% of users feel that it is better if there are open or large windows in the house. Many users think that designers should think carefully about building's outer façade of the west side where the sunlight directly hits during daytime.

8. Conclusion

This study aimed to collect evidence of the IAQ of urban typical households in Bangladesh through environmental monitoring, questionnaire survey and prediction by simulations carried out among the focus groups. The key findings have been given below:

a) The survey found that most of the household's users suffer from various health symptoms like cold, cough, nausea, etc., throughout the whole year. In most cases, these problems are more significant at night time and these problems are usually more noticeable in the bedroom.
b) Average indoor AQI fractions were found, 3-4 times higher (>300) than the normal range and the highest AQI range was found in the bedroom within the scope of 300-400, which indicated as 'Extremely Unhealthy' condition for the dwellers. It was also observed that in the kitchen, IAQ became very unhealthy within 15-20 min, which indicated AQI>250-300 in range. It might result into respiratory illness and heart diseases to the dwellers on continued exposure.
c) It has also been found that about 60-75% of the $PM_{2.5}$ and PM_{10} mass was remained considerably higher than the BNAAQS standard.
d) The prediction identified that 35-40% IAQ became very high (near about 38°C) from April to July, leading to a high level of health risk factors for the dwellers.
e) It has been identified that the lack of proper natural dust-free cross ventilation is the main problem for poor IAQ.

Some of the dwellers' characteristics include several variables and design parameters that has not been completely captured. Outdoor air quality, indoor climate parameters, insulations factors, HVAC system, and energy consumption have the probability of affecting IAQ concentrations and reducing health risk. [14-16]. The understanding of experimental investigations and data monitoring for IAQ of typical urban dwellings concerning AQI, $PM_{2.5}$, PM_{10}, AT and RH has been needed for further analysis to significantly improve occupants' comfort and health risks by residing in typical dwellings in Bangladesh.

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Shipping Container Housing for Architectural Resilience in Coastal Regions: Addressing Construction and Material Sustainability

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Abstract: The coastal zone of Bangladesh covering 47,211 square kilometers confronting the Bay of Bengal or have close contact with the Bay. Around 35 million individuals, representing 29% of the populace, live in the waterfront zone. The purpose of this research is to address the housing difficulties of coastal areas and investigating the potentialities of shipping-container-housing as a sustainable solution regarding construction and materiality. The arrangement of upcycled shipping containers has created waves for a long time now because of their inborn quality, measured development, and simplicity. They are resilient, stackable development components, with decreased development time, cost, and waste. Shipping-container-architecture has been acknowledged as more eco-accommodating relative to the utilization of other custom structure materials with concentrated carbon impression. The overall study is distributed in two phases. The first phase deals with the rationalization of resilient shipping-container-housing and the second phase deals with the design experiment. The first phase of the study has been established and justified through literature synthesis. Contrariwise, the design phase has been established through a hypothetical design for the fishermen community located in Kattoli, Chattogram, Bangladesh. The investigation expressed that the re-use of the mentioned structure results in a significant reduction in epitomized vitality in comparison with ordinary structures. It is further expected that the findings of this research would inspire architects' engineers, and researchers to enhance the practice of engaging shipping containers in the coastal area as a sustainable building material, which in turn would be applicable to all the areas with similar contexts worldwide.

Keywords: Container-housing-construction, Upcycling, Sustainability, Coastal region, Resiliency

1. Introduction

Bangladesh is inclined to various normal limits because of its geographic position [1] where the coastal zone holds one-third of the population facing different difficulties [2]. This nation is particularly defenseless to tropical disasters with carrying around 718,000 passing's in the ongoing recent 50 years [3]. As a result, it can be assumed the overall significance of coastal area regarding architectural resiliency. This study refers to the building of a resilient architecture to react to common and synthetic disasters and aggravations- as well as hauling changes because of environmental diversities including the reasonable issues in coastal areas. It was reported that numerous individuals constructed homes with upcycled shipping containers since they are viewed as more eco-accommodating than customary structure materials [4]. Customary materials include brick, concrete, tin, or the combination of two.

1.1 Aims and Objectives

This research expects to enable the appreciation of the positive outcomes of shipping container housing to achieve architectural resiliency in coastal areas of Bangladesh and similar contexts as well.

The specific objectives of the study are; i) Addressing the problem of coastal areas in Bangladesh, ii) Potentialities of container housing as a sustainable solution for architectural resilience in coastal areas of Bangladesh, iii) Exploring the container housing design and construction regarding the coastal area housing standards and resiliency demands. The first two objectives require literature review, physical survey, and case studies. The third objective will be achieved through site survey, analysis, and the proposed design.

1.2 Formulation of work process

After addressing the research problem and realizing the potentialities of container housing through literature study and physical survey, the necessities of coastal area housing were recognized. Furthermore, a study was conducted to decide development technique, ease, and convenient highlights. The paradigms of shipping container housing and the achievement related to the resiliency through the shipping container housing were approached to find various ways to achieve sustainability along with architectural creativity (Figure. 1)

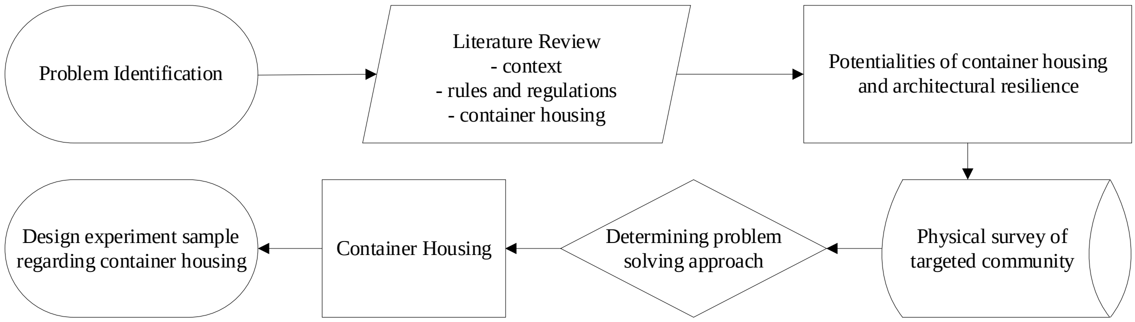


Figure 1. Broad methodology of the study.

The strategy of the investigation plans to result from an advanced adaptation of the container housing module dependent on natural viewpoints and described by innovative and technological excellence. In particular, the consequences of these exploration measures were breaking down to decide the last plan procedure for the proposed model module. Consecutively, the cycle includes the identification of the fundamental issues concerning housing esteemed through literature synthesis which thusly distinguishes the potentialities of container housing in regards to architectural flexibility. With acquiring direct data from the targeted community about relevant issues, a choice of problem-solving approach has been resolved. The proposed module depends on the type of manufactured components, presented underneath and with the design based on the characterization proposed by the groups through frequent discussions.

2. Literature Synthesis

A concise brief about the coastal area's significance and major properties of shipping containers have discussed (Figure. 2). Additionally, the synthesis incorporates the reason of container housing being a sustainable way in architectural design at coastal regions.

2.1 Importance of resiliency for coastal areas in Bangladesh

Coastal areas have additional danger hazard risk that evolves from tempests such as cyclones and expanded populace pressures, making flexibility and resilience especially basic in those areas. The coastal zone of Bangladesh covers more than 580 km and incorporates a region where 29% of the habitant's lives [5]. An investigation on the expense of adjusting to an outrageous climate assessed those 8,000,000 (eight million) individuals are as of now defenseless because of cyclonic storm surges which often leave the local communities devastated [6]. This numeric value will have an increment to 13.5 million individuals by 2050, and an additive nine million due to environmental change.

There is a dire need to restore and redesign insurance polders – regions of the low-lying area and upgrade the flexibility of seaside territories to twisters and other cataclysmic events. However, the versatile limit can be expanded through deliberate activity and thoughtful implications [7]. As the coastal zones face more natural hazards compared to urban areas, resiliency is a must to forestall a transient danger occasion from transforming into a drawn-out network-wide disaster. Along these lines, this tremendous coastal area needs broad management and comprehensive structure for a supportable and resilient turn of events, protection of coastal occupants' needs and to initiate necessary steps to ensure the safety of coastal communities [2].

2.2 Container Features

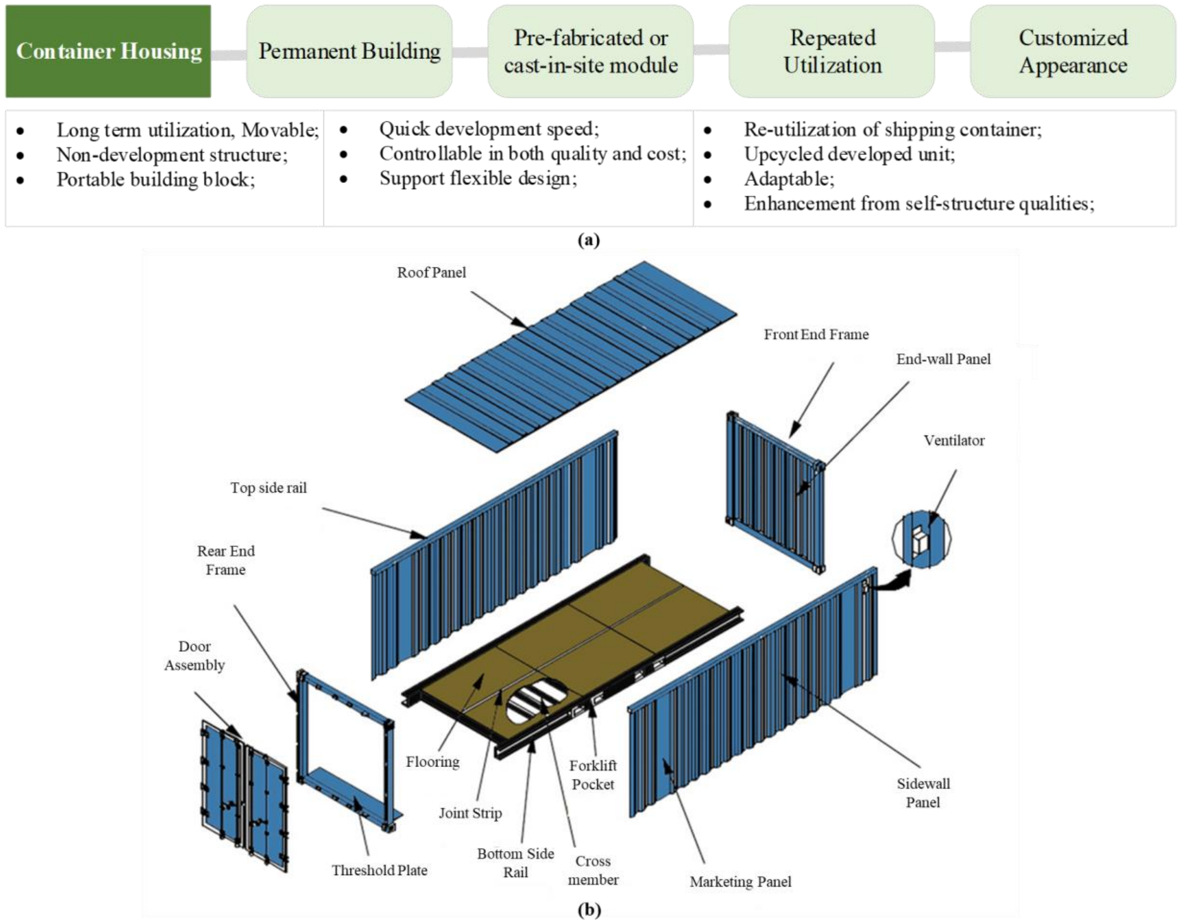


Figure 2. (a) Basic features of container housing (after, Copertaro, 2019); **(b)** Visualization of a shipping container (after, Obaidi, 2015).

Shipping containers are not used only for delivery items over the seas however can be changed into an excellent natural accommodation through utilizing upcycled shipping containers [8]. The shipping container has been intentionally designed with severe guidelines, not only to hinder the outrageous climatic conditions on ocean journeys, however, to withstand the stacking of 9 completely loaded containers [4]. The dimensions of a shipping container mean that they are an eminent secluded unit and their characteristic quality, weatherproof nature and availability make them an ideal particular basic segment or standard convenience unit [9]. In coastal areas, participation in natural calamities leads to the utmost experience [10]. To tackle these unwanted natural diversities and to reside in coastal areas alternatives to the housing settlement are essential. Upcycled shipping containers as a building material in coastal areas contribute to many architectural resilient components required for better accommodation [11]. Moreover, by reusing this module, there is clearly less interest in the brick, wood, concrete, and other structural materials resulting in the substantial reduction of embodied energy as opposed to traditional edifices. This accordingly brings down the complete exemplified vitality cost related to a home.

Shipping containers are eco-friendly as they are re-purposed into homes as opposed to being meltdown and it is 30% less expensive than an equivalent measured home built in brick or mortar [12]. Containers are "virtually indestructible" material and are designed to bear heavy loads, harsh climatic conditions, as well as rough seas. They can withstand wind pressure up to 289 km/hour when anchored properly [13]. Their structural stability results in houses of earthquake and cyclone resistance which makes them safer structures.

Shipping containers are potential in dropping construction time, cost, and surplus wastage due to its stackable nature of construction and more importantly numerous researches show that reprocessing containers for structures has an outcome of substantial reduction of embodied energy as opposed to traditional buildings [14]. Therefore, this paper explores a container housing design by upcycling, depicting a modular sustainable dwelling resolution in the coastal areas of Bangladesh.

3. Design Proposal

This phase of the paper would propose a container housing cluster module for architectural resilience through incorporating the potentialities of the shipping container and housing standards relevant to the coastal areas of Bangladesh. The framework is depicted as follows (Figure. 3).

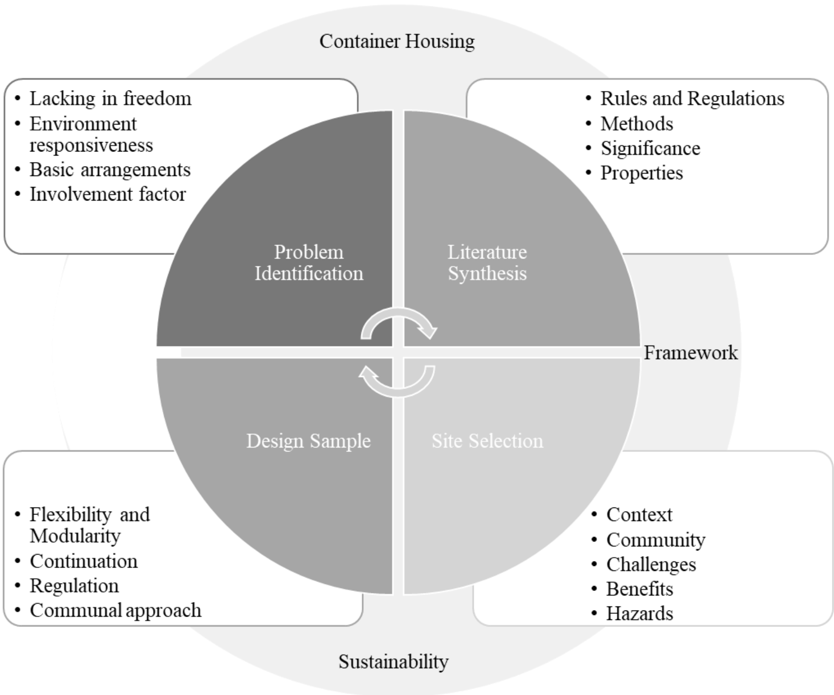


Figure 3. The design framework

3.1 Site Selection Criteria

The proposed site is located in Kattoli, Chattogram where the fishermen community (Jelepara) is residing here for more than a hundred years. The proposed site has the provision of ease of direct access surrounded by Kattoli coastline along with a mangrove forest and a dam at the west, open field at the north, agricultural lands at the south and Zahur-Ahmed-Cricket-Stadium at the east (Figure. 4). The fishermen of the community lead their livelihood through their daily fishing, they are supposed to go a long way relative to low tide and high tide schedule to attempt to their daily routine. So, the proposed site would be beneficial and time-saving for them. The coastal zone is occupied widely and progressively for shipment activities. Moreover, as a shipping business accelerates through Bay-of-Bengal and due to its close contact with Kattoli sea-shore the availability of shipping containers with reasonable prices has a great contribution as it is the prime element for shipments. These issues caused Kattoli to be chosen as the investigation territory for this examination.

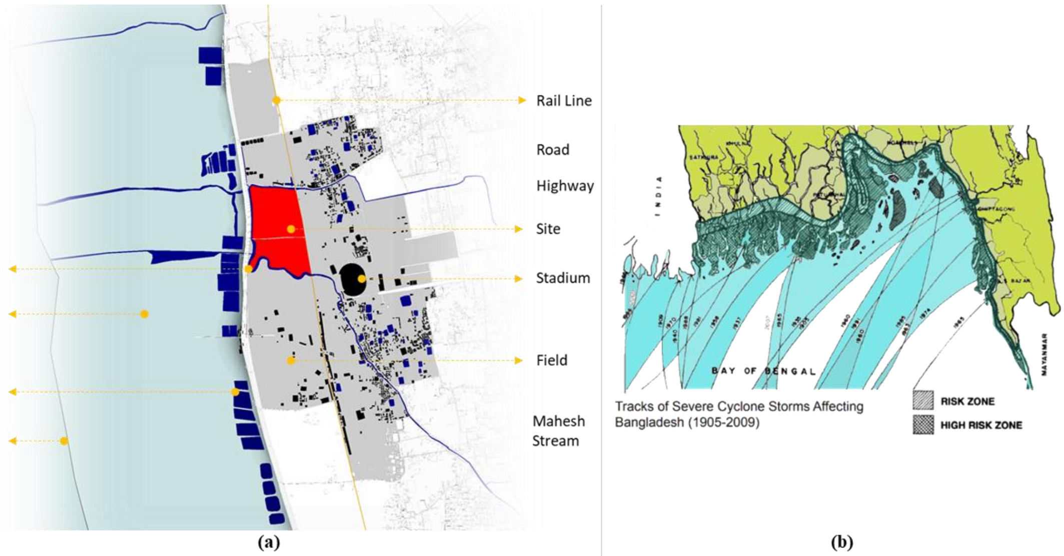


Figure 4. **(a)** Overview of the Study area; **(b)** Tracks of Cyclone Storms (Source: Haque, Tabassum, Aman, & Rahman, 2020).

3.2 Physical Survey

The survey was conducted physically to examine the livelihood, housing pattern, space use pattern, service, needs, vulnerability etc. in the selected area. The essential information was gathered through field study at a prime level utilizing a well basic survey. Information was gathered both by physical perception and meeting with fishermen at house, field, fishing spot and market. However, significant data on the state of anglers, site map, and climate were gathered from books, research articles, non-Government associations like as District Fisheries Office, and library.

3.2.1 Survey Findings

During the survey, it is observed that the housing structure is unstable, and poor space quality led to a chaotic environment and there is no dedicated community space and basic infrastructure of a standard housing thus leading to an inappropriate utilization and zoning of basic properties of the built environment. Vulnerability issues aroused due to the integration of poor building materials. (Figure. 5a-5g). Alternatively, it has been found out that there exists a tendency of using shipping containers 20′-0″ (in length) and 40′-0″ (in length) which is being assured as for portability and time management strategy. Moreover, the modularity aspects helped the user in case of pre-planning the functional requirements and needs as per module (Figure. 5k, Figure 5l). Coastal housing arrangements in Bangladesh as of now faces an assortment of issues identified with living condition, counting quality and amount livability issues, what's more, regulatory issues as ambiguous government guidelines with respect to housing development on the country's coastline.

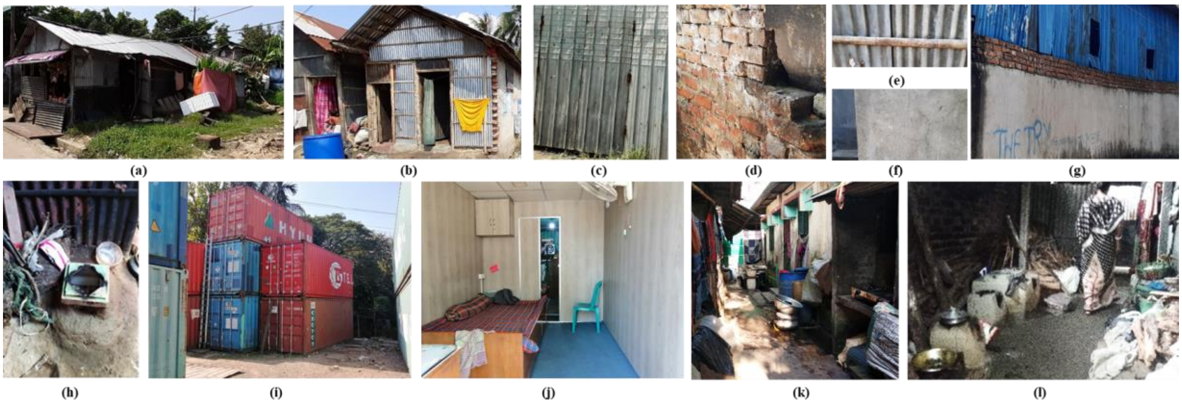
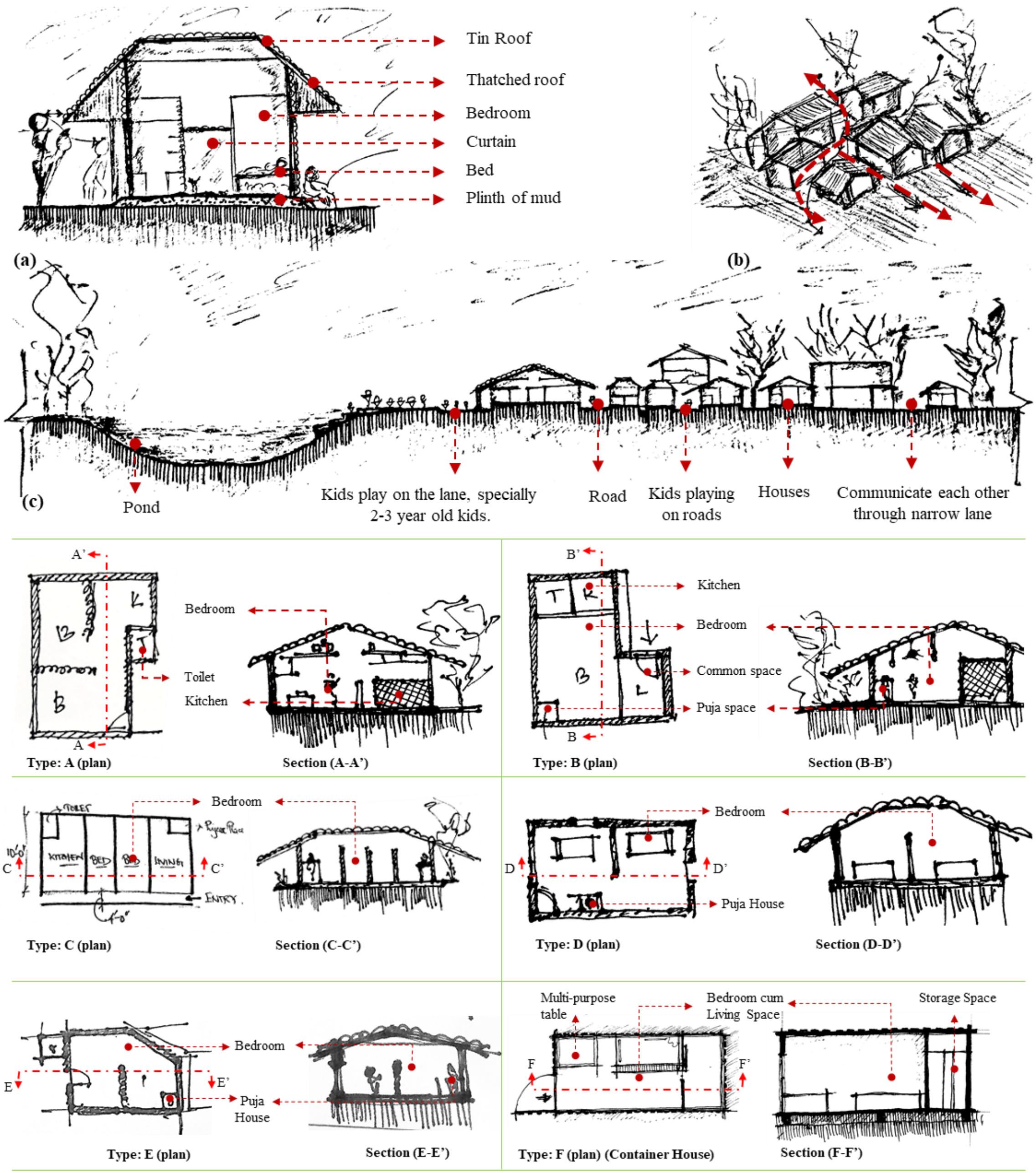


Figure 5. Housing Environment: **(a)** House Surrounding; **(b)** Poor condition of settlement; **(c)** Weathering tin; **(d)** Bricks; **(e)** Tin; **(f)** Concrete; **(g)** Brick, Tin and Concrete. Condition of service zones and settlements: **(h)** Poor kitchen facilities; **(i)** Shipping container vertical stacking system; **(j)** Shipping container settlement scenario; Communal activities: **(k)** Kitchen and settlement zone; **(l)** Communal kitchen scenario.

3.2.2 Existing House Types and Needs

Despite having an unplanned housing arrangement, numerous house types based on their function, size, orientation and multi-purpose spaces were found during the survey. The house functions contain the basic programs such as a single bedroom or double bedrooms partitioned through local curtains or made from straws, secondary kitchen corner, washroom, puja (worship) space, communal kitchen and toilet have been found identical (Figure. 5 and Figure. 6). The average size of the house varies between (100–300) square-feet incorporating the practice of different house orientations (Figure. 6). Alternatively, container house as a settlement hub has been encountered during the survey comprising of a regular (20′-0″) shipping container (20′-0″ x 8′-0″) which has been programmed as a living cum bedroom space (120 square feet) with storage (40 square- feet) (Figure. 6d). Moreover, from the overall physical study conducted, the following major needs were outlined.

- **Resilient Structures**- Need for flexible but strong settlements to survive in natural calamities and other dangers eliminating the process of relocation.
- **Communal Relationship**: Need of establishing community co-existing quality.
- **Essential endurance requirements:** Fresh drinking water, food, sanitation, electricity.
- **Privacy and Security-** Satisfactory privacy assurance, visual connectivity, security.
- **Self-completion**: Problem-solving qualities, inner potential and morality enhancement.



(d)

Figure. 6: Housing Arrangements: **(a)** Basic section of a typical house; **(b)** Axonometric view of the pattern and circulation; **(c)** Immediate setting of surroundings; **(d)** Six types of existing house patterns.

3.2.3 Coastal housing guidelines in Bangladesh

Climatologic and monetary thinking have consistently been a preeminent misgiving in any housing innovation being drilled explicitly among those gatherings of individuals who have been living right up-front relationship with nature for quite a long time. Nonetheless, the developing history of human settlement practice uncovers that natural variable have for some time been joined in human endurance and living innovation with extraordinary thought. During the time of normal catastrophes furthermore, ecological turmoil, it has essentially been seen that there is consistently a pattern of low causality among the customary house-inhabitants. There exist a set of traditional housing features and coastal housing guidelines in Bangladesh. For this study, the considered standards are the following:

"1) Security of residency is ensured for a set timeframe of in any event 30 years. 2) All housing is built with materials and techniques that allow easy maintenance, repair and duplication. 3) All housing and sites are adjusted to the neighborhood hazard profile to oppose intermittent disasters over 30 years. 4) All lodging offers an agreeable and sound inner atmosphere: □ Cross-ventilation is given by putting in any event 2 windows on inverse sides of the house in the primary room, also, in any event one extra window in each extra space; □ Windows are for the most part fitted with a framework for halfway or full blinding, in understanding with nearby practices. 5) All housing is adjusted to uncommon and explicit necessities of its occupants: □ 5 to 10% of the financial plan for the house is distributed to adjust standard house plans to the particular needs of singular family units (access incline, extra inner detachments, extra space or other) and takes into account the fluctuating needs of various individuals from a family unit (female and male, all things considered); □ This may likewise be spent nearby association, to be chosen in conversation with the person family. 6) All lodging is utilitarian, socially proper and versatile. 7) Allows the population to bridge the gap between the disaster and the opportunity to access a durable solution. 8) Consideration for emergency-situation responsive quick installation and dismantling processes. 9) Climate responsive design approach." [15-17].

4. Container Housing Module

The design structure procedure got started examining the data obtained from site analysis, physical survey, literature study, conventional logical viewpoint, user needs and from the knowledge of the researchers. The house plan was generated fusing the necessities and utilization of the potentials of shipping containers as demonstrated (Section 2.2) in order to offer the community a resilient solution towards their built environment. Housing rules and regulations of coastal region [15-16], standards, living pattern, longevity, privacy, aesthetics, resilience towards climatic issues, indoor-outdoor relationship were the main factors that were focused on while designing the proposal.

4.1 Design Generation

The module appeared in (Figure. 7) was intended for incorporating two families on the first floor which was accomplished by stacking up two upcycled shipping containers (two 40 feet shipping containers stacked upon four 20 feet shipping containers situated on the ground floor). The primary zoning portrays a centralized space for engaging the dwellers with several communal facilities as it was the notion of the fishermen community. Accordingly, it was accomplished by connecting communal dining and concealed spaces with other mutual supporting facilities. The centralized semi-outdoor space provides the enclosure through spaces and would assist with building indoor-outdoor relationships (Figure. 7b).

Moreover, the module is not only suitable according to its functionality but also can be transformed into an isolation unit during any pandemic situation (such as. COVID-19 pandemic) by representing each container as one unit or its portion. In addition, the centralized open space and the co-operative earning space can be transformed into a dealing zone where the dealers could visit to exchange goods. However, the stacked floors are connected by vertical circulation where the habitants living and resting alcoves were placed while finishing up with herb gardens and verandahs with a rooftop garden and other supporting facilities are located above (Figure. 7 and Figure. 8). In Bangladesh, three types of outdoor spaces prevail in design (in general)- interlocking, rectangular and square-shaped [18,21,22].

Figure 7. **(a)** Basic Form Generation; **(b)** Ground Floor Plan; **(c)** First Floor Plan; **(d)** Roof Terrace Plan; **(e)** Roof Plan.

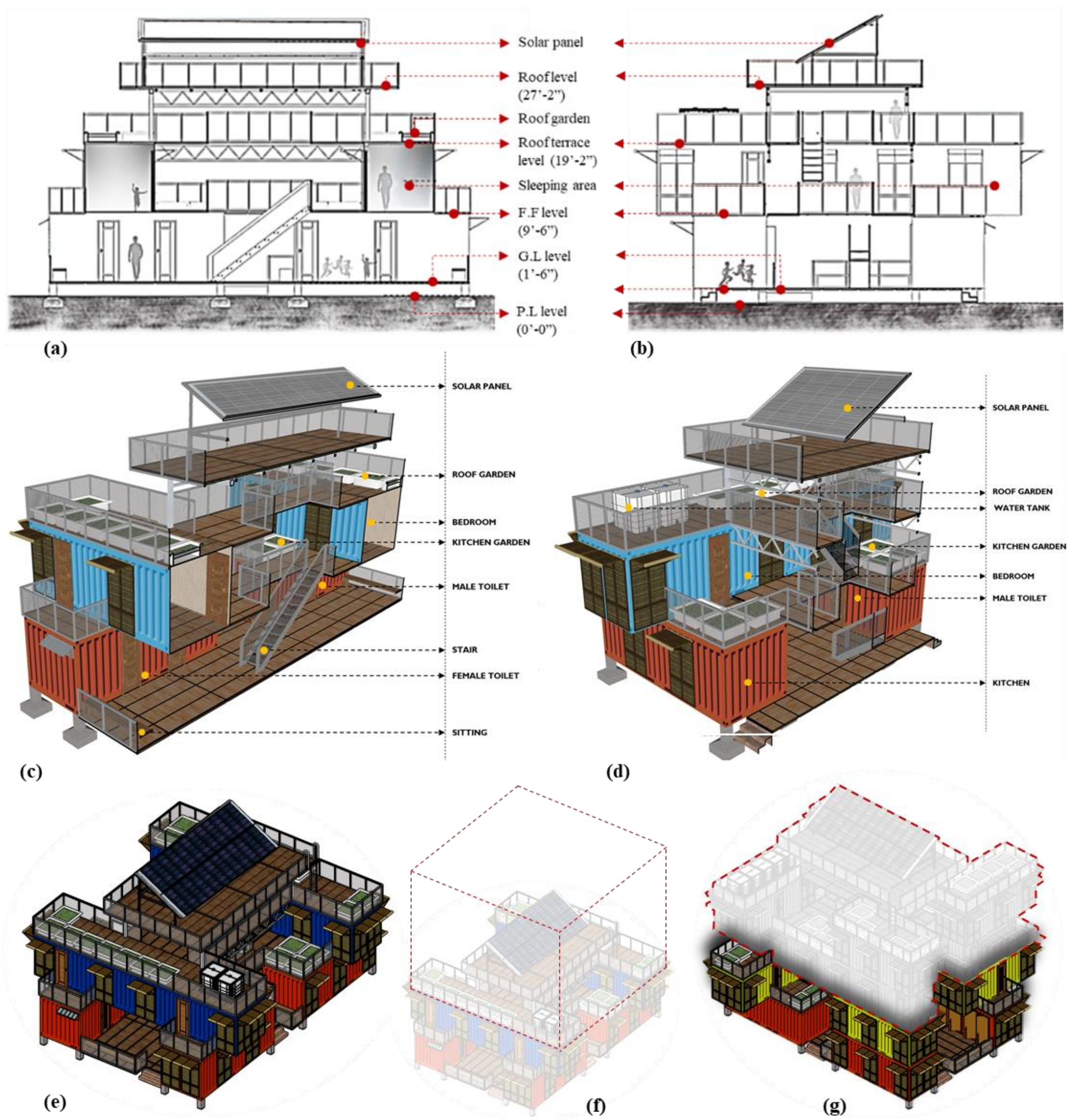


Figure 8. Architectural Sections: **(a)** Section A-A′; **(b)** Section B-B′. Axonometric visualization of sections: **(c)** Section A-A′; **(d)** Section B-B′; **(e)** Axonometric view of the sample; **(f)** Possibility of stacking vertically onwards; **(g)** Example of stacking procedure further as future extension.

Among all types, rectangular outdoor space was preferred based on the living pattern and lifestyle and prevailing practice of the community (Section 3.2.1). Moreover, the proportion of the space was dimensioned following up a standard rule; "length of the space cannot be greater than 3 times than its width" [18]. However, the shaded space can also be multi-purposed performing household chores such as fishing net repairing and so on. As mentioned in Shelter Cluster, 2018 the material used in construction should be stiff and load-bearing which should be anchored properly which is strictly followed in the design sample.

The ground floor plan (Figure 7b) demonstrates as, cooperative earning space (a1), communal dining space (a2), kitchen area (a3), male (a4) and female (a5) washroom, shaded enclosed space (a7) and seating (a8). The first-floor plan comprises of, sleeping areas (b1) with adjoining verandahs (b3), family living areas (b2), herb gardens (b4) close to the pathway (b5) and void to the ground area (b6) (Figure. 8a and Figure. 8b).

The orientation, openings, and landscape of the module were generated by considering the climate to catch the breeze and daylight. As the seaside zone is viewed, a consistent breeze wins from the zone into the landmass because of the distinctions in gaseous tension made by varying warmth limits of water and dry land [19]. As a result, openings at the west were highly considered as ocean breezes are more confined than prevailing winds. The shade of surrounded bamboo trees hinders the harsh summer sun, however, permits the glow of winter sun.

Additionally, it permits the wind to course through in the wake of cooling which goes into the house through wide-heightened operable windows, pushing out the warm air through the open space. The house lays on a plinth which in turn thusly handles the flash flood by incorporating its space under it (Figure. 8a and Figure. 8b). The visual connectivity from the plinth zone to the housetop can easily be visualized in terms of privacy, belongingness, inter-relationship and empathy. One of the potentialities of shipping containers alludes to its stacking is that the sample project represented can be inspired as far as stacking potentials through possible articulations of upcycled shipping containers.

The sample venture comprises six upcycled shipping containers (Figure. 8c). Four 20-feet (in length) shipping containers arranged beneath the upper two 40-feet (in length) habitant spaces. In the same way (i.e., lifting and stacking the units like 'Lego' squares) the sample module has the possibility of stacking vertically further to add some spaces to the initial capacities according to the requirements (Figure. 8e and Figure. 8g).

4.2 Technical Construction Details

Construction techniques are considered as the imperative stage relative to shipping container housing. The basic chunk of details and as well as other structural components got represented in (Figure. 9a-9f) depicts diverse components of the slab used as a plinth or floor section.

- **Structural Slab**- The overall structural slab comprises compressed bamboo, basic structural post, block step and footing. (Figure. 9a).
- **Plank support**- Recycled built-in compressed bamboo planks are utilized to frame the base of the structure (Figure. 9b).
- **Vertical Support**- Built-in steel structural post (3″ x 3″) shipping container is utilized as the vertical member to hold up slabs and additional backings (Figure. 9c).
- **Foundation System**- The upcycled shipping containers typically rests on typical concrete footing shielding the structure from immediate contact with the ground (Figure. 9e).
- **Joint support**- The entire section lay on the container through the typical footing as well as binding the slab with the container using the L-formed metal segment (Figure. 9f).

The technical solutions result in a durable and stiff solution regarding coastal area housing requirements as mentioned in (HBRI, 2018). Considering the represented horizontal joints and establishment (Figure. 9g-9i), it prompts the critical consideration of the vertical joining strategy of a two-faced shipping container (Figure. 9g). Two-faced upcycled shipping container co-joints through a solitary metal lash joint to fill the gaps and contact the upper segment and lower-bit of the containers.

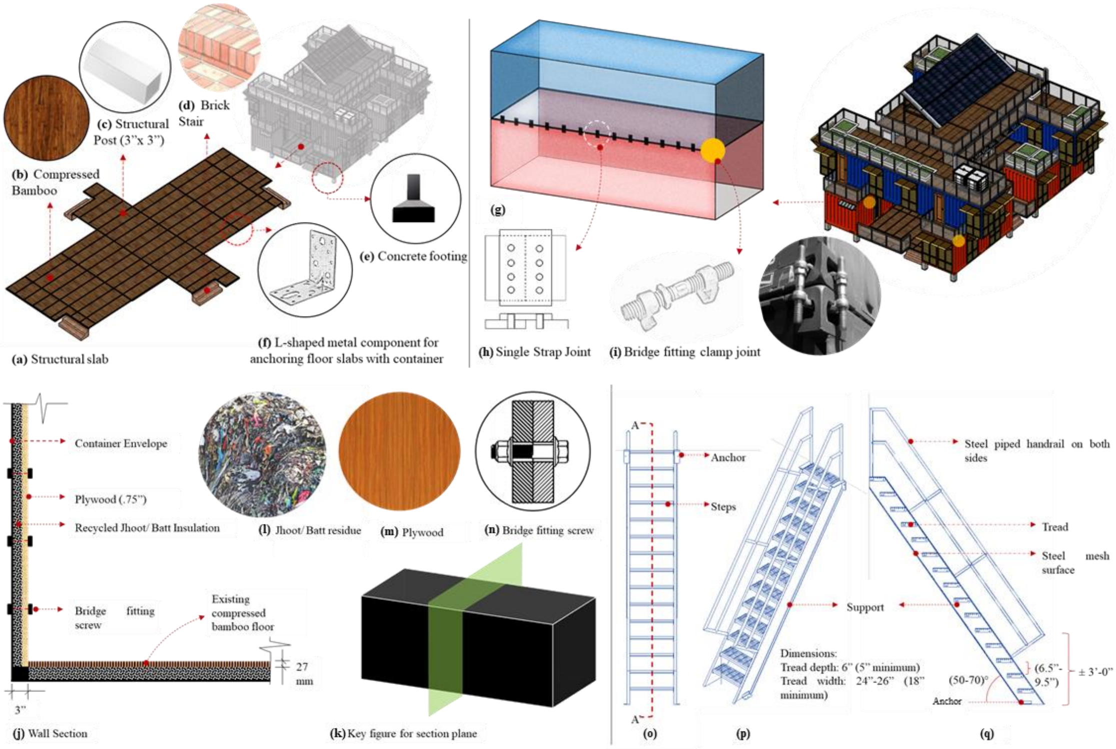


Figure 9. (a) Structural slab; **(b)** Compressed Bamboo; **(c)** Structural post; **(d)** Brick Stair; **(e)** Concrete footing; **(g)** Vertical joint of similar faced containers; **(h)** Single Strap Joint; **(i)** Bridge fitting clamp joint. Insulation strategy frameworks: **(j)** Wall section; **(k)** Key figure; **(l)** Jhoot/ Batt residue; **(m)** Plywood; **(n)** Bridge fitting screw. Ship Ladder Go structural details: **(o)** Plan of stair, **(p)** Axonometric visualization, **(q)** Longitudinal section.

The first is the foundation of the bowing moment in the followers towards the finish of the cover and furthermore at the skin interference end on account of a joint configuration. The second is the induction of articulation for the strip stresses actuated in the glue by the out-of-plane diversion (twisting) due to the whimsy in the load-path (Figure. 9h). Subsequently, securely associating shipping container envelopes to one other through scaffold clip joint or bridge clamp joint. Every container requires 4 bridge clamp fittings for safe horizontal flush connections [20] (Figure. 9i).

Regarding insulation issues, there are various specialized methods of insulating a shipping container. In this module locally found materials were used as insulation prior to the prevailing solution in Bangladesh (Figure. 9j-9n). Proposed insulation strategies are described (Figure. 9j):

- **Insulation material**- Recycled jhoot/batt found material oversaw from different residues of garments and processing plants having the quality of high thermal barriers. In this way, it covers the potential areas within the surface (Figure. 9l).
- **Finished Surface**- Plywood (.75") goes about as a supporting member for the insulation through the contribution of defining a finished texture (Figure. 9m).
- **Finished floor**- Existing compressed bamboo floor has been recycled and figured out a way to incorporate with interior surfaces which in turn executed as a firm solution for the floor.
- **Joints**- Bridge fitting screw assists to bind the two-material depicted in the above points with the containers to build the resiliency factor within the interior envelope (Figure. 9n).

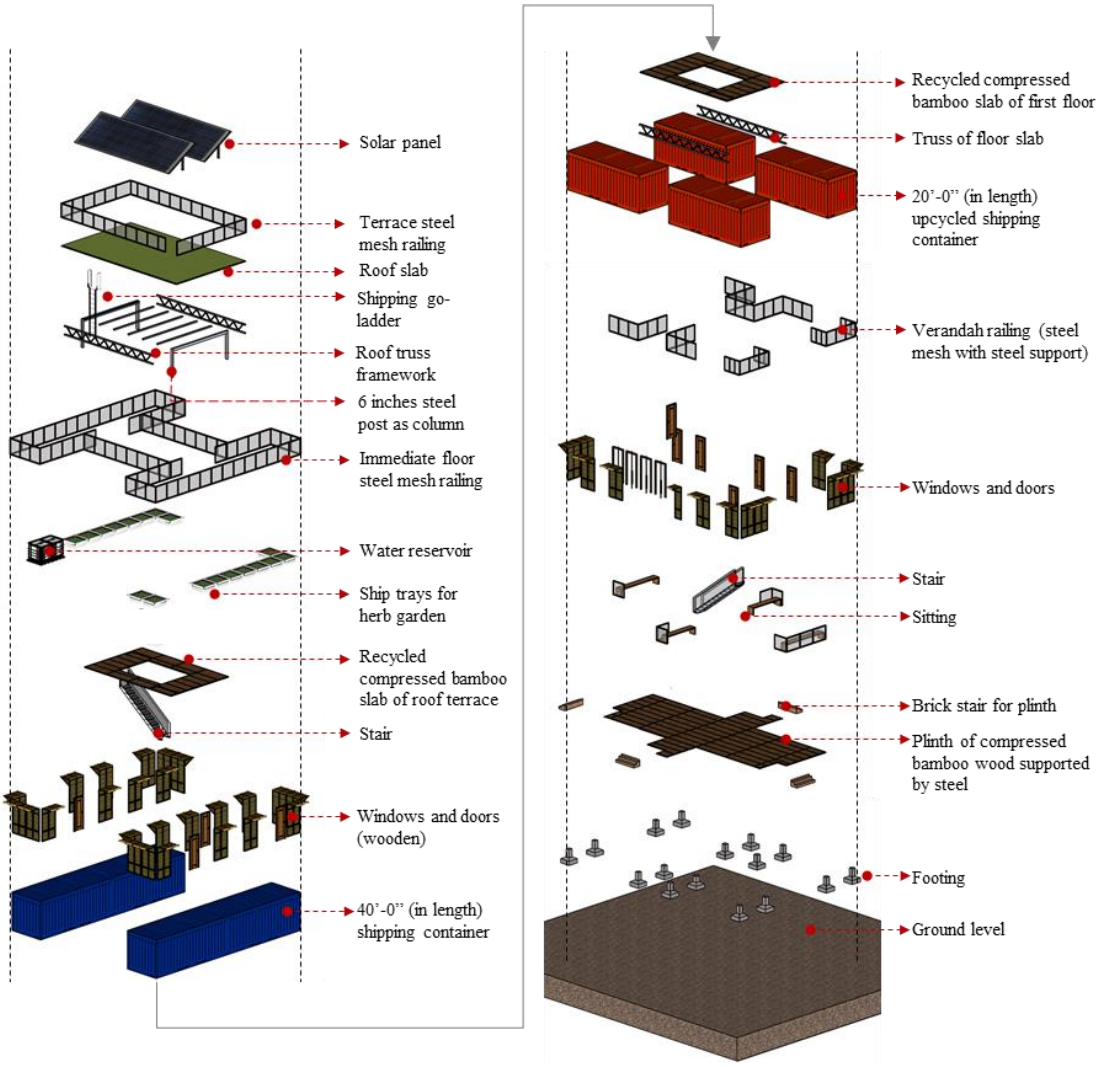


Figure 10. Axonometric view showing details of proposed sample house.

Other sustainable facilities were considered compiling the found materials in close contact to the ship-yard such as the solution to the ship ladder (Figure. 9o-9q). Different components of the sample house design have been respectively depicted (Figure. 10).

5. Discussion

This paper results to the overall study by tending shipping containers as a building material which is attained through researching its probabilities and prospective by means of setting up the strategies through a design experiment in coastal regions as a solution to the housing for fishermen community (Section 4.1). Different environmental performances have been carried out through literature synthesis depicting the behavior of shipping containers in such areas. Also, for a developing country like Bangladesh, this type of solution to the housing arrangements in water-fronts can bring up the utmost resilience through empowering different conceptualization and resilient approaches. As demonstrated by a design experiment (Section 4.1), an upcycled shipping container could be manipulated in such a way that it could bear any conceivable climatic changes due to its stiffness and as also as could be incorporated exploring its possibilities and can be treated with other sustainable highlights to draw out the best possible housing solution. Alternatively, the study proposes different supporting sustainable features which can not only ensure durability but also can fulfill the firmness in three stages (habitat, structure, and immediate surrounding (Section 4.2). However, taking into consideration calamity, e.g., cyclone, the practice of building with bricks and concrete would possibly act more vulnerable to cyclone if considered as a housing solution. Further, the solution could superfluously raise the cost of development expenses which would be quite impossible for the fishermen community to bear. In spite of that, upcycled shipping container could be a solution regarding the problem as it is relatively cheaper (acquiring a ratio of 50% cheaper regarding mass production) and can be easily designed as it prevails with such possibilities that are required so as to handle natural calamities in an appropriate way. From the data assembled, the investigation demonstrates that the most grounded highlights of this kind of material lie in one of its abilities for fast development through construction as well as through the strategy of development and furthermore its ability to effortlessly be dismantled and moved to an alternate site whenever required. Contrariwise, different development organizations and government authorities have a proposal on this very location and even some development programs have already been outlined by the government through various national and international funding. Moreover, for ensuring affordability the habitats are found practicing these initiatives as it is more cheap, stable and easily available. But they couldn't measure the sustainability aspects on it. Energy optimization by Haque et al., 2020 and Aman et al. (working paper) have measured the different aspects of environmental sustainability regarding the HVAC, daylighting, etc. and herein the design intention is to depict the construction and material sustainability of shipping container housing for architectural resiliency.

As a result, it's high time to give a thought to the housing development practices of the fishermen community in order to achieve resiliency in such areas. By adapting to the whole process of shipping container housing especially coastal housing development, architectural resiliency can be thoroughly achieved. It very well is assured that the potentialities of the shipping containers as a building material can be positioned to the possible solution as it straightforwardly represents the adaptability and plausibility when it comes to building architectural resilience in such coastal areas worldwide.

6. Conclusion

On the whole, the study initiated by addressing different expressions of the upcycled shipping container, re-introducing its features through logical expressions, re-purposing the abilities of the material in a more innovative approach, finding out the ways of interventions possible through the study of researchers and authors, considering the potentialities of the material based on coastal areas and re-introducing them in a more adaptable way and finally addressing the manageable features and experimenting through a design sample proving the resilience attitudes towards the architectural development in coastal areas. Worldwide problems do not have only one method of solution; rather the solutions must be tailored considering aspects of context, users, impacts and influences. This progress could be a thoughtful solution for the future housing rehearses in coastal areas and to the relative zones as such. Additionally, the design may vary between designers, architects, developers, etc. but considering the proposed approach and considering shipping container potentials could be a great way to attain sustainability and resiliency in the coastal housing developments. In the end, it is also expected that the discoveries of this research would motivate architects and designers to enhance the practice of drawing shipping containers in the coastal zones as a sustainable solution, which in turn would be appropriate to all the areas with comparative context globally.

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Session 3:

User Behavior and Engagement

Using Repertory Grid Technique (RGT) to Assess Children Attachment to Traditional Architectural Images

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Abstract: Global architecture as a trend has created an unbalanced visual identity by neglecting the cultural past and the traditional local architecture. This intellectual movement results in an emotional disconnection between the people and their locality. Al Ain of the United Arab Emirates (UAE) faces challenges when it comes to protecting its local architectural identity. At this point, UNICEF necessitates the participation of youth in perceiving and expressing ideas relative to their interactive visual built environments. Therefore, the study explores the potential of the 'brand image' of architecture for creating a sense of attachment in the children's minds towards their visual built environment. Centered on Personal Construct Psychology (PCP) (Kelly, 1955), a 'Brand Perception' framework based on the design principles of Interest, Pleasure, Desirability, Loyalty, and Recognition was established. An empirical study relying on RGT interviews was conducted on a random sample of 70 participants (Emirati and Indian, aged 7-12) from the city of Al Ain, UAE. The resultant emotional responses towards the 'photographic' stimuli of Local images (LI), Brand images (BI), Foreign images (FI), New images (NI), and Brand Indian images (BII), representing diverse architectural styles were validated using analysis of variances (ANOVA). For $p<.05$, the Emirati participants show a significant emotional attachment towards the architectural forms signified by the LI (T-value= 8.410, p = 0.000), BI (T-value= 11.920, p = 0.000) and BII (T-value= 7.770, p = 0.000). Whereas, the T and p values for Indian participants depict a significant inherent attachment towards the LI (T-value= 2.660, p = 0.009), NI (T-value= 2.980, p = 0.003) and BII (T-value= 1.250, p = 0.0214). Conversely, BII-3 (the Taj Mahal) creates a significant emotional response from the Emirati's only due to the resemblance in architectural visual expression to the Sheikh Zayed Mosque. The results suggest that the children are emotionally attached to the architecture of their locale. Exposure to Brand Images (BI) and Local Images (LI) representing the architecture of the locale imparted the highest emotional responses of loyalty (68.6%) and recognition (50%) in the Emiratis. Similarly, viewing the Brand India Images (BII) led to an increase in the Indian participant's emotional responses of loyalty (52.9%) and recognition (50.7%). Although NI influences the desirability of Indians, no significant effect is produced by FI and NI on the Emiratis. The findings envision an *"inclusive, people-centered, livable and culturally profound city"*, emphasizing the youngster's emotional attachment to visual architectural cultural heritage as an essential for happiness and wellbeing.

Keywords: Brand attachment, Personal Construct Psychology (PCP), Repertory Grid Technique (RGT), Children

1. Introduction

The visual built environment of today's cities is shaped by the architectural design, which is influenced by the theories and ideologies advocating the global image of architecture. These theories are affected by the rapid urbanization and technological advances led to the standardization of built environments, and the production of places that are remarkably the same. To illustrate, globalization influences cultural production, and since the built environment is considered within this production, we can say that globalization has affected the built environment and the way places are experienced. These theories initiate an unbalanced identity by creating new buildings that neglect the cultural past and the traditional local architecture. For instance, in the United Arab Emirates, the rapid growth in the architecture and construction sectors has led to a serious risk on cities losing their identities resulting in an emotional disconnection between the people's perceptions and the building image. This was due to the lack of restrictions applied on the adopted architectural styles. One of the most architecturally rich cities before the Union of the Emirates was Al Ain city, the birthplace of the founder of the UAE, H.H. Sheikh Zayed bin Sultan Al Nahyan. He shed light on the importance of preserving the architectural image of the city, and as he wisely stated, "Those who forget their past compromise their future." However according to Plan Al Ain 2030, Al Ain city lost its distinctive regional architectural style and replaced it with poor quality new architecture. As a result, Plan Al Ain 2030 has set four main objectives one of which is protecting and enhancing the cultural heritage of Al Ain. The urban structure framework of the plan is to be built around the culture and traditions of Al Ain city.

Architectural research conducted by Groat [1], Purcell [2], Nasar [3], Gifford et al. [4], and Agiel et al. [5] have examined the interpretation of buildings' appearance by both laypeople and architects in the field of meaning in architecture. They argued that the architectural forms developed by intellectual directions of architects have no reference in the minds of the laypeople of a locale and may result in their emotional disconnection with the built environment. It is evident that neglecting the cultural past is threatening cultural identity, especially when talking about younger generations. To retrieve the cultural identity and image of cities, a clear strategy that integrates the youngster's views through the design process must be adopted.

The strategy must set children's views and emotions towards their built environment as a key pillar since children's understanding of their cities is a key factor in the city's prosperity and cultural sustainability. In fact, UNISEF has set clear requirements in designing child responsive cities. It is plainly stated in the UNISEF handbook, Shaping Urbanization for Children, that children have participation rights that entitle freedom of expression and participation in decision making related to the built environment. It plainly mentions the need to, "Empower children to participate in built environment decision-making" [6 pp8]. The preferences, needs, and experiences of these children are different than those of the adults [7]. These preferences, needs, and experiences stem directly from the perceptions the children hold of their surroundings; therefore, understanding how children perceive and relate to the physical and social construct of their surrounding is central to respond to these needs in the planning process.

While the attachment concept has been studied in numerous contexts and from varying perspectives, no research has studied the perspective of the children's minds towards their visual built environment. It is important to realize that it is difficult to understand these perceptions and even more difficult to capture and reflect them in the planning process [8]. The aim of this study is to explore the potential of the 'brand image' for creating a sense of attachment in the youngster's minds towards their visual built environment. The research targets to examine the perception of young people, to better understand their interactions and experiences in visualizing the built environment.

2. Methodology

To overcome the challenges of understanding and quantifying children's perceptions to their built environment an approach different from traditional surveys had to be used. As a result, Personal Construct Psychology (PCP) was utilized. In the 1950's, psychologist George Kelly proposed PCP to deal with personal human experiences. This psychological approach aims to process the uniqueness of people by focusing on their personal meanings to objects, events, and ideas. In contrast to surveys that provide a shallow understanding to individual's perceptions by imposing predetermined assumptions. This is especially crucial when dealing with the views of children towards their built environment since their views are based on personal needs and experiences.

A Personal Construct is a unique, personal interpretation an individual has of their surrounding environment. In order to formalize and understand an individual's personal construct system, Kelly developed the Repertory Grid Technique (RGT). It is an effective technical method used to process and measure people's responses and views towards their built environment [9]. RGT allows the interviewer to mediate the interviewee's construct system without the interviewer's interference [10].

The RGT consists of three main components: the elements, the constructs, and the scales. There are two approaches in the RGT: (1) closed ended constructs and (2) open ended constructs. The former are pre-prepared bipolar scales by the researcher [9]. While the latter are bipolar constructs by the interviewee based on PCP (not included in this paper). For the propose of this study, RGT – closed ended constructs was used to create a quantitative analysis.

2.1 Empirical Study

This empirical study was used to elicit the children perception of traditional architectural images in Al Ain. The components of the study are the participants, the elements, the constructs, and the procedure. The participants were 70 participants (Emirati and Indian, aged 7-12) from the city of Al Ain, UAE. The elements were fifteen images divided into four types, local image, brand image, foreign image, and new image. The constructs were set based on variables studied in the theoretical framework and developed through PCP. Through the predefined elements and constructs, children were asked to arrange the elements on the specific pre-prepared scales. All of which were examined after the ethical approval form was accepted by the United Arab Emirates University. The results were analyzed and validated using analysis of variances (ANOVA).

2.1.1 Participants

The study was conducted on a random sample of 70 participants (Emirati and Indian, aged 7-12) from the city of Al Ain, UAE. Since cultural background of the individuals influences their responses, a control group was needed to measure the Emirati youngster's emotional attachment to their visual architectural cultural heritage [9]. Therefore, participants were divided to two groups, group one is considered as indigenous while group two has an Indian background but live in Al Ain at the time of the study. Each group included both genders. The age of the participants was selected to be (7-12) according to Piaget's theory of cognitive development. Piaget [11]. considered this age range to be the beginning of logical thought and unique opinions. The schools were chosen accordingly.

2.1.2 Elements

The elements can be the things, people, goods, images, and experiences that ease the creation of relevant constructs through the repertory grid method [12]. To understand the perceptions of children on building appearance, the elements were images of buildings following different design strategies. The design strategies were divided into four image types derived from the model of assessing perceptions of building appearance [9]. The fifteen buildings shown in the interview are shown in Table 1.

Table **1.** Elements used for RGT

IMAGE TYPE	BUILDING NAME		BUILDING CODE
Local Image	Remal Mall		LI _1
	Ayla Bawadi Hotel		LI_2
	Al Muttaredh Masjid		LI_3
Brand Image	Al Ain Brand Image	Al Jahili Fort	BI_1
		Qasr Al Muwaiji	BI_2
		Al Ain Palace	BI_3
	Indian Brand Image	Kandariya Mahadeva Temple	BII_1
		Red Fort	BII_2
		Taj Mahal	BII_3
Foreign Image	Al Ain University Campus		FI_1
	United Arab Emirates University Campus		FI_2
	Abu Dhabi University Campus		FI_3
New Image	Sheikh Zayed Desert Learning Center		NI_1
	Hazza Bin Zayed Stadium		NI_2
	Etisalat Building		NI_3

Local Image

The local images presented are images of recent architecture built in Al Ain that are designed based on the traditional image of Al Ain City. These current buildings were inspired by traditional architecture in terms of color, texture, ornamentation, rhythm and repetition, openings, and forms, some more than others. The three elements selected are: Remal Mall (LI_1), Ayla Bawadi Hotel (LI_2), and Al Muttaredh Masjid (LI_3), as shown in Figure 1.

(a) (b) (c)

Figure 1. Local Images (a) LI_1, (b) LI_2 (c) LI_3

Brand Images

The brand image represents a picture in users minds that differentiate a certain product from others. The product in our study is the buildings and the users are the children. Thus, the brand images are traditional buildings that have meaningful emotional connections to the people living in a certain area. To understand if children, from the United Arab Emirates, had a connection to their local past buildings, the study had to include another brand image in order to differentiate the results. As a result, brand images are included in two sections: Al Ain brand image and the Indian brand image.

To represent the brand image of Al Ain city, one of the three most well-known traditional buildings were selected: Al Jahili Fort (BI_1), Qasr Al Muwaiji (BI_2), and Al Ain Palace (BI_3), as shown in Figure 2.

Figure 2. Al Ain Brand Images (a) BI_1, (b) BI_2 (c) BI_3

To represent the brand image of India, three of India's architectural marvels were selected: Kandariya Mahadeva Temple (BII_1), Red Fort (BII_2), and Taj Mahal (BII_3), as shown in Figure 3.

Figure 3. India Brand Images (a) BII_1, (b) BII_2 (c) BII_3

Foreign Image

According to Deborah Hauptmann, in her article, "A Cosmopolitan View of Thinking and Being-in-Common," Local image is known in the sense of "belonging to" as opposed to being "excluded from" a culture or group, or as something "native," identifiable as being from a specific place; conversely, something foreign is understood as that which "comes from" somewhere [13]. Al Ain University Campus (FI_1), UAEU Campus (FI_2), and ADU Campus (FI_3) were selected to represent the Foreign Images in this study. Each building represents a different form of architecture, reflecting foreign identities as shown in Figure 4.

Figure 4. Foreign Images (a) FI_1, (b) FI_2 (c) FI_3

New Image

The new image is reflected on the recent architecture built in Al Ain city, which is designed with 'new' architectural elements. These elements are integrated in modern buildings through using new forms and materials such as huge glass facades and reinforced concrete. The general known indicator of the new image in buildings is the unclear connection to the local identity and cultural background. To represent the New Image in Al Ain City, Sheik Zayed Desert Learning Center (NI_1), Hazza Bin Zayed Stadium (NI_2), and Etisalat Building (NI_3) were selected.

(a) (b) (c)

Figure 5. New Images (a) NI_1, (b) NI_2 (c) NI_3

2.1.3 Constructs

Constructs are the basic units in portraying or scaling an object within its surrounding [9]. This study uses closed-ended constructs to establish a bipolar scale. Five variables were selected to measure the level of attachment the children had to the elements. The selection of the variables was based on evaluating different indicators that define the individual's personal attachment in relation to the physical environment [9]. These variables are interest, pleasure, desirability, loyalty, and recognition. These variables were developed to establish the constructs shown in Table 2.

Table 2. Constructs used for the empirical study

VARIABLES	CONSTRUCTS
Interest	The building holds my attention *in my city*
	The building does not hold my attention *in my city*
Pleasure	The building is pleasant to look at in my city
	The building is not pleasant to look at in my city
Desirability	This building will be my choice of preference for my city.
	This building will not be my choice of preference for my city
Loyalty	I would be proud to have this building in my city
	I would not be proud to have this building in my city
Recognition	The building represents a cultural image of my city
	The building does not represent a cultural image of my city.

2.1.4 Procedure

The procedure was divided into two stages: the preparation stage and the interviewing stage. The first step of preparation was to set up the online based RGT using the Rep.grid platform. The constructs and images were uploaded in the platform. The images were labelled according to Table 1. An option was set to randomize the images presented to the children. The preparation stage also included booking the computer lab at a suitable time for the school. On the interview day, the participants were divided into groups to make it easy to monitor the interviewing process. The school assigned a teacher to help in facilitating the interview along with the two researchers. The assigned teacher also randomly selected the participants from different classrooms based on the children's eligibility and desire to participate in the interview. Prior to the interview, all computers were connected to the Internet with the interviews ready to start. Once the children arrived, each group was introduced to the study and given a set of instructions that explained how to undertake the interviews. The researchers insured that the children completed the interview individually without being affected by other's decisions. The same procedure was followed in the second school for the group two, which included students of Indian background but live and study in Al Ain at the time of the study.

Figure 6. Procedure (a) Group 1 (Emirati Students), (b) Group 2 (Indian Students)

3. Results

A two-way analysis of variance (ANOVA) was conducted to compare the effect of different studied images (aforementioned) on human emotions with a sample size of un-replicated 70 surveys to generalize the findings from the sample to the population of Al Ain city, considering the effect of participates' gender, age and nationality of Emirati or Indian participants in age (7-12) years old.

The results were statistically surveyed using Minitab (Minitab 19 Statistical Computer Software. State College) in order to investigate the main effects and to evaluate the significance and adequacy of the calculated regression model.

Table 3 shows the effect of the nationality, gender, and ages of the participants on the empirical study considering the P-value and F-value.

Table 3. Significant effect of nationality, gender, and ages of the participants on the empirical study

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
Nationality	1	47.25	47.25	47.25	0.2	0.658
Gender	1	5.32	5.32	5.32	0.02	0.882
Ages	1	1287.04	1287.04	1287.04	5.55	0.032

Simple main effects analysis reveals that the nationality, and gender were significantly affecting the human emotions (p=0.658, p= 0.882) respectively. National participants are more emotionally affected by the studied images compared to Indian participants due to the location of four type sets of the images located in Al-Ain.

Among the studied human emotion, the loyalty has the highest average percentage of (56.36%) with the confidence interval of 11.02 considering Al-Ain population as shown in Figure 7.

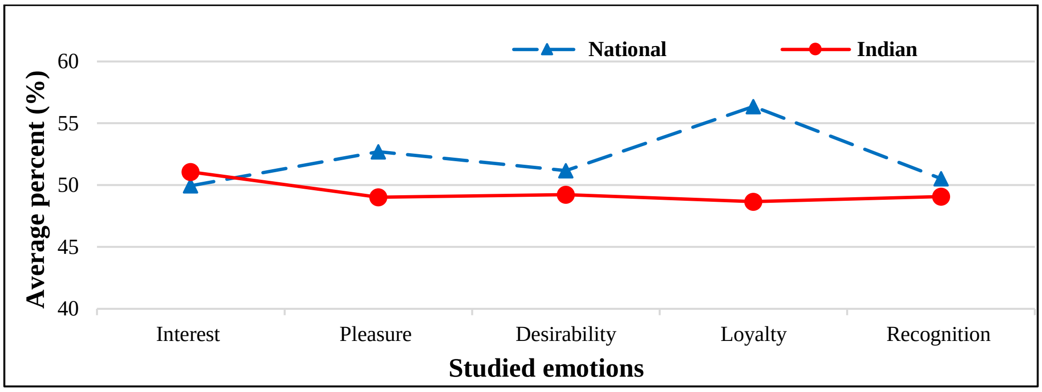

Figure 7. Significant effect of nationality of the participants on different studied emotions.

Similar response trend achieved by both gender with relatively higher magnitude of interest by female and higher magnitude of pleasure by male (Figure 8), but there were no differences between ages (p = 0.032) as presented in Table 4.

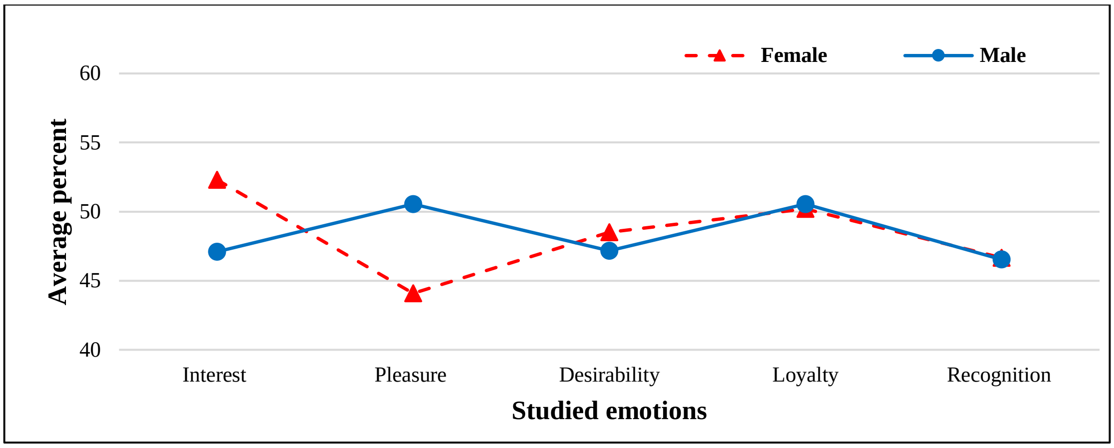

Figure 8. Significant effect of gender of the participants on different studied emotions.

3.1 Test of Normality

The Anderson-Darling statistics test confirms the normality of the data distribution for the five main image types with probability value higher than 5% significance level. The probability plots were generated to analyze the normality of the data and summarized in Table 5.

Table 5. Normality Test

	Emirati		Indian	
Image Type	*StDev*	*P-Value*	*StDev*	*P-Value*
LI	6.975	0.775	8.199	0.076
BI	6.863	0.346	9.527	0.583
FI	7.093	0.775	6.616	0.911
NI	6.846	0.394	6.610	0.363
BII	5.972	0.262	8.683	0.640

3.2 Test of homogeneity of variances – Levene's Test

The test of homogeneity of variances states that equality of variance for all groups is an essential assumption for performing ANOVA. Due to unequal sample sizes of the three groups (nationality, ages and genders), the homogeneity of variances was assessed using Multiple comparisons and Levene's Test. The results of the test of homogeneity indicate that the variances by factor and element (p=0.973 and p=0.188) and (p=0.491 and p=0.351) for national an Indian, respectively are equal. The condition of the fixed significance level of 5% of criteria for rejection is not satisfied, thus the null hypothesis is not rejected confirming the homogeneity of variance assumption as shown in Table 5.

Table 5. Homogeneity Test for element and factors

Method	**Emirati**		**Indian**	
	By Factors	By Element	By Factors	By Element
Multiple comparisons	0.839	0.293	0.427	0.356
Levene	0.973	0.188	0.491	0.351

3.3 Two-way ANOVA

There was a significant effect of type of images on human emotions of Emirati participants remembered at the p<.05 level for the LI, BI and BII conditions [(T-value= 8.410, p = 0.000), (T-value= 11.920, p = 0.000) and (T-value= 7.770, p = 0.000), respectively].

Whereas, both foreign and new images were not significantly affecting the participants' emotion of interest, pleasure, loyalty, and recognition. Instead, these two types of images increase the desirability of participants concluding the unsignificant effect of FI and NI of the Emirati's participants as illustrated in Table 6.

Table 6. ANOVA test for National Participants by factors

	LI	BI	FI	NI	BII
Mean	54.329	57.829	47.263	47.600	53.696
F-Value	8.410	11.920	1.310	1.650	7.770
P-value	**0.000***	**0.000***	0.191	0.132	**0.000***

* Significantly affecting the result

On the other hand, Indian participants showed a significant effect of type of images on human emotions remembered at the p<.05 level for the LI, NI and BII of India conditions [(T-value= 2.660, p = 0.009), (T-value= 2.980, p = 0.003) and (T-value= 1.250, p = 0.0214), respectively] while BI and FI have no effect on the studied human emotions Table 7.

Table 7. ANOVA test for Indian Participants by factors

	LI	BI	FI	NI	BII
Mean	51.027	49.457	45.827	51.427	49.337
F-Value	2.660	1.340	-1.680	2.980	1.250
P-value	**0.009***	0.182	0.950	**0.003***	**0.0214***

** Significantly affecting the result*

Comparison of the average effect of different selected images on Emirati and Indian participants' emotions is presented in Figure 9.

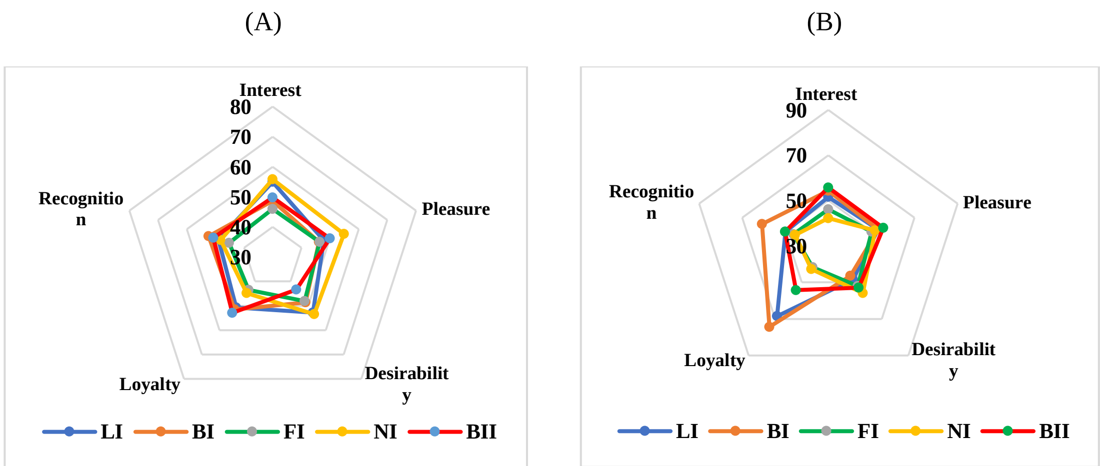

Figure 9. Average effect of different images on (A) Emirati and (B) Indian participants' emotions.

4. Discussions

The result shows higher level of loyalty emotion of Emirati's participants as compared with Indian participants especially when the local and brand images were presented to them. Presenting the Brand Images (BI) and Local Images (LI) representing the architecture of the locale imparted the highest Emirati's emotional responses of loyalty and recognition of (74.3% and 60.8%) and (68.6% and 50%) respectively. While the loyalty level of Indian participates is increased when they expose to the brand Indian images reaching loyalty level of 52.9% and recognition level of 50.7%. Also, local images have a significant effect in the Indian participants emotions due to similarities of some selected images with their architectural character.

The interest level of Indian participants increases when NI presented to the participants reaching up to 55.8%. Also, the local images raise the interest level of the Indian's interest (55%) highlighting the effect of the UAE culture presented by this group of images on the citizen while the Emirati's interest increased toward BII images (55.7%) indicating the fact that each category is more interested in other's culture.

This detailed studied reveals two interesting remarks i) the images known to the participants increase their pleasure, interest, and loyalty level. ii) the images that are not familiar for the participants increase their desirability level.

5. Conclusion

This study has found that architectural forms developed by intellectual directions of architects have no reference in the minds of the children of Al Ain and may result in their emotional disconnection with the city where they live in. Through Personal Construct Psychology (PCP), the researchers were able to understand the children's construct system without imposing the researchers' own views. This approach was used to uncover children's unconscious thoughts which are hard to verbalize. The use of PCP has an unlimited potential in the field of architecture, especially in integrating children's views in the design process.

Through the undeniable effects of globalization, cities face a problem of using new and foreign images of architecture in a dimension of losing their original identity. Planning sectors in cities should have strong policies to support the visual architectural heritage of the city. This includes creating a platform that integrates the views of laypeople and children throughout the design process, resulting in the enhancement of their happiness and wellbeing. Furthermore, a significant problem is that no importance is given to cultural sustainability in the architectural education, which is a key factor of the deterioration of architectural image of cities. It is necessary to teach cultural sustainability in architectural education through adequate cultural heritage and design courses.

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The Impact of the Economic Factors on Housing Occupants' Motivation to Save Energy in the UAE

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Abstract: In the United Arab Emirates (UAE), the residential sector is the second highest energy-consuming sector with an overall share of almost 27%; an inclination expected to keep increasing, urgently calling for strategies to control. A wide energy performance gap has been recognized as a result of occupants' behavior, catalyzing further research. Understanding the housing occupants' motivation to save energy can feed into adequate measures to lead to cost saving and resources conservation. The UAE has a distinctive population composition made of a relatively small national group and a much larger percentage of expatriates. There are major differences between the two groups, including energy tariffs, financial and non-financial subsidies and home ownership that result in different impacts on each group's behavior towards energy use and saving. Yet, this topic on occupants' motivation and behavior has not been explored in the conventional housing sector in the UAE. Hence, this study aims to explore the impact of the economic factors on local and expatriate housing occupants' motivation to save energy in the UAE. Semi-structured interviews were conducted with 32 housing occupants (14 locals and 18 expatriates) all living in the city of Al Ain in the UAE. The major finding reveals that economic factors influence, in different manners, housing occupants' motivation to save energy. Home ownership, incentives, and the mandatory energy costs were found to be the main motivational drivers for local occupants. The increased energy cost, fines and the comparatively lower income levels of the expatriate occupants were found to entice their propensity for energy-saving. Also, the lack of home ownership has prevented and deterred the expatriate group from saving energy as house renters. The study offers ample data which is timely and relevant to guide the development of effective financial strategies and incentives focused on local and expatriate residential occupants' motivation.

Keywords: Economic Factors; Housing Occupants; Behavior; Motivation; Energy-Saving; Semi-Structured Interviews; Locals; Expatriates; UAE

1. Introduction

The quest for energy conservation in the built environment is a global goal and has steered intensive research on identifying the factors affecting building performance, on adopting optimal strategies to promote building energy efficiency and overcoming various environmental issues [1]. This quest has called for an extensive research and development of new building materials and systems with a target of optimizing building resources performance which, in turn, would contribute to the global rise of the green building movement [2,3].

Despite this remarkable momentum for the well-being of the planet and its inhabitants, often enough the predicted energy-savings falls short of reaching set targets as wide discrepancies have emerged between the expected and the actual building energy performance, a fact that has been referred to as the *'energy performance gap'* [4,5]. The scientific consensus is that the building occupants' behavior is identified as the main culprit [4,6,7]. Evidence on the potential high energy-savings as a result of occupants' behavioral changes was provided by some researchers, with the caution that it is a difficult target to achieve and maintain over a long term [8,9].

Researchers agree on the evident benefits of this research topic following various studies on the factors influencing occupants' motivation to save energy. Consequently, it is vital to fully understand occupants' behavior and engage in research to guide behavioral changes which enhance and increase overall energy-savings targets [10]. Occupants' behavior and motivation may also be affected by a number of influential factors of which the economic factors were often identified as the leading ones [11,12]. In addition to the substantial effect of the economic factors as identified in the literature, the significant differences between the main population entities in the UAE (locals and expatriates), are expected to affect differently the behavior and energy-saving motivation of each population group. Hence, this research aims to explore the impact of the economic factors on housing occupants' behavior and motivation to save energy in the UAE as well as explore the differences, if any, among locals and expatriates in the study context.

2. Literature Review

Building occupants' behavior is largely acknowledged in the literature and found to have an extremely high impact on energy consumption [13–15]. There is a convergent body of literature that supports the intrinsic effect of energy cost on occupants' behavior and energy-saving motivation [4,13,16–19]. Huebner et al. [10] studied the potential factors affecting occupants' energy-saving motivation in the UK using interviews, surveys and energy meter readings. They concluded that reducing cost was the greatest motivator for changing behavior. Similar finding was concluded in the field study carried by Tanimoto and Hagishima [20] in Japan. Beyond the foreseeable impact of energy cost, some researchers found that the energy cost is a crucial motivator mainly for occupants that pay the utility bills [21–23]. This is mainly because they are aware of their energy usage and expenditure on utility bills. Some researchers argue that housing occupants tend to be prompted to reduce their energy usage when there is an increase in energy cost [17,24,25]. Long [16] using an extended database of 6,346 households in western United States, estimated that each percentage point rising in the energy price, leads to a 0.21 percentage point increase in energy conservation investments. Besides the effect on investments, it also drives occupants' daily practices.

Several energy-efficiency measures are available ranging from mandatory policies such as energy price to selective incentives. Many countries offer different types of incentives with a target of encouraging occupants to save energy in their houses, including financial and non-financial incentives. Some of them are aimed at positively altering occupants' practices while others have encouraged the purchase or the installation of energy-efficient products and appliances [26].

Occupants' income was defined as having a differing, but significant impact on energy usage and savings. Some researchers agree that the higher the income leads to more usage, and in turn, high willingness to save [12,27]. On the other hand, another group of researchers argue that the lower occupants' income, the higher the interest in energy-saving [28].

Furthermore, home ownership was found to have a significant effect on the occupants' willingness to take the incentives and participate in the campaigns, particularly the ones that call for home improvements [11,21,29–31]. Davis [32] found, using data from the residential energy consumption survey, that homeowners are more likely to own energy-efficient appliances than renters. This result was obtained while controlling some other factors including income, prices, and demographics.

All the impacting factors identified in the literature are sensitive to the specifics of a context. The context has been identified as having a potentially high impact on building occupants' behavior and energy-saving motivation [11,33]. In the case of this study, the United Arab Emirates present specificities that need to be investigated in order to address the issue in an optimal fashion in order to fully address the issue.

The UAE is a federal system of seven emirates, of which Abu Dhabi is the capital and largest emirate and has the highest percentage of Nationals (Emirati Citizens) referred to as locals with around 19% of Abu Dhabi's total population while 81% are non-Emirati residents referred to as expatriates, or expats [34]. Starting from January 2017, the energy price was increased for all residents living in Abu Dhabi, with a different share for locals and expatriates [35,36]. The energy price has increased by 27.6% for expats (from 21 fils/KWH to 26.8 fils/KWH), and 34% for locals (from 5 fils/KWH to 6.7 fils/KWH) [35,36]. After the increase in the energy price, local residents paid 1/4 the energy price set for expats.

Furthermore, part of the mandatory increase in the energy price is added on the energy bill if the daily usage exceeds a government-specified limit (green band allowance). The green and red rates differ among both groups. The tariff within the red band is 7.5 fils/KWH for locals and 30.5 fils/KWH for expats [36]. In addition to the applied tariffs, the threshold of energy billed at a higher cost differs among both groups. For instance, residents living in villas, the green band as shown in Figure 1, indicates a threshold of 400KWH for locals while expats are limited to 200KWH, beyond which the tariff increases. Similarly, apartment residents, are respectively billed a higher unit cost beyond 30 KWH for locals, whereas expats threshold is limited to 20 KWH (Figure 1). These facts may play a substantial role in the energy usage of each group.

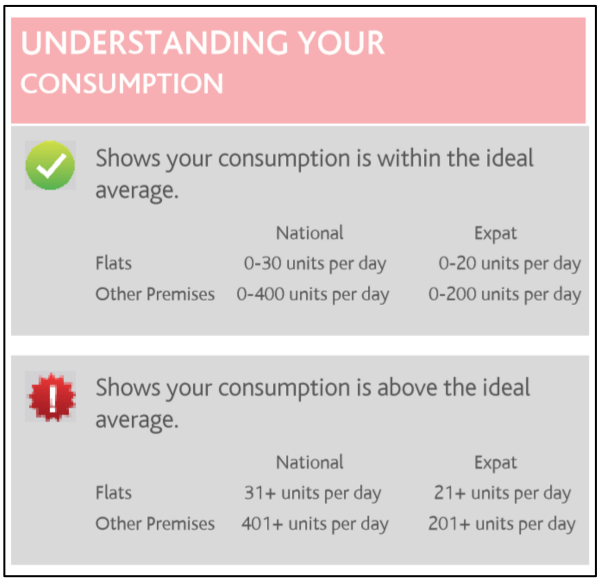

Figure 1. Extract of a Monthly Bill Showing the Difference in the Usage among Locals and Expats in Different Dwelling Types

As part of the UAE's regulation, expats' ownership of a property is restricted [37]. In addition, the expats' residency in the UAE is bound by employment, investment in a business or owning a property [38].

While the contextual specificities that are unique to the UAE may dramatically influence housing occupants' behavior and motivation for energy-savings, there are no studies yet exploring this topic in the conventional housing sector in this context. Hence, this study aims to explore the effect of the economic factors on driving local and expatriate occupants' motivation to save energy in their residences in the UAE. In this paper, the energy cost, occupants' income, home ownership and incentives are grouped under the term "Economic Factors" because they are related to the cost and are expected to positively or negatively affect occupants' motivation. This research aims to provide indicators to the policymakers to develop effective energy-saving strategies to efficiently address the specifics of all type of residents.

3. Methodology

The Semi-Structured Interview (SSI) was selected as the most appropriate research method to address the exploratory nature of this research. The interview design was based on an exploratory pilot study and in line with the question design provided by the literature [39]. As a result, a predetermined set of key and follow-up open-ended questions was generated focusing on the differences among both groups. Participants were selected according to criterion sampling [40] and included local and expatriate residents living in different house types and having different levels of income.

In this study, an ethical approval was first obtained from the Social Sciences Research Ethics Committee of the United Arab Emirates University (UAEU). Also, informed consent was used in this research at each phase (pilot study and semi-structured interviews) to inform participants about the interview procedure and obtain their written approval and guarantee of confidentiality. To ensure confidentiality and anonymity in results reporting, numbers were given to refer to the participants with a letter "L" refers to a local participant whereas the letter "E" refers to an expat.

4. Results, Analysis and Discussion

In the main study, semi-structured interviews were conducted with a total of 32 participants (14 locals and 18 expats) until saturation was reached for each of the considered groups. 13 out of the 14 local participants owned the houses they live in, either personally or through a family member. Only one local participant was living in the house as a renter due to the long distance between the family house and the university. By contrast, all expat participants were renters in Al Ain (Figure 2).

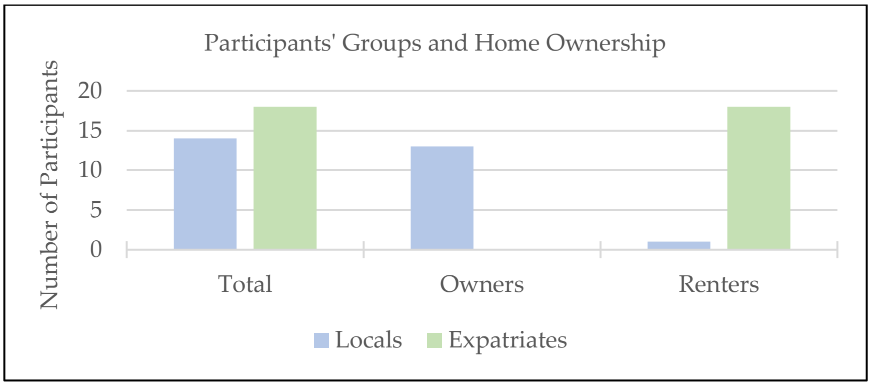

Figure 2. Participants' Groups and the Count of Home Owners and Renters in Each Group

As the financial factors may have an impact on occupants' behavior and motivation, it was important to have representatives from both groups with varying income levels. 6 of the selected participants did not have a monthly income. 11 of the participants had a monthly income of less than 10,000 AED, 7 participants had an income between 10,000 and 20,000 AED, 5 participants had income between 20,000 and 30,000 AED, and 3 participants had a monthly income of more than 30,000 AED (Figure 3).

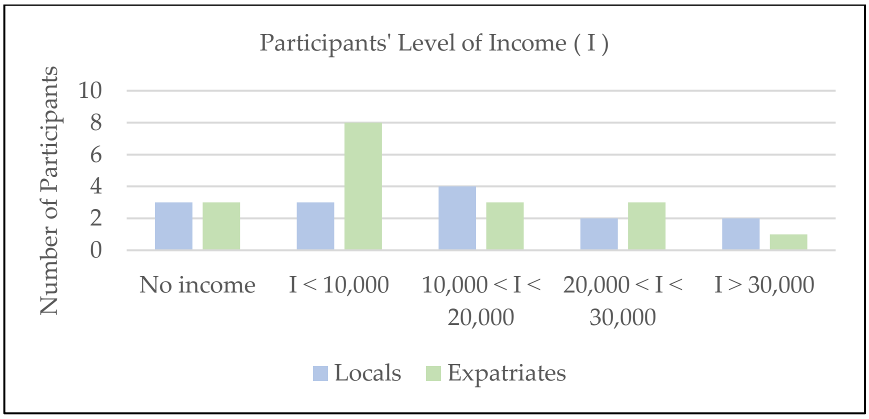

Figure 3. Local and Expatriate Participants' Level of Income

As previously mentioned, energy tariffs in the UAE differ depending on the dwelling being a villa or an apartment. Therefore, the participants' housing type was considered for correlation to occupants' practices and interest in energy-saving. In this study, most of the local participants live in villas, while the expats' housing varied between villas and apartments. Only two of the local participants were living temporarily in apartments, whereas 10 expat participants were living in villas and 8 in apartments (Figure 4).

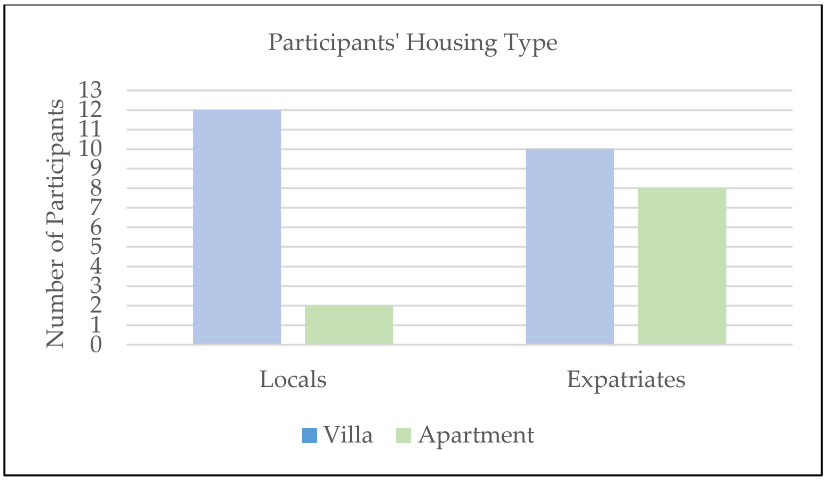

Figure 4. The Type of Participants' Residences

A thematic analysis was manually carried out on the 32 interviews, following a transcription of the full interviews. Based on the thematic analysis process [41], transcription, reading, pre-coding, codification and theme building was carried out. The process produced several codes which were filtered and duplicates of the same idea were removed. As a result, codes were grouped and sorted into 8 subthemes which are Energy Cost, Incentives, Fines, Home Ownership, Cost of Products, Occupant's Income, House Type and House Size. These interconnected subthemes were grouped under the main theme "Policies and Economic Factors". The study findings have been interpreted and discussed, as presented next, to answer the research question in relationship with the theoretical literature background. In the next sub-sections, examples of quotes from interviewees' responses are presented with the details of the participants in terms of residency status, home ownership status, type of residential building and income level.

4.1 Energy Cost

Energy cost was the first of the most addressed factors by both participants' groups. However, both participant groups showed different perspectives towards energy cost. All local interviewees who addressed the energy price as a driver stressed the current compulsory payment of utility bills. In the past, electricity and water were offered for free to all locals, then, regulations have changed and forced local residents to pay at a still subsidized cost. As discussed above, since 2017, the energy price increased by 34% for locals, but this seems to have triggered an immediate awareness in energy price and consequently usage as further highlighted by L_{13}, a UAE citizen:

> *"We were not caring much about how much we used, but now, we have to pay for the bills, we have to consider that. After the price has increased, it became kind of expensive."*
>
> [L_{13}, Villa, Owner, 10 K< I <20 K]

Comparatively, most of the expat interviewees were aware of the significant increase in energy rates for all residents since its increase in 2017, as mentioned by E_{10}:

> *"We spend a lot of money on the bills. We are living in this house from 9 years…I do not remember my father was complaining about our usage or the bills, whether in this house or the previous one. But after the increase in the electricity and water price before 3 or 4 years, he started asking us to be careful about how much we use…He always says it became*

expensive and the bills are high. So, we as a family always try to make sure to turn off all electrical plugs, lights and the AC."

[E_{10}, Villa, Renter, 20 K< I <30 K]

Although both groups were thought to be strongly motivated to save on utility bills, the study realized that locals appeared to be less stirred by the financial savings than expats. This could be because of the significant difference in the energy tariffs applied for both groups where the tariff applied on expats' bills is four times more than the tariff on that of the locals. The difference in the applied tariffs on utility bills between both groups seemed to play an important role in shaping their energy-saving motivation and likely determining their behavior. This result ties well with previous studies implying that the lower cost leads to fewer saving [17,25]. This was acknowledged by several studies including Long's [16], which estimated for every 1% rise in energy price, there is a 0.21% increase in energy conservation investments.

4.2 Incentives and Fines

The significant effect of the energy cost does not mean that all interviewees accepted or were willing to accept the offered incentives towards saving on utility bills. Most of the participants from both groups were not aware of the existence of the incentives. Regardless of their knowledge of the available financial and non-financial incentives, most of the local interviewees (approximately three quarters) seemed to be interested in the incentives and expressed a strong motivation into incentives for house renovations and improvements if the payback period of investments is short. By contrast, most of the expat interviewees commented negatively. For instance, an expat participant suggested that applying fines on purchasing inefficient products would be a more effective strategy than providing incentives to achieve significant reduction in energy consumption. The study noted a striking difference on this issue between local and expat interviewees' opinions. Some of the expat participants (around a third) agreed on the potential positive impact of applying fines, as they believe that this strategy would enforce energy-saving as consumers naturally tend to avoid paying fines by committing to the regulations. On the other hand, none of the local interviewees supported the idea of applying fines but rather highly supported the idea of incentives. Local interviewees believe that the governmental incentives to improve home energy efficiency will have long-term benefits.

4.3 Home Ownership

The difference in both groups' opinions in the incentives and fines strategies is mainly because home ownership for expats is very limited. One of the expat interviewees mentioned:

"I'm not living in this house permanently. I will not make changes in a house that I may leave at any time. I prefer to move on to another house rather than spend a lot of money on changes in a house that I do not own."

[E_{7}, Apartment, Renter, I <10 K]

This opinion was further reinforced by most of the expat interviewees. As expected, these findings indicate that the home ownership could be the most impactful barrier in expat participants' motivation to invest in energy-efficiency solutions. In contrast, home ownership was identified by local participants as a high motivator to accept the offered incentives, make nominal changes and achieve savings over the long run, as stressed by a citizen, L_{14}:

"This is our house, any change or improvement we do in the house, at the end we will be the beneficiary so why not."

[L_{14}, Villa, Owner, 10 K< I <20 K]

Similarly, by using data from the residential energy consumption survey, Davis [32] concluded that home ownership has a significant impact on appliance ownership patterns while controlling the other factors including income, demographics and energy prices. He affirmed that homeowners are more likely to own energy-efficient appliances than renters.

This was in fact an expected outcome in this study. Even though several local participants agreed to undertake the changes in their houses and the expats agreed on the minor basic changes, not all the potential changes were agreed upon.

4.4 Cost of Products

Approximately an equal number of participants from both groups addressed the comparatively high cost of the energy-efficient products. According to the expat interviewees' responses, only people with moderate to high income can afford the energy-efficient products and may prefer the option. Such difficulty was well expressed by E_{17}:

> *"In my opinion, it is not an easy decision to purchase products that save energy. For example, I cannot always select the very good products that save energy over the other ones because they are much more expensive."*
>
> [E_{17}, Apartment, Renter, I <10 K]

Similarly, another expat, E_2 shared her experience of purchasing an efficient product and observed:

> *"One day I heard about a washing machine that does not consume a lot of water and electricity…I went to the market to buy it; it's price was almost triple the price of the other products. I think these products are made only for rich people."*
>
> [E_2, Apartment, Renter, I <10 K]

According to the expats' responses, it appears that the long-term cost savings on operational energy were not taken into consideration. This could be linked to the uncertainty in their length of stay and temporary residency.

4.5 Occupants' Income and House Type

While the energy price motivates occupants to reduce the consumption, the extent of its impact seems to differ between the two groups, most probably due to the difference in the levels of income and the differentiated energy tariffs. An expat, E_{13} confirmed this sentiment when she stated:

> *"I came to the UAE 12 years ago…My income is not very high but still good. But the problem is that the electricity and water bills eat up a lot of the income. I have to be careful in my consumption…"*
>
> [E_{13}, Villa, Renter, 10 K< I <20 K]

Generally, expats have a monthly income lower than that of the locals. In addition, independent of the amount of energy used, both groups are billed differently, where the tariff applied on expats' bills is almost four times higher than the locals. Therefore, the high energy cost is a much higher incentive for expats to save money and energy than locals.

Interestingly, the house type (i.e., a villa or an apartment) was reported as a factor with a possible effect on occupants' practices. Although the participants' official utility bills were not part of the data collection process, participants who live in apartments tend to have lower utility bills compared to the villas. Nonetheless, they expressed higher motivation in energy-savings. A connection was found between occupant's income, house type and energy-saving motivation. By comparing the rental rates and participants' income, occupants who live in apartments usually have lower levels of income than those living in a villa which seems to be a reason for their willingness to positively change behavior to save on utility bills. To confirm that, most of the participants with a monthly income of less than 10,000 AED have stated making changes to reduce utility bills such as turning on water heaters just one hour before the use and keep a high temperature setting on AC. It should also be noted that this income bracket group appeared to be the foremost willing group to make further changes in energy usage habits. Conversely, participants that have a monthly income equal or more than 30,000 AED seemed to be the least interested group in behavioral changes and energy-saving measures. This finding is consistent with Trotta's [28] study that showed households that are living in a flat were 21% more likely to save energy than households in terraced and detached houses, because they usually have lower levels of income. However, this finding is in contradiction with Mortensen et al. [12] who argued that other reasons explain high-income residents' high interest in energy savings than others. Furthermore, the difference in the energy cost for different dwelling types (apartments and villas) in the study context [36] could be an important reason for obtaining this finding.

4.6 House Size

Most of the local participants (12 out of 14) indicated that the large house size is an obstacle for reducing the energy consumption as well as saving on utility bills. On the other hand, the expat participants did not comment on the large house size. This could be related to the UAE's culture, where usually locals' residences consist of large spaces as all family members live together including several generations and alliances. Despite the many positive aspects of these traditions on social and family life, but large spaces that are larger than what is needed for the number of occupants leads to high energy consumption which may hinder the energy-saving efforts. L_2, a local, emphasized the house size effect and suggested:

> *"I suggest to consider not only the house type but also the house size in determining the energy price as most of us own large houses."*
>
> [L_2, Villa, Owner, I >30 K]

According to the interviewees' responses regarding leaving the AC and lights on while leaving the room, this may further stress the high impact of the large house size and spaces that lead to high energy waste for the local group. The extent of the impact of similar simple practices was proved by Al-Mumin et al. [42] that showed a 39% reduction in the annual energy consumption that can be achieved just by turning off the lights when rooms are not occupied and setting the AC thermostat at 24 °C.

This study provided indicators that open research venues for further exploration. For instance, extending a similar study to a larger sample could be beneficial to collect an adequate amount of data for statistical analysis. Moreover, exploring the impact of COVID19 pandemic on the residential energy consumption and occupants' willingness and interest in energy saving in the context of the UAE could similarly be beneficial.

5. Conclusions

This exploratory study was carried out to collect pertaining data to local and expatriate housing occupants' practices and explore the impact of the economic factors on their motivation to positively modify behavior and save energy. This study was carried out in the housing sector in the context of the UAE through a qualitative research using semi-structured interviews with 32 occupants (14 locals and 18 expats). The analysis of data collected revealed several economic factors that may have predominant impacts on forming occupants' behavior. The findings highlighted the effect of the UAE's context where the policies and economic characteristics including the energy cost, home ownership and occupants' income appeared to significantly shape housing occupants' practices which may also underline the differences in the motivational drivers and barriers among interviewee groups. The increase in the energy cost for locals and expatriates since 2017, seems to have triggered an immediate awareness in energy usage. However, locals appeared to be less stirred by the financial savings than expats because of the significant difference in the energy tariffs applied on the utility bills. In addition, the difference in income levels may also play role in shaping differently their willingness in the financial savings, as generally-speaking locals receive higher incomes than expats.

Further, the findings indicated a wide gap between both groups' interest in energy-efficient house improvements and renovations. Locals seemed to be more interested in incentives that call for house improvements and adopting energy-efficient products, whereas expats appeared to be more receptive for incentives calling for behavioral changes compared to house upgrades. This difference most likely lies with the expats' limited house ownership in the country. The study findings helped provide indicators for financial drivers and barriers based on the occupants' actual motivation which, in turn, may be translated into effective behavior change strategies, incentives and initiatives targeting both population entities.

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Exploration Of Human-Centered Mass Customisation and Personalisation Potentials for Flood Shelter Evolution in Australia

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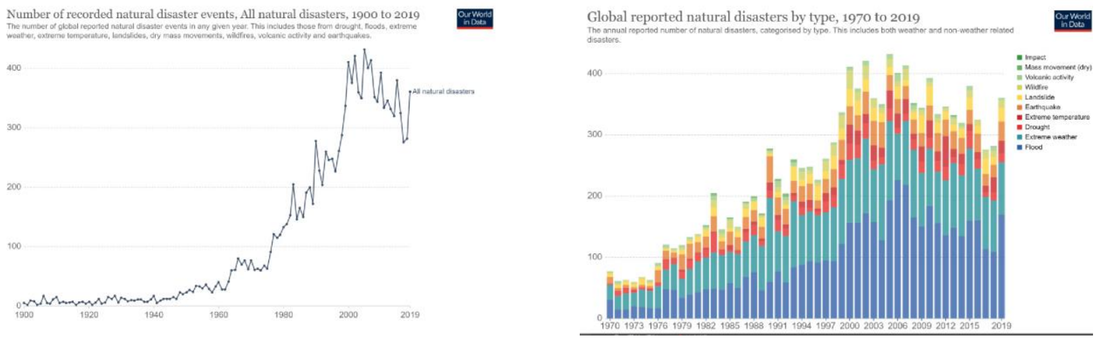
Abstract: Natural disasters have always plagued human life. Due to the global warming caused by frequent occurrence of floods, it has brought immeasurable impacts on politics, economy and human life. The relevant technology and development of post-disaster reconstruction and the physical and psychological humanitarian assistance to the disaster-affected population have been paid more and more attention by the governments and organizations of various countries. At present, with the development of science and technology, mass customisation has been widely used in the construction market. However, there is insufficient theoretical or practical research on post-flood mass customized reconstruction based on the needs and demands of the affected population and buildings. Therefore, this paper will focus on Australia's flood issues and to clarify the lack of "customisability" of today's post-flood shelter to accommodate human needs and demands for health, well-being, inclusiveness and affordability and stress the mass customisation and personalisation potentials to the improvement. Furthermore, this paper will explore a research framework by introducing human-centered mass customization to post-flood housing design under the theoretical research of mass-customisation and occupants' needs and demands. In detail, according to the study of post-flooding issues and current protecting shelter in Australia, a clear housing and occupants' needs and demands could be quantified. Then, deducing a conceivable research framework to emphasize the relationship between human needs with theories of human-centered mass customisation and personalisation based on these advantages in post-disaster housing reconstruction.

Keywords: Post-disaster housing; Flood issues; Mass-customisation; Human centered personalization; Human wellness

1. Introduction

From ancient till now, human and economic losses caused by crustal movement and hydro-meteorological disasters are common, and the scale of losses of these uncontrollable natural disasters is increasing in these years [1]. The data chart (Figure 1) from "Our World Data", could clearly show the amount of disaster event reports and the degree of each type of disasters. Although, with the development of communication technology and media industry, more disaster data can now be transmitted and recorded in the first place, it's obvious to see the amount of disasters has exploded in recent years [2]. These serious disaster trends also make more and more people realize the value and significance of disaster prevention and post-disaster reconstruction [3]. In general, after a natural hazard, architecture plays an important role not only in restore infrastructure coverage but responding to the functional need for comfort and safety of those affected. Both the temporary needs for immediate shelter, as well as permanent demands for long-term living stability are key elements which are decide whether the post-disaster architecture is successful [4]. In addition, humanitarian support is much more imperative as physical and mental health treatment for people who has affected by disasters. From the IFRC's 2020 World Disasters Report, millions of people living in a standstill situation are not receiving the humanitarian assistance they desperately need [5]. This paper will take humanitarian design as the goal to explore the methods and strategies of Mass customization and personalization housing design for post-disaster reconstruction.



(**a**) (**b**)

Figure 1. Data statistics of disaster issues from Our World Data. (**a**) Number of disaster events in the world from 1900-2019. ; (**b**)Different types of disasters occur in the world from 1979-2019.

In specific, from the key findings of the Australian climate change department, extreme sea-level events of storm surges will escalate coastal inundation risks [6]. This severe issue has been widely concerned by relevant research organizations and practitioners. However, there are still insufficient design considerations in people's need and demand in relevant post-disaster housing or constructions. As a result, many post-disaster reconstruction buildings cannot provide a comfortable and free-living environment for people to use permanently. Improving people's comfort and adaptability from flooding and sea-level rise issues in Australia becomes an important topic in recent years. Considering the background of global warming and extreme changes of environmental atmosphere, mass customization has its value in friendly environmental housing construction for its advantages of affordable and energy cost reduction. "The concept of mass customization coincidentally emerged as a mean to customize end-user products without sacrificing the production efficiency, effectiveness or low cost." [7]. For the condition of post-disaster housing development, it is necessary to efficiently, economically and rapidly restarting the housing and infrastructure coverage. This makes the concept of mass prefabrication or customization useful in the process of post-disaster reconstruction. Furthermore, with the aim of achieving sustainable development, mass customization residential should have the ability of variability and adaptability, which is to fit the demand of changing occupancy patterns from the transition of temporary to permanent [8].

1.1. Flooding issues in Australia

From the report of NCCARF, climate change is a major and urgent global issue. Climate warming means high-risk flood events, and in the 21st century, continuous and frequent severe floods "almost certainly" will occur. This may cause more serious damage to property and the environment. Floods are already the country's most expensive natural disaster [5,6,7]. In Australia, flooding issues are commonly follow by heavy rainfall into the river and possibly appear in central and western New South Wales and Queensland areas. The flood caused by sea level rise up is another condition in coastal area of east and west Australia. One of the heavy flooding record in Australia was in the Lockyer Valley, Ipswich and Brisbane, summer of 2010-2011. The rare flooding has killed 35 people and left more than 200,000 homeless with a direct and indirect loss of up to 6.64billion dollars. In Brisbane, the river peaked at about 4.43 meters height during this flood occured. A large number of houses were destroyed with uncountable vehicles lost and damaged showed in figure 2-(a). The flooding took nearly two weeks for the waters to recede, and the town was already saturated.

Infrastructure, such as water and electricity pipelines and road surfaces, have been damaged to varying degrees, which undoubtedly adds considerable burden to the reconstruction. In March 2021, another flood accident just happened in Hawkesbury, West Sydney. One of the most striking images is Windsor Bridge after the flood, which is submerged by water showed from figure 2-(b).

(**a**) (**b**)

Figure 2. post-flooding issues in Australia. (**a**) the disruptions of town housing after flood in Theodore of Queensland on January 1, 2011. ; (**b**) flooding water has submerged the Windsor Bridge in West Sydney, March 2011.

1.2. Identification of research gap

According to the United Nations Environmental Protection Organization report, global warming has become a significant trend. Sea level rising caused by warming and subsequent instability of the atmosphere will lead to a large number of flooding disasters [6-7]. Fortunately, the Australian government attaches great importance to the post-disaster administration and specifies the guideline to rapid infrastructure restoration of affected residents. (The National Flood Risk Advisory Group, 2008) However, post-flooded families' wellness cannot be achieved just by short-term shelter repair and subsidy support. From an architectural perspective, it is still a blank space to explore a permanent housing design plan that can continuously meet people's needs over time and withstand the hazards' impacts of climate change [8-9]. In order to realize such a plan, it is necessary to incorporate human-centered and personalised design into the research process of post-disaster housing reconstruction for human wellness. At present, there is not enough relevant research data in this field for post-flood housing reconstruction in Australia or beyond.

Furthermore, mass customization for post-flood housing reconstruction was hardly researched and used in today's post-flood reconstruction projects as a value engineering concept mentioned above. Although mass customization has the advantages of agility and affordability to meet the needs of post-disaster housing reconstruction, the singleness of its results does not meet the complicated functional requirements brought by the long-term living experiences of post-flood occupants. Therefore, to enhance housing quality and to improve human wellness for post-flood issues, the combination of mass customization and human-centered personalized design for post-flood shelter is of self-evident importance as the core value that this paper wants to explore which is showed on figure 3.

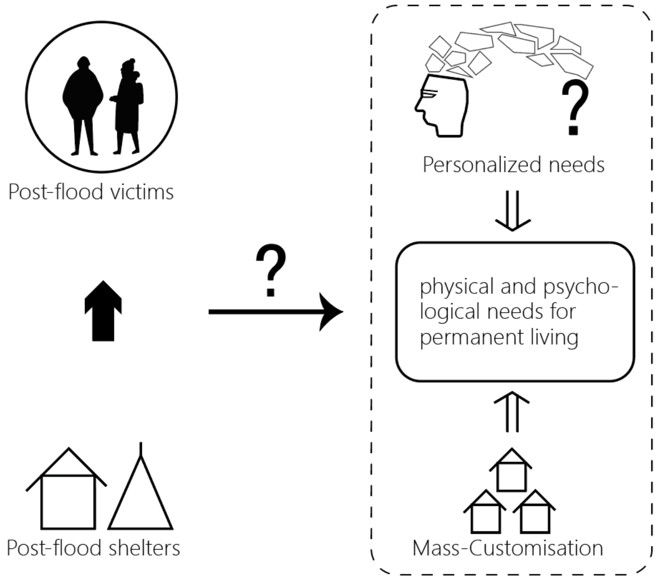


Figure 3. This is a figure shows the diagram of research gap and research aim framework. The analytical diagram was made by author.

2. Literature Review

The literature review summaries supported identification resources focusing on particular research questions under the study field. A literature review is a way to map and access research areas for further research questions or hypothesis justification according to describe previous research[10-11]. This research explores a design solution for post-flood housing reconstruction issues in Sydney, Australia, intending to improve human living experiences by combining theoretical relationship with environmental experience design and mass customisation. Based on the above research purpose and to further design and test the research results, a series of thematic study areas will be selected as detailed research in different stages of the literature review. "Post-flood housing reconstruction and permanent transition, Environmental experience design (EXD), Indoor environmental quality, Human environmental relations, Psychological trauma therapy and human wellness, mass customisation, mass personalisation and so on...

2.1. Occupants' status and needs for post-flood issues in Australia

Post-flood reconstruction as a long-lasting process is often accompanied by consuming a large number of human and financial resources. However, in terms of injury prevention for future disasters, post-flood reconstruction undoubtedly offers an opportunity to increase the stability of resistance. This requires an in-depth study of the potential impacts of natural disasters that may occur to increase the building's adaptability [12]. In order to understand the problems of flood issue, the short-term and long-term impacts for people should be analyzed and judged, respectively. According to the research of short-term impacts by flooding issue, it is easier to find the objective emergent needs for human and infrastructure. From the chart-table 1, office of the Queensland chief scientist, the researchers drew a clear picture of the short-term human and social impacts of flooding, using both tangible and intangible economic costs [12,13].

In short, the short-term chart impacts of flood issue can be summarized as economic and environmental factors. Disruption to transport and the damage of building construction could be seen as economic impacts. The pollution of water and ecological damage will be considered as an environmental factor [14,15]. Though these issue analyses are still in the rough and early stages, it clearly delineates the flexibility, agility, and affordability needs of building materials and design strategies under the requirement of sustainability and environmental protection for post-disaster reconstruction. Hence, from mentioned needs and requirements above, mass-customization as a design and construction strategy which quite fit the situation of post-disaster housing development has the value to discuss in this paper.

Table 1. The short-tern impact of flooding for human and society. The Queensland research office put these defects into tangible and intangible ways.

Can the lost item be bought and sold for dollars?	Direct loss	Indirect loss
Yes-monetary (tangible)	building property; infrastructure collapse; individual materials; livestock	Damage of transport disconnection; Damage of business interruption; cost of infrastructure reconstruction
No-non-monetary (intangible)	normal trajectory of life is broken; disappearance of good memories; ecological damage	Post traumatic of human psychology; disruption to living ; loss of community; Short supply of environmental resources

In summary, the short-term chart impacts of flood issue can be summarized as economic and environmental factors. Disruption to transport and the damage of building construction could be seen as economic impacts. The pollution of water and ecological damage will be considered as an environmental factor. Though these issue analyses are still in the rough and early stages, it clearly delineates the flexibility, agility, and affordability needs of building materials and design strategies under the requirement of sustainability and environmental protection for post-disaster reconstruction. Hence, from mentioned needs and requirements above, organizing a road map of design framework for post-flood housing will take into consideration of these housing and occupants' status and needs. Based on the case study research of current post-flood issues, a series of post-flood defects and human needs or demands could be quantified as below figure 4 diagram. Those defects and disadvantages should be considered as problems during the reconstruction process with related solving strategies.

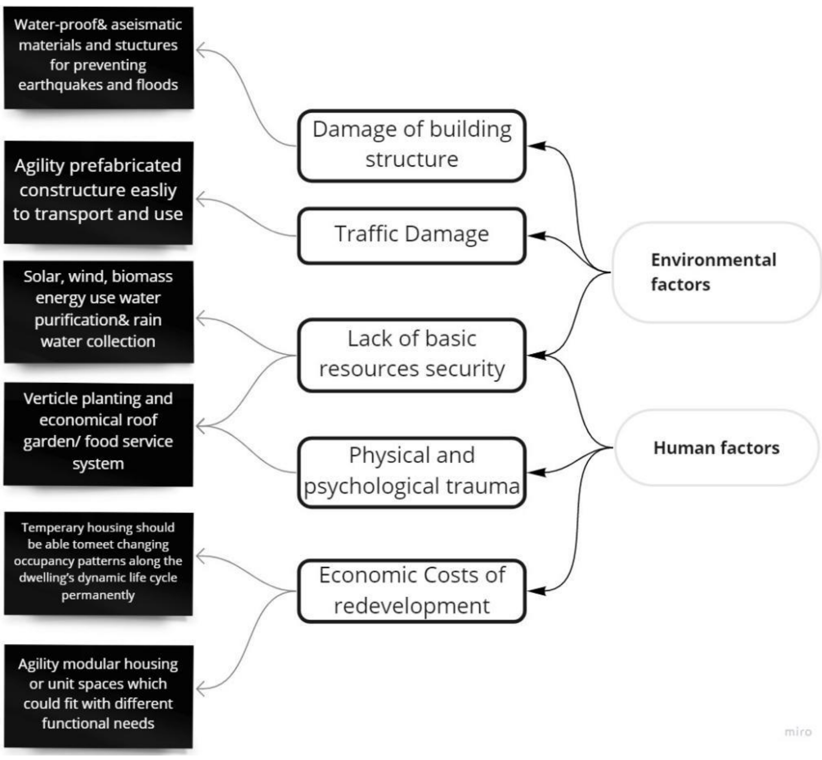


Figure 4. The summary of current environmental and human factors with potential related solving strategies based on the case study of current post-flood issues in Australia. This diagram was made by author.

2.2. Mass Customization for post-flood issues

"Mass customization is a manufacturing paradigm that enables customized and personalized design at a cost near mass production." said Dr Larsen(2009) has made a definition of the way to understand mass customisation. Mass customization has the ability of building unit affordably with a higher quality performance for its pre-fabricated in industry. Also, the short time period construction makes mass customization has a higher relevant to future architecture industry.[16] Joseph Pine published his book "Market of One- Creating Customer Unique Value through Mass Customization". With the aim of meeting the customer's needs, it explores a scientific strategy from production development to marketing to achieve low cost and high quality [17]. In building market, mass customization achieves a higher margin and is more advantageous for its mode of "one for all" to delivery products for a large amount of clients in agility, flexibility with lower unit cost [18].

With the mentioned advantages of mass customisation, it could be introduced as a concept to guide the post-flood reconstruction projects. From the perspective of construction, mass customisation can quickly form effective post-flood housing rather than simple shelters in a short period of time. Prefabricated modular units can be quickly replicated at a manageable cost. Then, the construction materials could be selected in local places without additional transaction process, since the 3d printing robots can be built at the base instead of people, thus avoiding traffic difficulties caused by floods in the process of transporting materials and manpower. Nevertheless, the research of human need related to mass customization in post-flooding house construction is still insufficient. The lack of previous projects could be proved to adequately address the aftermath of the disaster and the satisfaction of the affected population [17,18]. This paper will focus on the real human needs and demands to emphases on mass customisation for buildings with the aim of pushing a set of the feasible design scheme for the flood environment in Australia to make mass customisation more in line with diversified expectations and successfully implemented.

2.3. Human-centered personalisation for post-flood construction

2.3.1. IEQ and BS for post-flood housing design parameter collection

House, as a shelter which is protecting people's live and growth, plays an important role in connecting with human well-being [19]. In general, people may spend 66% of their living times at home during their whole life. This means that indoor environmental conditions will affect people's mood and happiness both physically and psychologically for a long time [20]. The same as post-flood victims, a living shelter with delicate design spaces which can fit victims needs and demands, in the long run, will make them feel more like home. However, in order to develop a post-flood housing design towards human well-being and comfortable use, intangible needs and comfort should be displayed through visible parameters and charts in a quantified way. Indoor environmental quality has a direct relationship with the level of occupants' conditions through a series of parametric quantification [21]. Nevertheless, indoor environmental quality as an evaluation component is hard to quantify psychological factors in a specific way due to the difficulty of intangible factors measuring. It usually could be quantified as physical factors of air, lighting quality, thermal and acoustic condition and so on [22]. Hence, in order to build a link of relationship between these tangible physical conditions with intangible psychological factors, IEQ should be combined with the theory of Behavior Settings (BS).

The theory of Behavior Settings (BS) is established by Barker. This theory mainly describes the relationship between individuals and the environment and explains the influences that 'units of the environment' (behaviour settings) have on human behaviors (Barker, 1968) [23]. This theory is helpful and useful in the architectural and urban planning field in that it can inspire people to consider how space and environments influence human and their behaviour. "It is to be incredibly powerful and incredibly useful in thinking about how does a physical a social setting actually influence what we do." (Dr Benjamin Cleveland) [24]. Post-flood housing reconstruction not just to build a shelter for self-living, but to re-build the social relationship for post-flood victims. Moreover, Barker defined behaviour Settings as independent spatial units with boundaries of time and space. They have a great deal of coercive power over what happens within them [25]. Indeed, the environmental atmosphere has the power to impact human behaviors. The theory of Behavior Settings contains which can help to create more comfortable and targeted environments. Though it is not recognized by mainstream psychology yet, Behavior Settings has been widely approved by environmental psychology, ecological psychology and sociological social psychology) [26]. Interpreted from another point of view, people's behaviour can reflect their psychological feelings towards the environment settings. This approach quantifies the intangible psychology for post-flood victims by collecting data on their behaviors in space by observation and interview. Consequently, Behavior Settings provides a theoretical basis for exploring human psychological preference with the aim of collecting human-centered parameters in human psychology.

Furthermore, it intentionally perceives the psychological feeling of physical space reflected by human behaviours and then tests people's comfort level through behavioural data collection [27]. This paper will introduce IEQ parametric system to combine with BS to quantify the real needs for post-flood victims both in physical and psychological factors and the grading coefficient of building envelope. Testing the parameters by the EXD evaluation system provide feedback in a timely manner. Parameter data collection can clarify the demand factors and directions for the next design phase.

2.3.2. PTSD design strategies for victims' well-being

According to (Stanke C, Murray V,2012) study of post-flood impacted victims of common disorder from higher and, middle-income countries, it showed mental health problems such as depression and anxiety are more pronounced among adults affected by flooding than in the normal population. [28] Post-traumatic stress disorder (PTSD) occurs at all age, which has been widely focused on as an issue for post-disaster re-organization. "Well-being as a concept, it constitutes a broader category for people to understand happiness."(White, 2010) Well-being could be trace by research the relationship between human and environment, human and social interaction and human itself [28, 29]. In fact, interior and exterior spatial design have been linked to the interaction of environmental and mental health among PTSD post-flood victims. Same as other PTSD patients, they can benefit from the supportive spatial and environmental design to cope with the stress and negative emotions [30].

In detail, indoor space design can help patients enhance their response to therapy. Interior spacial scale, interior colour settings, daylight exposure, indoor window settings with the view of outside nature, and so on, as main elements control the consciousness of users by regulating negative emotions. The design of outdoor spaces can optimize patients' feeling of happiness, which is a way to get rid of PTSD. A green open space with wide vegetarian provided a high-quality space atmosphere for fresh air and reduced noise pollution. With the aim of psychological stress recovery and provoking physical activities for potential social interaction, outdoor spatial design has its value for post-flooded victims to overcome PTSD issues [28,29,30,31]. In order to achieve the transition from temporary shelter to permanent housing, providing a living community with PTSD therapy for post-flooded victims well-being, in the long run, is important as one of the design options in this paper.

3. Research Questions Formulation

Organizing a research question is of essential importance of exploring a valuable research framework of exploring a human-based mass customisation to improve the post-flood housing design and human well-being. Under the discussion of mentioned research above, there are some speciasl research aspects could be narrowed confirmed to support this research road map. The key question will revolve around the theme of exploring a theoretical framework of potential human-centered mass customisation and personalisation for improving the wellness of flood-affected families through the clear research scope and theoretical system of reference. Furthermore, to answer the key question, there are a series of questions that should also be considered in the following diagram. The key research question should be related to “how to build a road map for human-centered mass customisation and personalisation based on reviewing the post-flood housing and occupants’ status?”.

Under the proposed key research question, a series of sub-questions should be put forward to answer and research. These SQ1, SQ2, SQ3.....will clearly define each step of the framework organization and meet the need of each requirement in building this road map. Such as, "SQ1, What are the needs and demands of post-flood victims ?", "SQ2, What are the advantages of mass customisation that can support the post-flooding shelter evolution?", "SQ3, What are the detail theories should be considered as human-centered personalisation strategies into post-flood shelter revolution?" and so on...

4. Discussion

The literature review mainly exploring the theoretical relationship of mass customisation and human-based personalisation when applying to a post-flood housing re-development. Generally, post-disaster redevelopment inevitably needs to go through the following four stages, immediate relief within hours to a day, immediate shelter within days to a week, temporary housing within few weeks to months, long-term housing for years or more [32]. However, the effectiveness of temporary housing to long-term housing reconstruction is limited by a lack of planning and management by the government for its higher functional needs and recovery cost [33]. Based on the mentioned above, the research scope will focus on discussion about the transition from temporary housing to long-term reconstruction development from shelter to permanent housing with the aim of achieving post-flood families' wellness.

As the diagram of the theoretical framework shows in figure 5, this paper explores this temporary to permanent transition by researching the physical and psychological needs of post-flood victims and affected building envelope for human wellness implementation. Both human and building factors can directly or indirectly affect post-flooded families' behaviours, emotions, and safety to long-term living experiences [34]. Along with the factors research of post-flood shelter revolution, the key theories of human-centered mass customization and personalisation will be introduced during the design process. In addition, figure 6shows the relationship between the research procedure and the introduced theories. The diagram clearly shows how the theory framework has been considered and applied to the research process as it develops. In the process of quantifying the data of the post-flood impacts, indoor environmental quality (IEQ) for post-flood housing conditions and post-disaster traumatic therapy for human well-being will serve as a theoretical framework to guide and define as the process of human-centered personalisation design. Then, the output design prototype will be replicated under the basic human needs and demands.

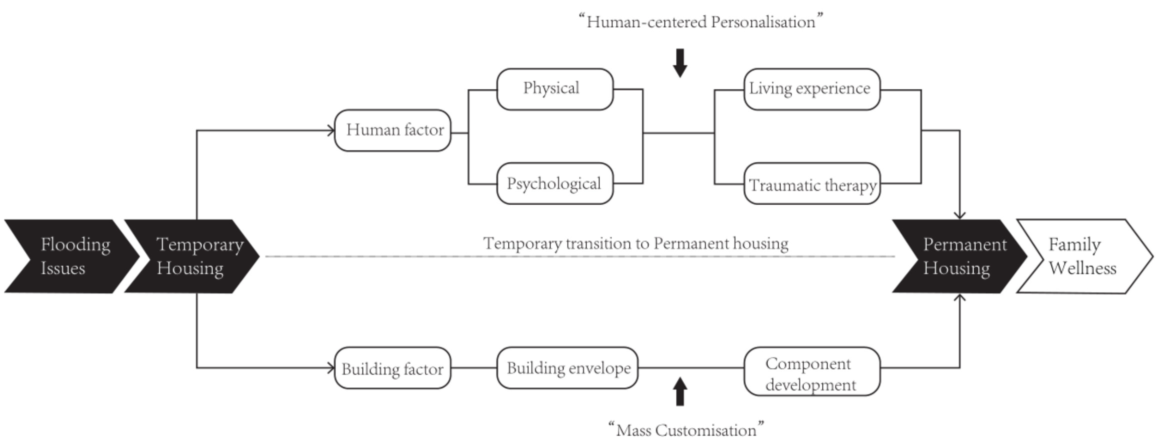


Figure 5. Diagram of theoretical framework for building and human factors. This figure is made by author.

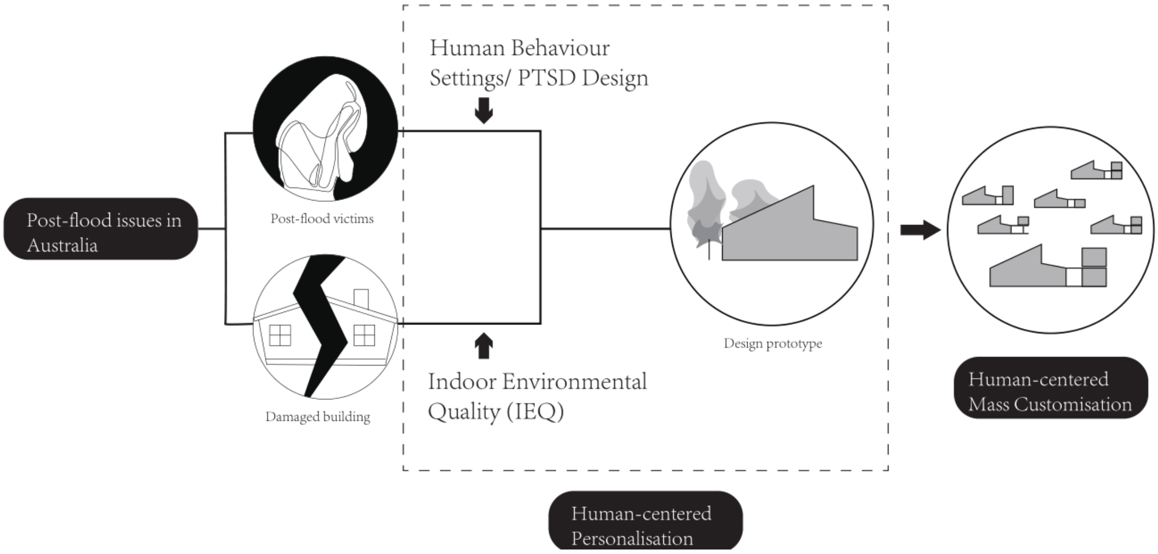


Figure 6. Diagram of the theories applied in the whole research framework organization. This figure is made by author.

It is the goal of humanitarian architecture to provide welfare and happiness for residents of vulnerable communities such as disaster areas and slums through construction. Humanitarian architects and designers have also sought to create and design safe, supportive and sustainable alternatives [28]. In order to achieve human-centered mass customisation and personalisation for post-disaster housing, human needs accompanied by their using experiences, should be considered seriously during the design process. At this moment, experience design has been successfully applied in industrial design, which is focusing on the improvement of products' interface to facilitate user satisfaction in meeting physical and psychological needs and demands. However, this concept of experience design is rarely applied in today's architectural design practices, and even it impact users' physical and perceived comfort levels in the built environment [35]. In order to achieve the personalized needs of post-area reconstruction, there must be a set of theories or a group of systematic evaluation criteria to measure and test the results of the design stage [36].

So far, the research and discussion on relevant fields are still in the primary stage. Meanwhile, there is no set of the perfect evaluation system to serve as the detection basis for the personalized satisfaction of post-disaster buildings, and many gaps are waiting to be filled. Nevertheless, EXD(Environmental Experience Design) as a cutting-edge research field has supported a deliberate attempt that affiliates experience design and environmental psychology with creating a suitable environment according to the needs and demands of users [31]. In detail, EXD is to propose design strategies and solutions to achieve the overall objectives of the building by analyzing the user's perception of the built environment. It could be seen as a functional analysis method to help identify "performance of user functionality" and improve the design process by asking what the user's needs are and how they are met to "meet the user's needs" [35,36,37].

In order to realize the transformation from mass-customization towards mass personalisation, for combining the convenience, affordability and assembly flexibility of mass prefabrication with the unique site environment requirements of post-flood reconstruction and the personalized needs of the affected population, EXD design strategy has its value as a tool to guide the design process and to test the outcome of this post-disaster housing development. The system through the phases of the set objectives for building and testing standards, giving clues as to the specific place of the action and clarifying the desired performance characteristics. It then identifying potentials and aimed outcomes by quantifying and defining design criteria step by step [38]. At present, the EXD designing tool is still at the forefront of theoretical research and evaluation based on existing buildings. Whether it can be used as a tool to guide and promote the design stage, and specifically applied to the design, analysis and detection of post-disaster reconstruction projects, is still lacking sufficient research and attempts. This would be the next step for further exploration under this paper research.

5. Conclusions

Exploring the theoretical framework of human-centered mass customisation and personalisation for post-disaster shelter revolution enables human well-being. According to the selection and research of relevant theories, a reasonable research process framework is finally formed based on the needs of the post-disaster population and building. Through the relevant parametric data collection with design theories, a design prototype will be created to meet the needs and demands of post-flood victims. In addition, the testing process of data measurement which mentioned on the discussion, to ensure that the design results can be effectively feedback and improvement. Subsequently, the design methods and data collection methods corresponding to the design thinking framework will be another consideration in this study. This paper mainly focuses on the discussion and design of the research framework. It is expected that the specific design methods and data collection methods corresponding to such a design framework will be studied and determined in the next stage. At the same time, such a research strategy can help us rethink the principles and focus of post-disaster architecture design in other type of post-disaster building design during this Covid-19 situation.

Supplementary Materials: The following are available online at https://www.abc.net.au/news/:, Figure 1, (**a**) the disruptions of town housing after flood in Theodore of Queensland on January 1, 2011. ; (**b**) flooding water has submerged the Windsor Bridge in West Sydney, March 2011.

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Designing Urban Public Spaces for Walkable Mobility of Elderly Residents: A Model of Assessment & Strategic proposals- Case of Bangalore City, India

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Abstract: Sustainable residential neighborhoods in urban areas are zones that should be essentially characterized by pedestrian-friendly environs; *walking* being one of the basic prerogative rights of all residents. This research addresses walkability of elderly pedestrians in urban spaces taking the case of Bangalore (*Bengaluru),* the cosmopolitan capital city of *Karnataka* state in India. Elderly persons prefer walking as a primary mode of commutation in their immediate neighbourhoods for accessing most of their needs. Hence, outdoor mobility becomes an important aspect of urban design. In most heavily populated Asian cities, crowded urban spaces & vehicular traffic pose threat to pedestrians. A growing concern about elderly mobility is *Falls* leading to injuries & fatalities. In 2017 & 2018, statistics showed nearly 1/3rd of pedestrian victims in Bangalore were senior citizens reasons owing to absence of safe walking-friendly spaces. Hence, this research led with the intent to analyse urban spaces & devise an empirical mode of measuring the quality of spaces so as to enable derivation of suitable planning & design decisions thereupon. The aim is to understand relationship of physical environment, the '*milieu*' of public spaces and degree of walkability. Based on a *system's approach* of perceiving sequentially from the scale of a neighborhood to a street edge, the research formulates a methodology of primary surveys called as *Elderly Pedestrian Audits* tested in four selected residential neighborhoods & addresses three main aspects to evaluate walkability- streets, junctions and amenities interface. Final mean scores have revealed that public spaces in the studied neighborhoods are not conducive for walking. As strategic solutions, a systematic *Path analysis* as derivatives of the audits & leading to an in-depth proposal of a *'Wholesome pedestrian mobility'* concept is formalized towards creating walkable neighborhoods.

Keywords: Urban spaces, Public realm, Elderly Pedestrians**,** Walkability assessment

1. Introduction

Everyone has a right to life, right to freedom and right to access civic amenities. 'Right to city' as coined by Henry Lefebvre, the French sociologist points at such a freedom be enjoyed by all citizens of a nation [1]. '*Right to Walk*' is as simple a right as a basic bodily function; it's a life need & a right of all user groups within urban neighborhoods. Walking is an essential & basic transportation mode; beginning and end of any public transit as well [2]. Ageing comes with its own health-related concerns some of which are genetic, whereas much is due to people's physical and social environments – including their homes, neighbourhoods, and communities, as well as their personal characteristics – such as sex, ethnicity, or socioeconomic status [3]. Ageing is not a constraint to keep leading a normal, engaging and socially vibrant life. At this very juncture, most striking aspect would be the urban spaces that elderly move around in their territory - *circle of living*- their immediate neighborhoods [4].

Professionals such as urban planners, designers, architects, policy makers & transport planners vested with shaping of neighborhoods assume forefront responsibilities to achieve goals of Smart growth principle of creating walkable neighborhoods to become sustainable communities [5]. Once the spaces are designed for elderly, they become friendly to all other user groups as well. 'Do neighborhood public spaces provide safe and easy pedestrian mobility to elderly residents? How can the pedestrian mobility be measured?' These are some of the questions that the research raises. Especially in most Indian cities & such developing nations of Asian sub-continent that are heavily populated, urban spaces are densely occupied with people and activities of diverse degrees [6].

The public spaces in a neighborhood are arenas of multiple activities with various stake holders claiming their right on the spaces apart from the pedestrian or the walker, who bears the wrath of the cluttered sidewalks or altered public realms. Hypothesizing this inquiry as- "The physical environment or 'milieu' of public spaces define the degree of walkability for elderly in urban neighborhoods", the study proceeds ahead by devising a defined methodology for investigation.

This paper shall discuss the model proposed by the researcher towards assessing public spaces for elderly pedestrian mobility & investigations conducted in four neighborhoods of Bangalore city in India. Formulation of such an audit methodology to evaluate public spaces is one of the main contributions of the research. First section discusses, the Audit methodology for surveys in detail devised post the pilot study & validation. Next section briefly presents the results of the surveys conducted in the four study areas & deductions thereupon. The last section finally discusses proposed strategic model to achieve walkable public spaces in residential neighborhoods.

2. Materials & Methodology

2.1 Walkability & Woes

Senior citizens tend to have affinity to pedestrian friendly neighborhoods suggest a study conducted by Susan Handy et al, in Northern California [7]. With respect to residential choice, elderly showed stronger preferences for driving-reducing neighborhood characteristics. It may be noted that design for elderly has gained forefront in architecture; in building design [8] but there is a lacuna in understanding and designing neighbourhood public spaces with them as users. As per World Health Organization (WHO), walking is a basic necessity of seniors to lead a physically active and healthy lifestyle. *Outdoor mobility* is an important and integral aspect of urban planning and design. It is always the first and last mode of transport in any trip; forms a crucial link between land and motorized transportation modes especially the public transit. Erik Erickson's theory of 'ego integrity & despair' defines that the last stage of life can be tackled well if seniors are given an opportunity to lead an independent and wishful life [9].

A growing concern about elderly mobility is Falls; accidents leading to injuries & fatalities as a result of cognitive decline & less timing given to cross roads leading to alarming road related traumas [10]. Results of a research by (Pruthi et al., 2012) showed that nearly 48% of emergencies were due to traffic accidents of which major concerns were severe head injuries in pedestrians [11]. In Bangalore city, pedestrians are at risks while using streets with a low safety index of 0.63 as compared to other cities as per a report by Government of India (GOI) [12]. In 2017, 29% of pedestrians killed in Bangalore were senior citizens 60+ years with major concerns being shortage of walker-friendly pavements and crossings as per a study report by the Footpath Initiative, published in Times of India newspaper on Jan 18, 2019. Ministry of Social Justice and Empowerment, GOI adopted the National policy on Older persons in January 1999 and 2011; aimed at improving life of elderly has placed forth related concepts to give elderly a dignified place in society. It gives impetus to 'Ageing in Place' and related facilities required to achieve this.

2.2. Neighborhood study areas

Study areas are selected from two sets of residential neighborhoods in Bangalore (Fig 1). First set is in the older parts of the city (in the first ring) dating back to 1800s; culturally rich residential neighborhoods – Basavanagudi & Chamarajpete, adjacent to each other. The second set (in the second & third rings) include fairly newer areas with a mix of varied socio-economic demographics- Vijayanagar & Govindrajnagar. Each study area of nearly 1.5 to 2.0 sq. km includes combination of planned grids and organically developed parts. These are city's popular residential areas which have been pride of Bangalore and seen many citizens ageing successfully. But as times changed, the physical environments have undergone transformations owing to building regulations, new technology, amenities, infrastructure enhancement and newer perspectives of evolving public spaces [13].

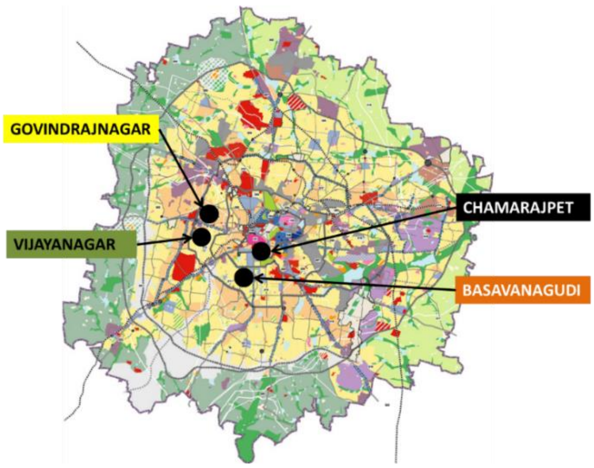

Figure 1: Four study neighborhoods

Table 1. Study Neighborhoods Profile[1]

SN	ASPECT	1 Vijayanagar	2 Govindrajnagar	3 Basavanagudi	4 Chamarajpete
1	**CONCEPTION**	Planned	Organic	First planned neighborhood	Partly planned
2	**FORMED IN**	1960s	1980s	1898	1892
3	**PLANNING PRINCIPLE**	Spontaneous grid	Grid	• Grid originally • Spontaneous eventually	• Old areas- Organic • New areas- Grid
4	**POPULATION CHARACTER**	Heterogeneous	• Diverse • Industrial housing • Newer apartments	• Original inhabitants • Oldest localities • Migrants/Varied	• Migrants • Original settlers
6	**SOCIAL INDEX**	Medium- low	Low- medium	High mainly	• Medium to high • Low in inner core
7	**PROPOSED RESIDENTIAL LANDUSE**	50%	59%	66%	31%
8	**STREET PATTERN**	Mostly dis-continuous	• Disorganized • Partly Planned • Mostly Old	• Linear • Grid • Traditional fabric	• Random mostly • Newer grid • Linear/ narrow
10	**MAJOR DETERMINANTS**	• Chord road • Market area • Maruti Mandir	• Nagarbhavi Main road • Industrial area vicinity • Magadi road	• Gandhi bazaar • Bull Temple road • Historical nodes • Culturally strong	• Kalasipalyam bus station • Mysore road

11	**PROMINENT FEATURES OF THE NEIGHBORHOOD**	• Fast developing mixed use • Newer advancements such as metro rail, city scale 'West of Chord road', retail commercials with a vibrant informal market	• Organically developed • Predominantly residential • Economically lower middle class • Local retail • Good public transport connectivity • Politically active ward hence many public upliftment projects underway	• Oldest & first planned • Many heritage & historical landmarks - *Big Bull Temple, Dodda Ganesha* • Culturally rich • Economically middle class and upper class	• Old settlement adjacent to the historical core of the city (old CBD) • Grid plan • Narrow streets • Cultural mix of population with migrants • Commercial zone embedded within residential fabric
12	**PUBLIC SPACES**	• Large public parks- linear parks along main road • Ward level public amenities • Informal market • Religious nodes • Transit nodes • Shopping complexes	• Small public parks • Streets as active spaces • Playgrounds • Semi-public uses- community halls	• Cultural nodes • Tourist destinations • Large green open spaces/ parks • Philanthropical institutions • Public fairs and celebration/ gathering spaces • Streets such as Gandhi Bazar • Large street junctions designed as green nodes	• Smaller public parks • Streets & market areas • Religious nodes • Local grounds • Eateries

[1] Based on 'Revised Master Plan Bangalore 2015, Planning District Report.

2.3 Survey methodology- 'Elderly Pedestrian Audits'

The methodology of pedestrian surveys formulated in this research aids in investigating public spaces under three main aspects- (i) barriers to mobility (streets & sidewalks) (ii) crossing at junctions (iii) street-amenities interface. Such a qualitative & quantitative analysis formulates an assessment model called as 'Elderly Pedestrian Audits'. The neighborhood evaluation surveys include data collection involving: Investigations & Observations (Fig 2 & Table 1).

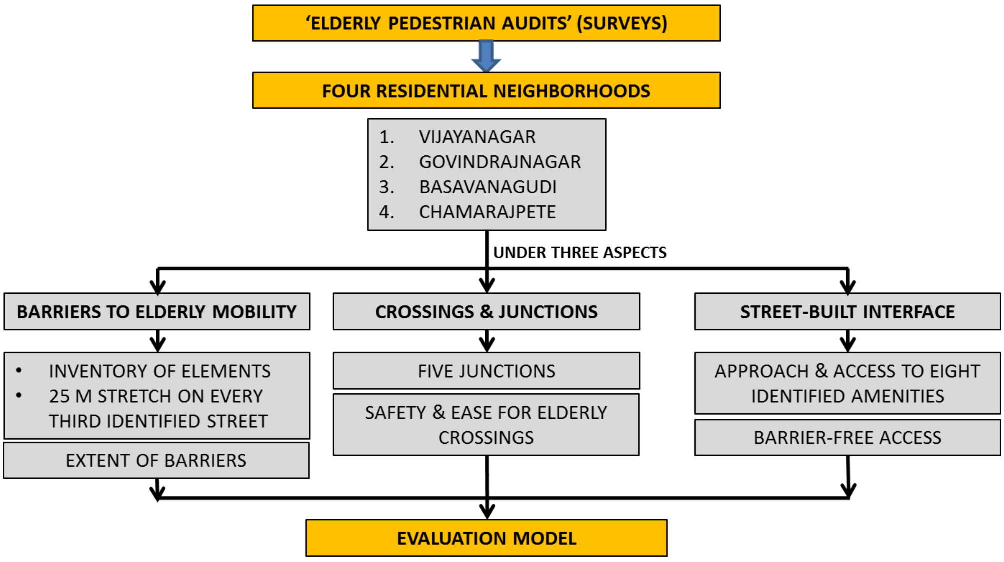

Figure 2. Elderly pedestrian audits

Table 1. Pedestrian Audit aspects

SN	Audit aspect	Method	Outcome	Module of measurement
1	**Barriers to elderly mobility**	Investigations (*by self observation*) by researcher along 10 to 12 identified street segments based on an inventory list	Quantifying the types and extent of barriers	25 m module as representative of the street with maximum length of 100m.
		Investigations (*by participant observation*) researcher accompanying or tracing 3 journeys/ paths of elderly in each study area	Elderly perceptions and behavioral patterns	
2	**Crossings & junctions**	Examination of 5 junctions	Perceiving safety and ease to cross junctions	• 15 m in both directions from each turn/corner at the junction • Cross-over paths between streets at the junction
3	**Street-amenities interface**	Examination of access & approach to 8 essential amenities identified	Degree of barrier-free transition between street & amenities (built or unbuilt)	20 m along both directions upto the entry of the amenity to be examined

Initially, a pilot study was conducted in Vijayanagar study area involving three streets to deduce survey attributes, validation, reliability test and revision of the survey instruments, as required towards formulation of final audits. First stage included reconnaissance survey & second stage involved a formal in-depth study with an intensive precise observation towards data collection of the study areas, approximately for a dedicated period of 45 days each (Table 2).

Table 2: Pedestrian audits: Time of observation during the day

SN	Time of observation		Reason based on elderly outdoor routine
1	Morning	6 AM to 9 AM	Morning walks, exercise, socializing times
2	Noon	11 AM to 1 PM	Errands, needs, other works
3	Evening	5 PM to 7 PM	Walks, socializing times, leisure

Additionally, Participant observation survey & Questionnaire survey/ interview schedule are conducted to get respondent opinions. The questionnaire is divided into three segments seeking opinions from elderly on- their profiles, activities & mobility and neighbourhood characteristics. Questions include tick from the options, binary scale, Likert scale and column in case of additional inputs. In each of the four neighborhoods, questionnaires are distributed using simple random sampling technique. Based on the elderly population in the neighborhood, sample size is determined using Central limit theorem rule. It is distributed to any two or three households with at least one elderly member available in the family, on the identified street- for every third such street in the study zone demarcated. The street selected to distribute the questionnaire to 2 or 3 households is along which audit surveys for barriers to mobility are conducted, variation happens only when in case of unavailability of elderly respondents/households. 15% of the questionnaire survey numbers is conducted in the form of interview to collect opinions.

Principal components analysis (PCA) to understand the factor loadings of the questions and Cronbach's Alpha (CA) to test the internal consistency for the Likert questions was adopted using SPSS statistical analysis. The instrument underwent one revision to arrive at an acceptable level of validity and reliability. There was a provision for local spoken language *kannada* version for some of the elderly respondents. Thus, the pilot study in Vijayanagar study area included testing reliability of survey tools with specific objectives w.r.t the three audits and the main findings that finalized the survey tools. Central tendency of scores was used for analyzing the survey outcomes. Tabulation and SPSS software was adopted towards analysis based on normality text & Regression analysis

The surveys were spread out across summer & rainy seasons between April & September, which are the two distinct seasons in the region, although not much of a variation in terms of comfort conditions year along otherwise, in such a moderate climate as Bangalore city. However, co-related to this, the survey addressed aspects related to the climate & manifestations for elderly walking in terms of: **Comfort** – Aspect of shading during hot days & seating to rest/ pause related queries is posed in the interview & questionnaire schedule. Elderly display increased skin sensitivity and hence, these are an important parameter of design. **Walking surfaces**- Materials used for sidewalk finishes co-relating to aspects such as slippery/ skid character especially for elderly pedestrian, storm water drainage in the public areas during the Audit surveys. Elderly falls & injuries are predominant on slippery surfaces. Hence, the point of inquiry.

The research considered the cases of both aspects- elderly as an individual by himself/ herself owing to such life circumstances & in the social context/ group as well. The interview schedule included interviewing elderly in social groups with their peers during morning walks or seated in parks. The questionnaire queried on the intent of elderly's aspirations to be with people & with other age groups, for which 73% expressed that they wish to socialize. These opinions impact design decisions. The participant observation survey involved tracing the path of elderly under 2 circumstances- walking alone or with a companion / being escorted by a family or friend. Certainly, as suggested, the research may further be formalized to test the psychological implications of socio-behavioral patterns of elderly being alone or otherwise.

2.3.1. AUDIT 1- 'Barriers to Elderly Pedestrian Mobility'

An **inventory of elements** is formulated from the pilot study conducted in Vijayanagar on a subset of the elderly participants. A **model for audit** is developed to gauge the spaces for barrier-free mobility. A **matrix** is further evolved that co-relates the evaluating parameter and rating scale for walkable quality for each study component. Each of the elements are based on issues and their impact on elderly physical health such as motor skills, negotiation abilities or reflexes in facing barriers, gait & speed in accordance with bone mass, arthritis etc. The inventory elements each with a code have been broadly classified under vehicles, natural elements, sidewalk surface levels, infrastructure & public/citizen interference (Table 3 & Fig 3).

Table 3. Audit 1 Inventory list

Inventory element	Code	Components	Mode of counting in the study module
Parking		Designated parking lots Street side Scattered Pockets Illegal parking	Numbers of vehicles parked
Two wheelers	1a		
Cars	1b		
Heavy vehicles	1c		
Auto rickshaws	1d		
Trees	2	Public property/ Any tree in the ROW Tree base/roots on footpath	Numbers
Grade changes	3	Level variation in footpaths due to-broken/raised slabs, repair, digging, poor workmanship, access/entry to plots	Numbers of points of occurrence
Reverse ramps	4	Access ramps to individual plots breaking continuity of footpaths, resulting as reverse slopes	Numbers
Kerb	5	Treatment of egde between footpath and street-inappropriate kerb stone/ sloping/ broken/ misplaced	Numbers of points of occurence
Infrastructure		Poles/ columns Panels Pits Open/ closed	Numbers
BESCOM poles	6a		
BESCOM transformer	6b		
BSNL poles	6c		
BSNL panel box	6d		
Drains	6e		
Man holes	6f		
Debris	7	Debris due to road works, digging, repairs, building construction, activities	Numbers of spots of debris
Garbage	8	Designated collection points, Haphazard & uncontrolled lots	Numbers of spots of garbage
Footpath		Sidewalks, walkways meant for pedestrian only Private appropriations Hoardings	Numbers of points of occurence
Broken	9a		
Missing	9b		
Narrow	9c		
Encroached	9d		
Too high	9e		
Signage/ hoardings	10	Civic signage posts Banners/ Advertisements	Numbers
Vendor/ Carts	11	Hawkers/ Push carts Tin shops/ Temporary sheds	Numbers
Stray animals	12	Dogs, cattle	Numbers
Shop spill-overs	13	Display space on footpaths by shops	Numbers
Moving traffic	14	Vehicular traffic on road posing threat to pedestrians on or off footpath	Numbers of spots of conflict

Figure 3. Illustration of Inventory elements as Barriers to mobility under Audit 1 *(Images by Author)*

Final audits involved on-site observations & perceptions, supported by captured images & videos. Post- survey, the field notes are entered onto a final legible formatted log sheet and then compiled digitally for further statistical analysis using SPSS. '***Scene analysis***' is the term coined for the methodology proposed originally by the authors in this research as a manual hand-work, post-survey analysis method. It is an extension to field-observations with captured visuals as a base data to intensify the scrutiny & perceptions of the cross-sections at strategic intervals based on the inventory list (Fig 4). Towards this, reliability & validity is based on Triangulation method using *Investigator triangulation*. Three colleagues & two research scholars (urban studies) were requested to undertake the post-survey exercise of 'scene analysis' images provided by the authors, in an independent & anonymous manner- 5 images each from the four study areas under street characters. The results showed that the investigator analysis results were 75% to 85% consistent with the number of observations made against each of the 'scenes' provided. Hence, the 'Scene analysis' tool was adopted & eventually provided valuable insights to the assessment framework.

Figure 4. Pedestrian realm 'Scene analysis.' Left: Before- (Photo-capture) and Right: After-analysis

Audit model formulation: Survey scores are entered in the field notes as 'E' scores- number of times the element or inventory (barrier) occurs in the stretch. Post survey, 'E' scores are grouped under four coded value subsets called as 'V'-values. Frequency of 'V' values for each element is assigned 'n' value. The average tendency of the inventory occurrence is expressed as 'Level of criticality- L%' and likewise graded as low (level 0), moderate (level 1), high (level 2) and extreme (level 3) (Table 4).

Table 4. Audit 1 model- Example for entries for 'E'-scores & Matrix of V, n, L scores

		'E' scores									
		STREET 1	STREET 2	STREET 3	STREET 4	STREET 5	STREET 6	STREET 7	STREET 8	STREET 9	STREET 10
CODE	INVENTORY A	6	3	4	0	0	2	7	1	0	0
		E = Number of occurrences/repetitions of inventory as observed during the audit & noted in field notes									

		'V' values											**LEVELS**							
													level 0 low		**level 1** moderate		**level 2** high		**level 3** extreme	
		STREET 1	STREET 2	STREET 3	STREET 4	STREET 5	STREET 6	STREET 7	STREET 8	STREET 9	STREET 10		**n**	**L**	**n**	**L**	**n**	**L**	**n**	**L**
												For 'V' values of =>	**0**	**%**	**1**	**%**	**2**	**%**	**3**	**%**
INV CODE	INVENTORY A	3	2	2	0	0	1	3	1	0	0		4	40%	2	20%	2	20%	2	20%
		V= Coded value assigned to 'E' scores for inventory A entered as field notes during survey. (Table 4.1) Shall be colour coded, as gradient increases from 0 to 3											n= Frequency of 'V' values are indicated in first column							
													Level of criticality (%) L= (n*100)/S, where S= Number of streets considered for study							

The model based on the survey scores essentially arrives at a Level of Criticality (L%), Level of Tolerance (T%), Level of Accessibility (M%) scores for streets, crossings and street-amenities interface respectively with the formula.

$$L\ (\%) = (n * 100)/S$$

where, L= Level of criticality, expressed as percentage is defined as the overall mean score of the inventory element indicating barrier to mobility in the study zone

S= Number of surveyed- streets, crossings or amenities

n= Frequency of 'V', which is the coded value assigned to field scores-E by interval grouping method for the specific inventory in consideration. For eg. V= 0 when E= 0, V=1 when E= 1 & 2 etc.

Average tendency of an inventory element across all the studied urban spaces is expressed in Levels of 0, 1, 2, 3 indicating criticality posed by that element. Further, for assessing implications on elderly mobility, 'Pedestrian impact assessment (PIA) is devised; numerically with a corresponding rating scale from low to very high & extreme impact (Table 5 & Fig 5).

Table 5. (i) 'Barriers to mobility' Audit model- Level of criticality (ii) PIA rating

Levels	Degree of barriers to mobility	0-9%	10-19%	20-29%	30-39%	40-49%	50-59%	60-69%	70-79%	80-89%	90-100%	
		Level of Criticality, L % (degree of barriers to mobility)										
Level 0	Low	Lo	Lo	Lo	Lo	Lo	HL	HL	HL	HL	HL	Implications on Elderly mobility
Level 1	Moderate	M	M	M	M	M	M	M	M	M	M	
Level 2	High	H	H	H	H	H	H	H	H	H	H	
Level 3	Extreme	E	E	E	E	E	E	E	E	E	E	

Case	Colour code	PIA Rating	Implications on Elderly mobility
1	Lo	Low	Elderly able to continue walking safely in a linear path on the sidewalk
2	HL	Hi-Low	Elderly may walk on sidewalk with a wavy path
3	M	Moderate	Elderly may have to get down onto street & traffic *once* form the sidewalk
4	H	High	Elderly may have to get down onto street *multiple times*
5	E	Extreme	Elderly totally on the street, sidewalk not conducive for walking path

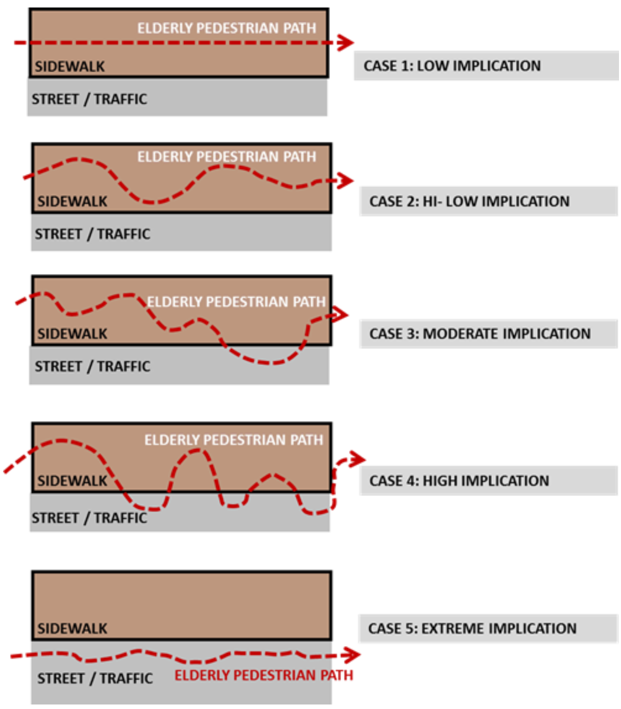

Figure 5. Rating & implications

2.3.2. AUDIT 2- 'Crossings and Junctions'

Survey is carried out at five prominent junctions of various typologies (Fig 6) in the study areas. The junctions are rated under eight inventory parameters along an approach path of 15m all around from the point of each intersection.

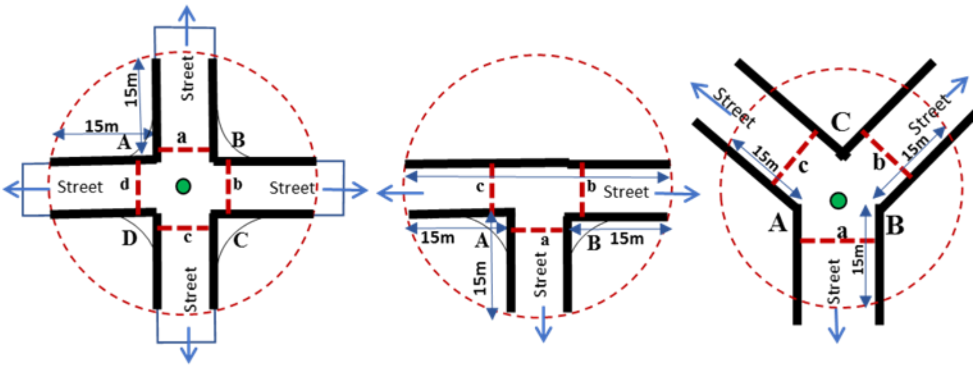

Figure 6. Junction Typologies in Residential zones

The details on the inventory parameters and related issues against the inventory to be examined at the study junction are listed (Table 6).

Table 6. Inventory parameters for 'Crossings & Junctions' Audit

SN	Inventory parameter	Issues- barriers	Illustrations at crossings, turnings, junctions
1	Footpath	• Curvature: sudden turns, blind turns • Unsafe bends • Absent/ too narrow • Broken • Side drains	
2	Grade changes (Gradients)	• Levels (intentional or poor design) • Steps • Unscientific or poor workmanship	
3	Traffic light & other infrastructure poles	• Inappropriate placement • Blocking path of movement • Utility poles	

4	Other barriers	• Signage/hoardings • Garbage/debris • Encroachments	
5	Traffic/parking	• Traffic too close to walkway or bus stops • Vehicle parking on footpath or streetside • Bus stopping	
6	At-grade pedestrian crossing	1. Absence 2. Unmarked 3. Crossing hitting the median 4. Ends with no safe landing	
7	Raised pedestrian crossing (Normally Speed humps doubled as crossings)	1. Inappropriate ramp/curvature/ gradient 2. Unmarked 3. Inappropriate finish *(slippery, or with small dents between tiles where walking stick may get stuck)* 4. Ends with no safe landing	
8	Uncontrolled crossings	1. Absence of traffic light 2. Absence of police 3. Absence of yield signage, light blinkers or such 4. Absence of traffic island or dividers between two-way streets	

The counting shall be as follows:

1. For parameters 1 to 5, the number of times the inventory as barrier is recorded at each turning corner is entered in the field-log in the zone of study- 15m along both directions.
2. For parameters 6 to 8, each of the four issues (as listed in Table 3.7) against every parameter, if witnessed is entered as 1, if not witnessed entry shall be 0.

2.3.3. AUDIT 3- ‘Street-Amenities Interface’

Eight basic essential amenities are identified frequented by elderly - shopping daily needs, doctor’s clinic, bank, post office, library, bus stops, parks or bill payment office (Bangalore one kiosks) and examined for a list of five inventory parameters. The study shall examine 20 m along both directions from the entry to the amenity. Against each parameter, four key issues are listed (Table 7). During observations, if any of the four issues is witnessed as YES, score of 1 shall be entered in the log and if NO, then score is 0 & summated.

Table 7. Inventory Parameters for ‘Street-amenities interface’ audit

SN	Inventory parameters	Inv Code	Issues	Illustration for the inventory & related issue
1	Sidewalk approach (refers to access path quality in the *pedshed* zone)	1a 1b 1c 1d	Sidewalk absent/narrow Sidewalk broken/Irregular Reverse ramps to individual properties breaking the walking path Grade differences *(requiring getting down & up the sidewalk)*	
2	Ramps (Refers to levels/grades at entranceof an amenity from street level, levels in the approach sidewalk zones)	2a 2b 2c 2d	Absent where there are level differences Unscientific design *(inappropriate: start & end, curvature, width)* High slope- gradient Slippery finish	
3	Handrails (At points of grade changes- steps, ramps or points requiring support)	3a 3b 3c 3d	Absent where required Hindrance when provided Poor material *(slippery grip, non-weather proof)* Poor design*(inappropriate height, unaesthetic)*	

4	Flooring for the access/ interface zone (Refers to the flooring for public zone only such as Sidewalk or front porch finish)	4a 4b 4c 4d	Slippery finish Uneven /poorly laid Broken, porous(For eg. Walking stick getting stuck) Inappropriate material/design	
5	Any sort of barriers to mobility (In the zone of approach and access, apart from sidewalk related aspects)	5a 5b 5c 5d	Open drains/storm water channels Plantings/ tree roots Parking Encroachments – hawkers, debris/ garbage, private appropriations	

3. Neighborhood Audit Results & Outcomes

Under Audit 1 across the study areas, the Level 3 scores implying 'extreme' impact on elderly mobility is nearly 50% which conveys that elderly pedestrians need to 'walk on streets' braving the vehicular traffic as the sidewalks are laden with barriers making it impossible to walk continuously on them (Table 8). Similarly, results under Audit 2 for crossings, 42% junctions have been rated 'unsafe' for crossings that is pedestrians need to walk on streets & crossing path is undesignated, unclear & unfacilitated for cross-over (Table 9). While under Audit 3, 48% amenities rated as 'extreme' under level 2, implying that approach paths can happen only on streets while access to the amenities is unsafe and difficult due to the various degrees of barriers to elderly users (Table 10).

Table 8: Final Scores for Audit 1: 'Barriers to mobility' in the study areas

		Impact levels & degree of barriers				
SN	**STUDY AREAS**	**Level 0** low	**Level 1** moderate	**Level 2** high	**Level 3** extreme	
1	Vijayanagar	4%	19%	28%	50%	**Level of criticality L% values**
2	Govindrajnagar	5%	15%	29%	52%	
3	Basavanagudi	7%	15%	36%	42%	
4	Chamarajpete	4%	10%	41%	45%	
	MEAN SCORES	**5%**	**14%**	**33%**	**47%**	
	Rating of Implications on elderly mobility	**L** Low	**M** Moderate	**H** High	**E** Extreme	

Table 9: Final Scores for Audit 2: 'Crossings & Junctions' in the study areas

		Impact levels & degree of risk			
SN	STUDY AREAS	Level 1	Level 2	Level 3	
		low	moderate	high	
1	Vijayanagar	15%	33%	53%	Level of Tolerance T% values
2	Govindrajnagar	20%	35%	45%	
3	Basavanagudi	18%	43%	40%	
4	Chamarajpete	10%	60%	30%	
	MEAN SCORES	16%	43%	42%	
	Implications on elderly crossing	L	M	E	
		Low	Moderate	Extreme	

Table 10: Final Scores for Audit 3: 'Streets- Amenities interface' in the study areas

		Impact levels & degree of barriers			
SN	STUDY AREAS	Level 0	Level 1	Level 2	
		low	moderate	high	
1	Vijayanagar	13%	35%	53%	Level of accessibility M% values
2	Govindrajnagar	8%	60%	33%	
3	Basavanagudi	10%	40%	50%	
4	Chamarajpete	5%	40%	55%	
	MEAN SCORES	9%	44%	48%	
	Implications on elderly accessibility	L	M	E	
		Low	moderate	Extreme	

Final mean scores show that neighbourhood public spaces in the city are not necessarily favourable for elderly to walk, in terms of physical environment with resulting psychological implications such as loss of confidence & fear of falls. Other factors such as design of public spaces, contractors implementing civil works, labour skills, multiple stake holders & vested interests further add to apathy.

Co-relative analysis of Audit (survey) based- *'observed' criticality score* (A) & questionnaire based- *'perceived/expressed' criticality score* (B) under 14 common parameters shows that between datasets, standard deviation for set A is 10.21 and set B is 10.09. So, a consistent criticality level is seen within the two sets amongst the co-related parameters. The correlative coefficient between the observed and perceived data is +0.5, indicating a moderate positive linear relationship via a fuzzy-firm linear rule (Fig 7).

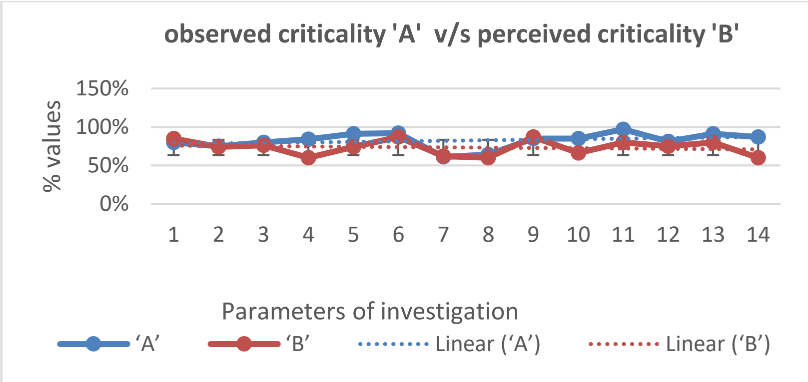

Figure 7. A v/s B & standard deviation (s)

These audits shall become tools to continually and periodically assess public spaces for walkable degree and the research proposes a certain level of threshold scores (with lowest PIA scoring as each audit outcome) under the three audits to be maintained at all times by the city to maintain the walkability standards. Urban space management needs to be outlined and executed to achieve the set goals (scores). This management strategy shall be discussed ahead as proposals.

4. Discussions

4.1. Strategic proposals 'Elderly Pedestrian-mobility framework'

The devised audits in this research lead to proposal of a strategic framework to design urban spaces. To begin with, a roadmap to public space design is formulated that enlists a set of design parameters in a hierarchical manner from macro to micro aspects; depicted as 'Public space model' (Fig 8).

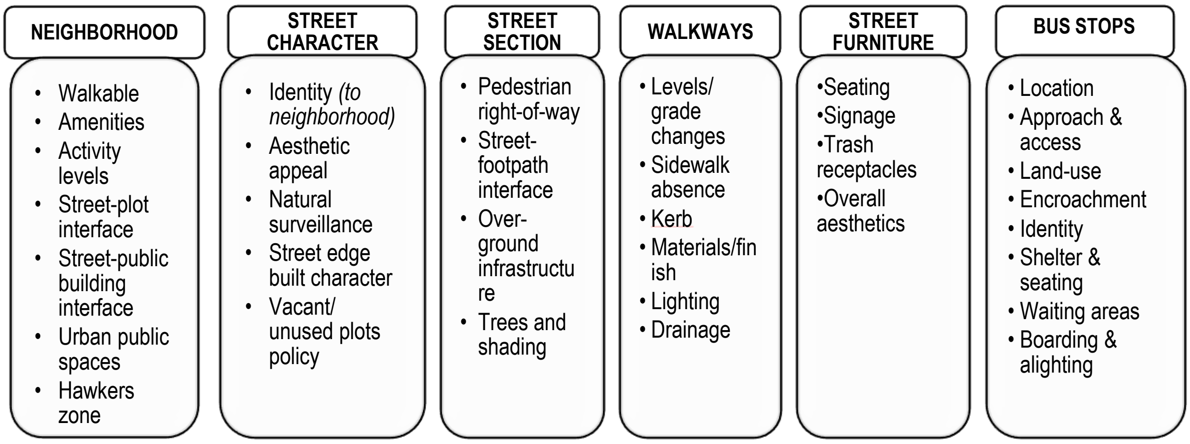

Figure 8. Proposed Roadmap to 'Public space design'

Under the larger ambit of such a public space design is required specific resolutions. Towards this, strategies are evolved as derivatives of the three audits & termed as 'Elderly pedestrian-mobility framework' (Fig 9).

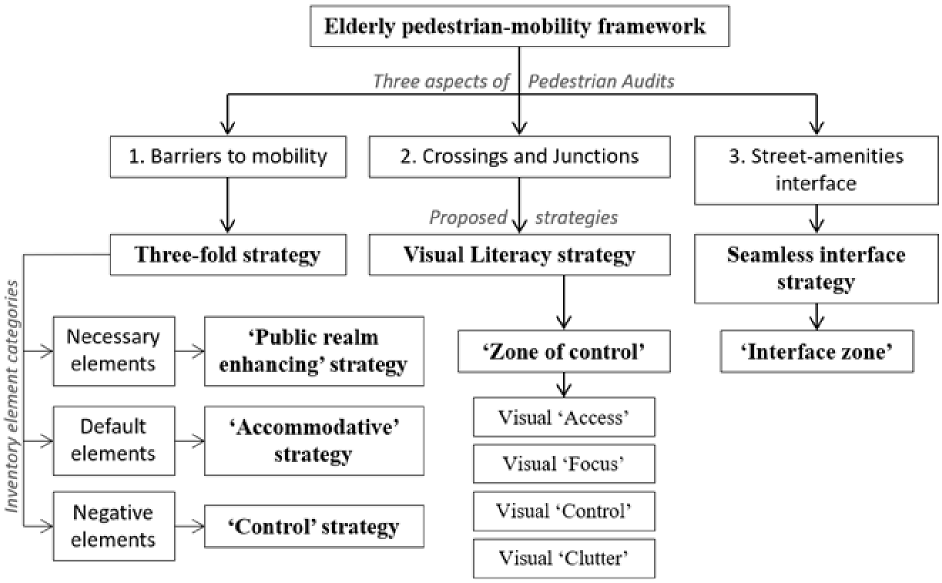

Figure 9. Elderly pedestrian-mobility framework

4.2. Three-fold Strategy addressing 'Barriers to Mobility'

Firstly, the inventory elements of audit 1 have been grouped under three categories (Table 11). Each group has its own significance & objective is to understand the elements and suitably arrive at strategic decision-making towards their ideal placement and design. 'Three-fold strategy' is envisioned with a specific strategy for each category & a threshold for range of scores implying lowest impact levels to be maintained and monitored at all times.

Table 11: Three categories of Inventory elements & related strategies

SN	Category	Relevance	Components	Aspects/Issues	Proposed strategy
1	**Necessary elements** (First order of design)	Are essential and important Are elements of good public realm design	Footpaths, Signage, Landscape, Street furniture, Artworks	Design Location &Treatment Durability Identity Beauty/aesthetics Function/usability	**'Public realm enhancing' strategy**
2	**Default elements** (Second order)	Are supporting elements of urban Infrastructure Unavoidable urban activities	Infrastructure elements- over ground utilities like power cables & poles, traffic posts, Vending/hawking, Vehicles	Location Design Safety Aesthetics Clarity Access to maintenance	**'Accommodative' strategy**
3	**Negative elements** (Third order)	Are a result/ remnant of various urban processes Are to be controlled/ avoided	Parking, Grade changes, Reverse ramps to individual sites, Debris, Hawking, Stray animals, Spill-over, Encroachments	Order Location Regulatory mechanism/ monitoring Civic sense Surveillance Hazards	**'Control' strategy**

4.2.1. 'Public realm enhancing' strategy- For Necessary (positive) elements

These elements add beauty & comfort but if not designed amicably, act as barriers themselves. Design strategy aims at inducing an affinity to the place, natural demand for a civic responsibility towards a cleaner environment and a physical realm imposing a psychological confidence amongst the elderly (Table 12).

Table 12. Parameters for 'Necessary elements'

SN	Necessary elements	Objective	Design
1	**Pedestrian infrastructure**		
	Sidewalks, footpaths	Safe Pedestrian movement Enhance user comfort& pleasure of walking Visual & physical access	Natural surveillance – active street edges At grade/ levels Continuous paths Anti-slippery
	Lighting	Safety Surveillance Visibility	Focus Intensity design Lamp post design & location Energy efficiency and maintenance ease
	Amenities such as drinking water, rest rooms	Provisions for basic & essential comfort of elderly	Strategic location for placement Accessibility User-friendliness
2	**Street furniture**		
	Seating	Pause points Resting/respite from walk Pleasure/comfort Socializing	Durability All-weather resistance Maintenance-free Ergonomic
	Signage	Directions Order Instructions	Legible Non-corrosive Location & placement
	Sculptures	Add interest Focal elements Mark territory Define neighbourhood character Give identity	Interesting/appealing Instill pleasant thoughts Ideally placed
3	**Landscape elements**		
	Trees, plants	Shade Respite Visual appeal	Ideally planted Flowering or shedding qualities Non-rupturing roots Efficient ground around Catchment for water
	Kerbs	Bifurcate people & motor vehicles Notional edge to landscape or footpath	Low height Sloping at points for transition Durable Efficient rainwater drains

4.2.2. 'Accommodative' strategy- For Default elements

Aims to understand the elements that are bound to be a part of the public realm by default, hence must be meaningfully & logically accommodated; includes elements such as under infrastructure or informal vending activities. With a governance intervention perspective, a co-ordination amongst various statutory bodies becomes crucial. An integrated plan needs to be drawn up by a coordinating committee to oversee the implementations of each civic body. Design of the public spaces should be introduced formally in the city master-plans which outlines specifics of design with these elements and activities into consideration. This shall be reinforced as urban-byelaw with the concerned urban development/ town planning authority. A multi-dimensional approach to urban space morphology becomes obligatory with pedestrian as focus and default elements to be accommodated in the left-over spaces. For this, inventory list of all possible urban elements as listed in the Pedestrian Audit system must be created subjectively.

4.2.3. 'Control' strategy- For Negative elements

Aims to list out all the elements that are a result of certain urban processes and pose threat to elderly pedestrian mobility (Table 13). Community participation and involvement aids in enforcing the regulatory and governing strategies setup by local bodies.

Table 13. 'Control strategy'- Aspects & Objectives

SN	Negative elements	Strategy	Objectives	Outcome
a	Parking- public & private vehicles	'Traffic management plan'	Heavy traffic restriction along residential streets Through-traffic restriction Control of vehicular speed Discipline amongst drivers	Neighbourhood level plan in the ambit of the larger regional plan Hierarchy of traffic routes Traffic calming design- imposed and subtle
		'Parking strategy'	Regulation of erratic parking along streets Prohibition of vehicles on walkways Bifurcation of pedestrian zone & vehicular zone	Designated parking lots/ block-wise lots for residents & visitors Byelaws to aid parking within property boundaries Access of vehicle into each property designed while not breaking the walkway paths
		'Land use zoning'	Regulation of land use to control activity levels Discouraging private vehicle use for accessing amenities	Specific zoning & byelaws Block size design Provision of basic amenities in walking ranges
b	Routine activities- shop spill over, encroachments, waste management	'Activities management plan'	Restrictions to merchandise display on walkways Regulation of private appropriations onto public ROW	Specific guidelines for commercial activities Zero-tolerance for spill-overs Private modulations within property limits
		Neighbourhood level 'Waste management strategy'	Regulation of haphazard garbage collection points in public spaces Walkways clear of garbage or debris	Waste management plan Community participation Resource management plan Natural surveillance & active frontages
c	Developmental activities- constructions & debris	'Routine accommodation strategy' (as in Complete streets policy)	Elderly pedestrian safety; to avoid discomfort, slips, injury or fatality Prohibition of spill-over of private construction activities onto public space Regulation of public developmental works to avoid inconvenience to pedestrians	Guidelines for construction activity, approval process and routine tracking system Illegal, unauthorized and unapproved activities to be monitored Imbibe ways to contain the works & materials within property lines or designated zones

			Provision for immediate clearance and appropriate disposal of debris	City to devise a 'sustainable construction' roadmap involving recycling and reuse of building materials, green concepts to reduce waste & debris pileup
d	Design & engineering-grade changes, reverse ramps, width of walkways	'Street infrastructure strategy'	Offer easy, smooth, continuous path of walking along streets Ergonomically designed realms	An integrated architectural & engineering design system to build a good reliable street-walkway system Material, technical, physiological, aesthetical considerations to build street-walkway system Interface between street and properties designed to avoid hindrance to pedestrians and smooth access to the property

4.3. Visual Literacy Strategy- Addressing Crossings & Junctions

Approach path to junctions- 15 m zone from each turn towards both directions need to be conflict-free for + junctions and 12 m for T junctions (or minor junctions involving tertiary streets). (Fig 10) Crossings shall be designed with a '*Visual literacy*' strategy which will give the elderly pedestrian and vehicle drivers a clear perception of the junction, to avoid masking of view or path by any element.

- Enhance '*Visual access*'- clear view of the junction at an approaching distance of 20m: strategic placement of poles, trees, infrastructure elements
- Create '*Visual focus*'- provision of clear focus towards crossing: marked crossings, angular turns, pedestrian platforms, traffic lights
- Impose '*Visual control*'- clear scan of junction to pedestrians and drivers likewise to know each other's paths- well lighted, legible and impactful signage, markings
- Reduce '*Visual clutter*'- avoid any kind of element that add clutter to the scene and haze the vision: limit/avoid activities such as hawking at junctions, encroachments, hoardings, inappropriate landscape elements

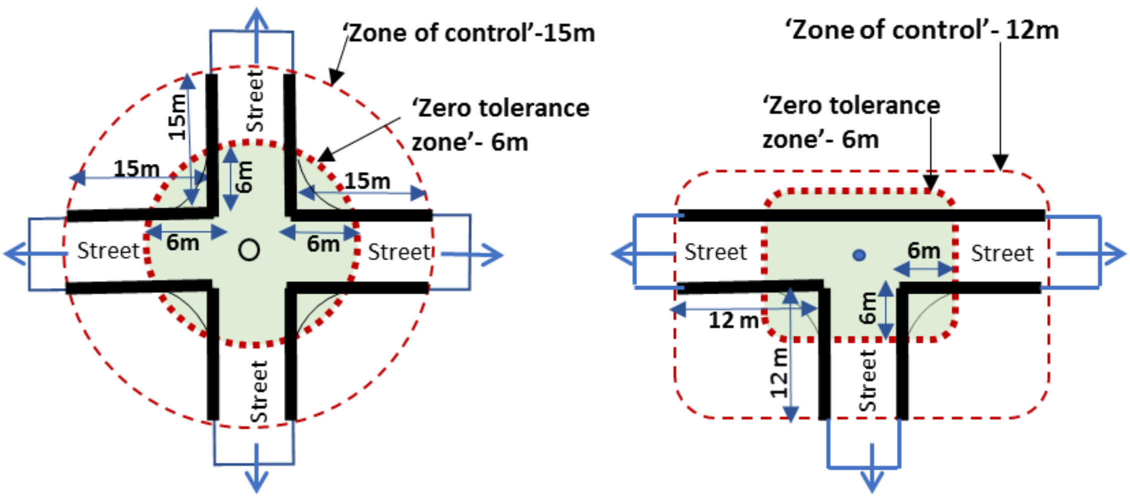

Figure 10. 'Zone of control' & 'Zero tolerance zone' junctions

4.4. Seamless interface strategy- addressing street-amenities interface

A seamless transition from street into amenity is intended as a part of the larger inclusive mobility strategy for elderly. Access and approach to amenity shall be two-fold. One, pedestrian approach to the amenity in the walkable radius and two, barrier-free entry/exit from the amenity. A minimum of 20 m, considered from the access point to the amenity on all sides to have absolute barrier-free approach called as 'Interface zone' with a 'zero tolerance zone' of 10 m (Fig 11 & Table 14).

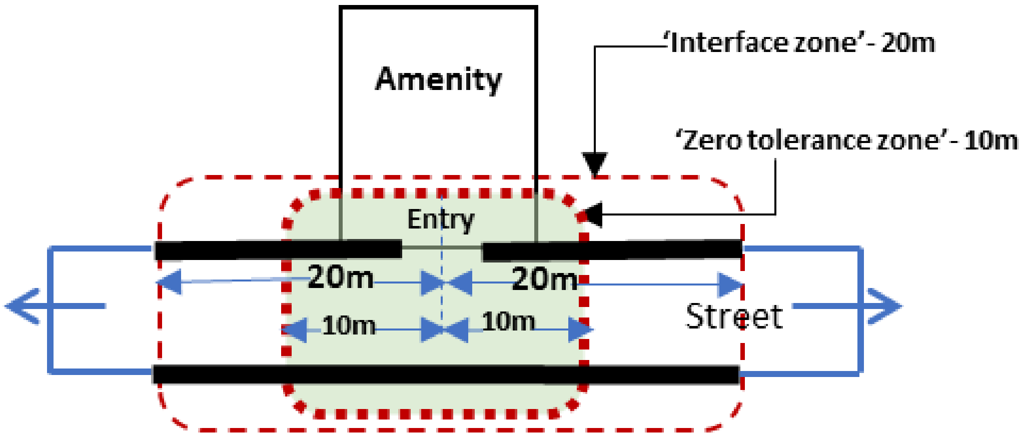

Figure 11: 'Interface zone' & 'Zero tolerance zone'

Table 14. 'Interface zone'- Inventory for the Audit survey & related design specifications

SN	Inventory	Principle of design
1	Sidewalk approach	Upto a distance of 20 m from the entry point to amenity from street 'Zero tolerance zone' of 10 m from entry to be a critically barrier-free zone Drop-off zones Connected to nearest transit stop with smooth pedestrian paths At-grade access paths
2	Ramps	At every grade change appropriate ramps of not over 1:10 Material: anti-skid and anti-slippery
3	Handrails	At all places where grade change is evident Bifurcation between pedestrians and vehicles Design parameters w.r.t material, aesthetics, anthropometry and geometry
4	Flooring for the access/interface zone	Non slippery & Anti-skid Tough/ resistant to wear & tear/ weather proof Aesthetically pleasing Themed for legibility Local materials Tactile for visually challenged
5	Barriers to mobility	Identify all barriers as listed in pedestrian audit inventory list 'Three-fold' strategy to address barriers to be applied in the interface zone

If every amenity becomes approachable by foot within a radius of 20 m, then a grid of such amenities shall in totality weave together a mesh of accessible public spaces in the neighbourhood. This shall induce a sustainable livable community based on walking as a main mode of transport.

5. Conclusions

The research substantiated that the physical environment '*milieu*' of public spaces defines the degree of walkability for elderly in urban neighborhoods. Methodology of Pedestrian audits was formulated that assessed the urban space morphology under the following three main strategic & sequential steps: [14]

1. Determining the composition of the public realm
2. Measuring the walkability in the public space milieu
3. Designing the public space milieu

The model of 'Elderly pedestrian-mobility framework' is a comprehensive strategy plan which encompasses- network of streets & public spaces, street junctions and access to amenities; with guidelines for a pedestrian infrastructure to achieve barrier-free navigation in the urban spaces of neighbourhoods in populated cities of nations as India or Asian countries (Fig 12).

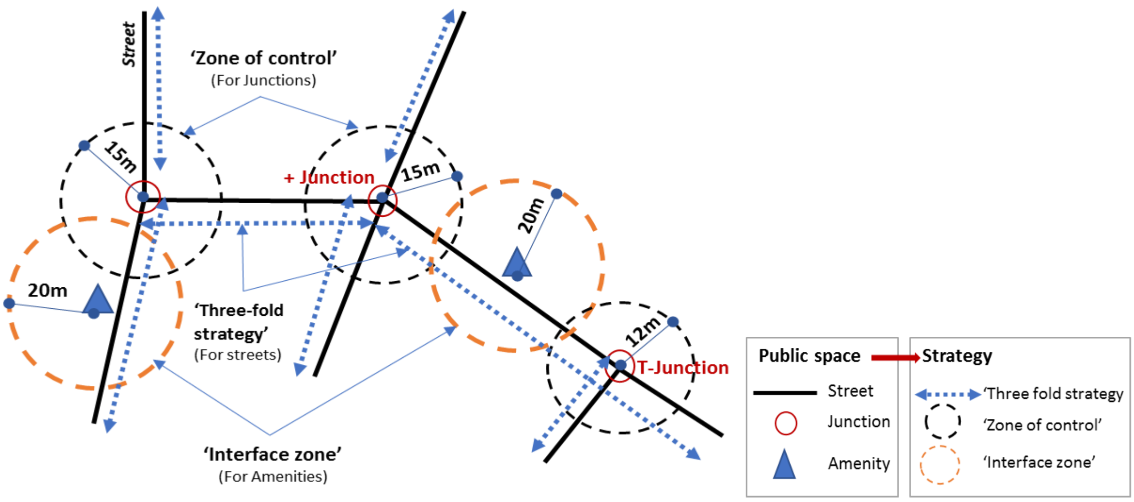

Figure 12: Comprehensive strategy diagram of 'Elderly pedestrian-mobility framework' to make the neighbourhood public spaces inclusive to elderly pedestrians

Public space is a complex system with diverse components, activities and processes in an Indian urban setting in addition to the people as pedestrians and users there are vehicles, trees, utilities or encroachments. Sidewalks become strewn with barriers to walkability. This study enlisted list of all such elements as inventory 'barriers to elderly mobility'. **Hence, first step is to understand and determine the composition of the public realm and its physical environment.**

Further, Plurality of public spaces become integrated with the evolving public culture. It is a sub-discipline of environmental design and spatial configurations in neighborhoods. Elderly people attach meaning to public spaces either positive or negative w.r.t safety, comfort, ease and cheer. Friendliness to pedestrians is the first step of democratic public spaces in a city. Measuring the dynamics of public spaces towards such an inclusive walkable mobility is thus essential. This measurement requires testing the physical environment & its impact on walkability determining the social and perceived neighborhoods. Pedestrian impact assessment (PIA) as a tool for grading and maintaining a permissible threshold of scores by way of periodical auditing should ensure a flawless walkable environment. **Hence, measuring the walkability of the public space for elderly is the second step towards definitive understanding and assessment.**

The guiding principles of the public space design are derived from the evaluation model, hence are essentially based on the first two steps. There is thus a logical derivation to design that becomes a comprehensive integrated approach to formulate the pedestrian environment. The design principle of elderly pedestrian realms is based on three main requisites - Navigation (*walkable*), Thresholds (*crossings*), Access (*amenities*). Each of these is essential to complete the walking loop and shall remain incomplete when even one factor fails in design; unobstructed linearity along streets- sidewalks being the prime intent along with the added characteristics of supporting pedestrian infrastructure. Hence, design of the public space milieu in residential neighborhoods towards elderly walkability is a derivative of the understanding and measurement of the physical environment as a system of interconnected loops. The research opens avenues to further formalized research with specific focus on the psychological implications & socio-behavioral responses of elderly while being solitary or otherwise in the public realms of their dwelling zones.

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Prefabrication in the UAE Housing Sector: Review of Potentialities and Challenges

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Abstract: The construction sector accounts for the largest percentage of the total final energy use and carbon emissions worldwide. In the particular case of the UAE, the energy share consumed in buildings stands at a massive 70% with the residential sector carrying a heavy energy usage for cooling to mitigate the local extreme hot climate. This residential market sector is mainly in the form of extensive government-sponsored housing programs and large privately-funded rental developments. The dominant construction method for both government and private housing projects is in the form of a concrete post and beam structural system with insulated concrete blockwork infill. However, field investigations of this construction system, through thermography auditing, identified major thermal bridging due to different types of construction defects, not encountered in the precast construction system. In the pursuit of sustainable development and building energy efficiency, the UAE government has lately endorsed precast concrete construction in recent local housing programs. Several research studies confirmed the benefits of prefabrication construction method as well as its higher thermal and environmental performance. Still, this approach is met with economic and social resistance, thus hindering the growth potential of prefabrication in the UAE. Therefore, this paper discusses, through a rapid review and case studies, the challenges faced by construction industry in adopting prefabrication and the cause of these challenges. Further, the study explores the benefits of precast concrete construction that would potentially raise awareness on the feasibility and economic potential of precast concrete construction specifically within the UAE context.

Keywords: Prefabrication, Housing, Challenges, UAE, Sustainability, Energy efficiency, Opportunities, Social acceptance, Adaptation

1. Introduction

The urban growth in the UAE coincided with its rather recent economic boom, as result of its immense oil revenues [1]. The UAE's annual growth of 2.3 per cent from 2010, resulted in urban extension reflecting on the construction sector. The construction sector in the UAE is growing rapidly, the Business Monitor International (BMI) has reported a 6.6% growth in the construction sector in the UAE during the year of 2017. Amidst the country's overall growth, the residential sector developed mainly in the form of extensive housing programs provided either by the government to its citizens or privately developed for the rental market. The residential sector accounts for a significant amount of newly constructed detached houses, amounting to about 65% according to National Statistics Center [2].

Along with the economy and population growth, the energy supply and demand in the UAE is also increasing. Electricity production shows an annual increase of more than 13.5%. Similarly, energy consumption has increased 5.14 TWh each year in the same period; which is 13.3% each year. Particularly, results show that 75% of electricity is consumed in buildings, among which 40% goes to cooling and air conditioning [3]. 2005 Data demonstrate that 45.9% of the energy consumed was attributable to residential buildings and only 2.5% to commercial building [4]. In general, the findings highlight the ongoing energy demand growth in the UAE. However, the issue is being tackled through several governmental policies, initiatives, and goals set by the UAE state of energy.

The UAE government does acknowledge the issue and are introducing several energy conservation measures as an attempt to limit the energy consumption and reduce the carbon footprint. Currently the only regulated Emirates are Dubai and Abu Dhabi [5], where since 2014 the Dubai Green Building Regulations Limit U-values for the roof and walls to a maximum of 0.3 W/m2 K and 0.57 W/m2 K respectively, and the Estidama PEARL code applied in Abu Dhabi, which prescribes (at its lowest rating) maxima for roof and wall U-values of 0.14 W/m2 K, and 0.32 W/m2 K respectively [6]. More recently, in 2017, the UAE Ministry of Energy introduced the political feasibility of policy options for the UAE's Energy Transition where it announced a new UAE Energy Strategy 2050 that outlines a number of UAE energy targets for 2050 including: Energy Efficiency targeting 40 percent improvement relative to the current annual growth in electricity. Additionally, it targets increased implementation of Energy Efficiency (EE) standards with monitored building performance and audits to achieve greater EE technology adoption and demand site management [7].

The effect of workmanship quality on overall building energy performance is gaining increasing attention due to its unexpected impacts on the built environment. Mostly, workmanship errors that are encountered during construction affect the thermal performance of buildings [8]. Researches have shown that building envelopes contribute to more than 50% of the embodied energy distribution in major building elements in residential buildings; it also contributes to approximately 50–60% of the total heat gain in buildings [9]. Recent field study focusing on housing defects, especially those occurring in the building fabric, identified the nature, type, and origin of defect [11]. The field investigation explored conventional construction methods (reinforced skeleton system) as well as a prefabricated housing site. The results indicated a number of construction defects ranging from lack or discontinuity in building envelope insulation, thermal bridging, and discrepancies due to non-compliant design changes [12]. All occurring in the conventional construction while the prefabricated exhibited none of these deficiencies. These all carry a heavy burden in terms of building energy efficiency, thus visioning the prefabricated housing as a superior or more efficient method. However, the growth and acceptance of this remains hesitant. Besides the energy efficiency in the housing sector and the built environment in general, the UAE government acknowledges the need for a faster provision of housing units to meet the growing population demand [10]. However, prefabrication in the housing sector in the UAE remains timid and limited to very few projects.

The aim of this paper is to review and explores the various benefits of precast concrete construction in terms of environmental, economic and social that would potentially raise awareness on the feasibility and economic potential of precast concrete construction along hindrances of adopting prefabrication and possible challenges for its growth within the specifics of the UAE context.

2. Methodology

The rapid review methodology was chosen to conduct this research. Rapid review is variation of systematic literature review, with simplified components or omitted ones to produce information in a shorter timeframe work [13]. The approach used to conduct this rapid review followed the protocol proposed in Lagisz et al [14], which include five steps: problem definition, search string and filtering process, screening, data extraction and synthesis, and quality assessment of selected studies. Ideally all of the outlined steps would be completed during a rapid review; however, there will be instances where some steps may need to be skipped, or some steps may not be completed as thoroughly as they would be if more time were available [15]. In this research, due to the short timeline and availability of resources, the authors decided to skip the last step regarding quality assessment of selected studies. The research question for this review was refined to "how precast concrete construction benefits in terms of environmental, economic and social would increase feasibility of adapting prefabrication in UAE, and what are the challenges for its growth?". The authors searched for primary studies in the main collection of the Science direct database and Taylor & Francis database, two search strings were devised for this rapid review. The aim of the first search was to capture articles related to benefits of concrete prefabrication. The second search focused on prefabrication in UAE, using additional search on Google Scholar and Google to capture relevant grey literature of interest that may not have been found through primary database search. Articles deemed eligible consisted of either academic articles or selected grey literature (industry reports), or selected case study articles, that met the study scope.

3. Prefabrication and Sustainability

In prefabrication construction method, a certain amount of building components is manufactured at specialized facility, transported to the construction site and assembled into buildings, which is distinct from traditional construction method, where construction materials are transported to the construction site and cast in situ [16]. The existing literature, attests of various benefits that are associated with prefabrication compared to conventional methods such as: : better building quality and high quality control [17], improvement of the speed of construction and improved productivity [18], reduction of the overall cost of construction [19], reduction of the construction waste [20], reduction of the environmental impacts [21], improvement of working condition and health and safety of the workers[22], reduction of the environmental impacts to residents around construction sites[23]. Prefabrication construction method is synonyms to sustainable construction method, due to pervious listed advantages that can be classified as environmental, economic and social benefits.

The environmental benefits of using prefabrication construction method has been identified in many researches in terms of Lifecyle assessment (LCA) analysis through: materials and resources consumption, embodied energy, Green House Gases (GHG) emissions, and waste production [24]. Cao et al., carried out a comparative study of environmental performance between prefabricated and traditional residential buildings in China. The results revealed that the sample prefabricated residential building (PRB) construction was more efficient in energy use, with a 20.49% reduction in total consumption compared to the sample traditional residential building (TRB) construction, including a 35.82% reduction in resource depletion, a 6.61% reduction in health damage and a 3.47% reduction in ecosystem damage [25]. Another study compares the carbon emissions of precast and traditional cast-in-situ construction methods based on a case study of a private residential building in Hong Kong, using Life cycle assessment (LCA). It is found that the carbon emission of the studied residential apartment is 669 kg carbon dioxide equivalent per one square meter floor area, and precast construction method can lead to 10% carbon reduction for one cubic meter concrete, suggesting adopting more precast concrete can lead to less carbon emission [26]. Hong et al investigated the life-cycle energy use of prefabricated components and the corresponding effect on the total embodied energy use for a number of building projects. Result showed that recycling process could achieve 16% - 24% energy reduction, and energy savings are also obtained from waste reduction and high-quality control, saving 4% - 14% of the total life-cycle energy consumption [27]. In studies exploring the influence of prefabrication on construction waste reduction, Li et al study proposed a dynamic model for quantitatively assessing the impact of off-site prefabrication on construction waste reduction and the corresponding waste handling activities [28].

In terms of the effect using prefabrication in the reduction of the overall cost of construction, a comparative study of the direct costs between prefabricated housing system and traditional construction technology is carried out in China Mainland. A comparison of direct cost is made for 100 m2 of walls between precast concrete wall panel and the cast-in-site wall by using the method of fixed set of prices. The result showed that the prefabricated system has a higher mechanical and material costs (124.3% higher mechanical cost and 134.6% higher material cost), while it has a lower labour cost (86.5% lower labour cost). The overall direct cost of the precast concrete wall panel is not much higher (105.5%) than the traditional brick wall [29]. In similar study about cost reduction in prefabrication construction method, compared cost performance for 20 mediums to high rise residential buildings of eight projects by a leading UK housebuilder over a five-year period (2004–08), using four types of construction method: precast concrete cross-wall panel, in-situ reinforced concrete (RC) frame, steel frame and timber frame. In all cases, detailed cost comparisons were completed for build method selection. The study demonstrated that precast concrete cross-wall panel was found to be consistently cheaper than RC frame or steel frame by 11% to 32% in the projects. The process of developing and innovating precast concrete cross-wall technology led to sustained cost savings up to 25% from its first use, and improved cost effectiveness of 20-storey high rise buildings over other solutions [30].

Looking to the social benefit of prefabrication, Jaillon and Poon (2008) examined the sustainable aspects of adopting prefabrication in high-rise buildings, and assessed the economic, environmental and social aspects of using prefabrication [21]. The finding revealed that, improved site safety is a major benefit of prefabrication when compared to conventional construction. Compared to the industry figures, the studied case studies show a significant reduction of accident rates (63% lower), with an average of 22 accidents per 1000 workers. The other advantage of prefabrication is the reduction in construction noise and dust on-site, thus benefiting both the employees and the neighboring communities [21]. From the previous studies, prefabrication can be considered as a safe, economical, and environmentally friendly method for the construction industry.

4. Prefabrication in UAE's construction industry

The precast market in the UAE is growing with steady pace, with an expected growth rate of 4.4% between 2018 and 2024, and it is representing roughly 30% of the UAE construction market [10]. Precast products are classified into three main categories; structural precast products which accounts 50% of the overall precast market value followed by architectural products (30%), and miscellaneous products (20%) and shown in Figure1 [31].

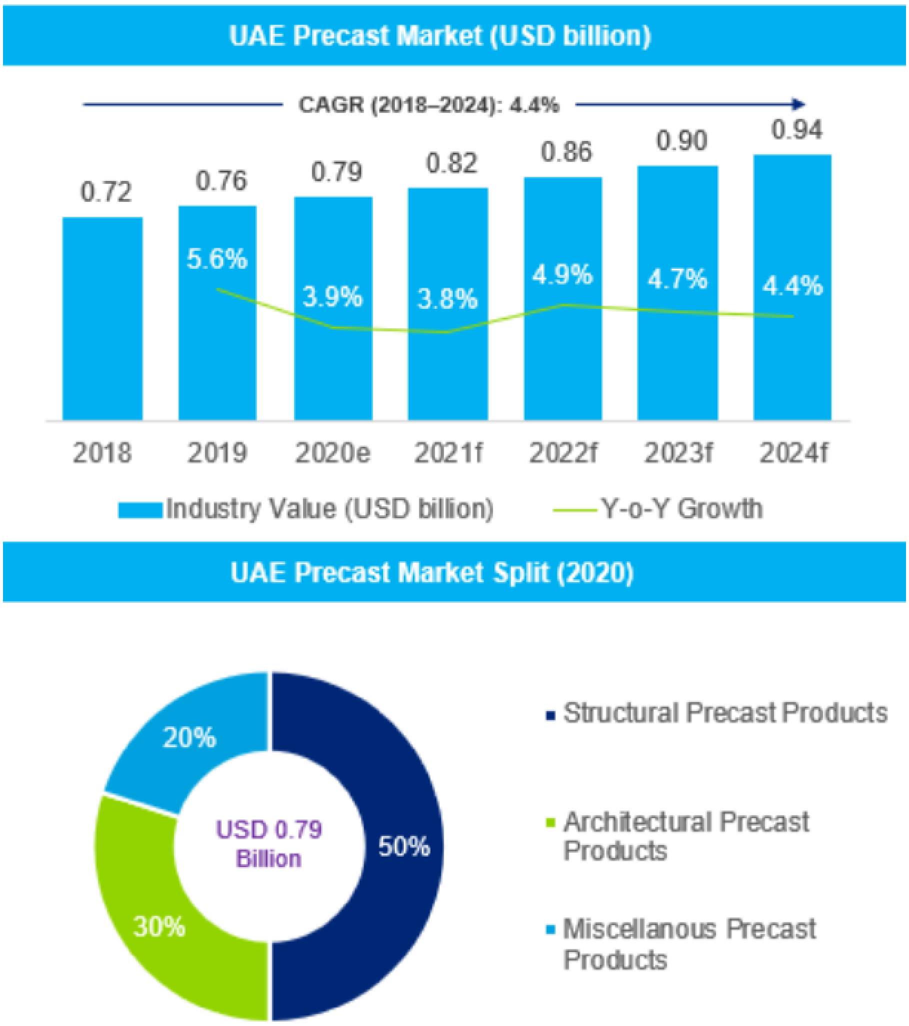

Figure 1: UAE precast market share 2018-2024 and market supply [31]

There is tendency toward adopting precast construction method in government and private housing projects in UAE. For the repetitive and massive nature of these project applying precast construction method is an efficient alternative to the traditional building techniques. One of the main factors to consider in selection of precast construction method is the rapid rate of production reducing the construction time. This seems to create attraction within both the private sector and the government housing providers. A recent development in Dubai, named DAMAC Hills neighborhood, developed by one of the main private developers in Dubai (DAMAC) represent a regular size villa with 500m2 plot area each required a total duration of 6 months for engineering, assembly and final delivery. This is due to the use of precast lite panel which dramatically increased the speed of installation/completion in comparison to the traditional concrete and AAC (Autoclaved Aerated Concrete) block work as illustrated in Figure 2 [32]. DAMAC Hills neighborhood development offers real state apartments and villas enclosing well-built residential units. It is a self-contained community with plenty of amenities, and it is home to the Trump International Golf Club Dubai with nearly four million square feet of parkland. The project comprises 2000 units with 1200 units across three residential apartment towers and 800 units in the Paramount Hotel tower. The property located in Dubai's Business Bay area has a total built-up area of 4 million square feet. The masterplan is divided into categories of housing: Villas on the Golf Course, Villas in the Park, Golf Residences, Park Residences, The Trump Estates, DAMAC Villas by Paramount Hotels & Resorts, Fendi-styled villas, Trump PRVT Mansions, and High Gardens apartments as illustrated in Figure 3 [33].

Figure 2: DAMAC Hill construction site [32]

Figure 3: (a) DAMAC Hill master plan [33]

Another example is Al Falah villa development in Abu Dhabi, which is one of the biggest national housing projects in UAE funded by the government. Al Falah community was planned around five distinct zones labelled villages and a town center. The master plan comes in hexagonal shape bounded by four existing roads. The hexagonal shape is divided into six almost equal triangles; five of them are representing the five residential villages while the sixth represents the town center.

According to G.H.M designer, the selection of hexagonal shape was due to the vibrant tradition of using geometric principles in the Islamic architecture and art as illustrated in Figure 4 [34]. The five villages consist of about 4800 detached houses with various sizes and architectural styles. The basic plan is similar while architectural style finished included three references labelled as Andalucía, Gulf Heritage and Modern styles, there are three different sizes of villas 3bedroom, 4bedroom, and 5bedroom villas. Each villa size has three architectural styles; Andalucía, Gulf Heritage and Modern styles. Villas with same size shares same floor plan with difference in façade design according to the architectural style [35]. The following Table 1 shows perspectives for the three different sizes and the three architectural styles [36]. In terms of construction method, 4,126 villas were completed in 24 months using precast construction method, while only 730 villas were completed in 20 month using traditional cast-on-site [10]. Pre-stressed hollow core planks used for floors, precast panels as walls and ground beam forming the full raft foundation perimeter. The high-performance U-Value of a precast envelope ensure continuity of insulation throughout the building envelope to mitigate thermal bridging (0.47 W/m2. K U-Value with 200mm thick precast insulated 'sandwich' panel) [37]. Furthermore, in Al Falah project, using modular bathroom units installed at the precast erection stage created a clear time saving of approximately 8 program days per villa which signifyingly reduce the dependence of bathroom MEP final-fix installations and associated testing & commissioning inspections on ceramic tiling completion [37].

(a)

(b)

Figure 4: (a) Al Falah concept master plan [34], (b) Map location of Al Falah villa development.

Table 1: Villa classification by architectural style and size in Al Falah villa development.

	THREE BEDROOM VILLA	FOUR BEDROOM VILLA	FIVE BEDROOM VILLA
ANDALUCIA			
GULF HERITAGE			
MODERN			
Number of stories	1Story	2 Stories	2Stories
Floor Area	293.15 m2	356.96 m2	418.38m2

5. Challenges of adopting prefabrication in UAE

There are different housing programs in UAE, real state housing program where developer build for sell/rent the residential units, and national housing programs, where the government build for the local citizen. Within the national housing program there are two methods of housing provision. First, the government provides residential units within integrated community and delivers thousands of houses for middle income sector which represent almost 40 percent of all households in UAE [10]. In this housing provision recently, the government adopted precast construction method as a fast production and sustainable construction method for its environmental and economic impacts. Second, the government provide a plot of land and financing to build a house, where this initiative delivered using conventional cast in site and considered as an individual construction.

UAE's precast market is fragmented with only 8-9 contractors being approved by the government agencies, more precast companies should compete with quality products to shift towards sustainability [31]. The application of prefabrication in the individual residential construction sector is challenging, most house owners are hesitant to use prefabrication owing to the slightly higher cost of prefabrication when compared with conventional construction methods. **Ann Grace Villanueva** highlighted that precast products are generally expensive as compared to the in-cast concrete, and the cost of a typical villa made with precast concrete is 25% higher as compared to in-cast concrete, but this cost could be overcoming with higher volume (500 – 1000 housing units) to reach the same cost of in cast concrete method [31]. However, most of residential fabric in the cities is made up of individual residential construction. For this reason, unless there is a financial change of the cost of prefabrication, most of the house owners will be reluctant to adopt prefabrication.

The other reason that hindrance the implementation of precast construction method is the lack of public awareness and knowledge of precast concrete method. It is important that all construction industry members from contractor, consultants, to house owners are fully aware of the importance and benefits of precast as sustainable construction method. This will increase the interest and motivation to pursue knowledge and decision making that will contribute the least damage to the environment [38]. Other drawbacks of prefabrication are impaired aesthetics and inflexible design change. A study carried out in Al Falah community in Abu Dhabi (one of the biggest national government housing projects) reported that 67.2% of houses filed modification and addition permits within three years from handover date, due to inflexibility of the design that inherited by using precast concrete construction methods. Based on the records of permits requests by owners, the majority of the modifications and additions were related to increasing the level of privacy, and accommodating family expansion. These materialized into modification of double height entrance Lobby, as it seems to be generally not preferred, as, the main gate was not providing enough privacy as needed in Emirati culture, and the French window is not a suitable design for Emirati [10].

Apart, from this account based on modification and additions, there is currently no detailed study in UAE on residents' feedback, perception, adaptation or satisfaction with the prefabricated housing units.

6. Conclusions

Adequate housing provision remains a goal and a concern in developed and developing countries. Prefabricated housing units stand as a fast and efficient construction method, saving construction time and being more energy efficient. In the United Arab Emirates, the government recognizes the shortage of housing and the need for fast production, indicating prefabrication as a lead path to meet the demand. However, the growth of the prefabrication sector remains slow and the challenges behind it have not yet been fully explored. The existing cases indicate social acceptability as a potential barrier. In Al Falah development, rich of over 4000 units, the residents have undertaken several changes to the original design, indicating a non-fit solution. However, this warrants a full exploration and an in-depth study of the residents' perception, satisfaction and acceptability prior to recommending residents involvement in the design, opportunities for personalization and customization for a better response to the needs.

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Users' Preferences for Office Spaces in Akure Metropolis

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Abstract: The paper examines the Users' Preferences for Office Spaces in Akure metropolis. Data was collected through questionnaires from the occupants/tenants of office properties in Akure, Nigeria, estate surveying and valuation firms' management portfolio. A total of 50 offices (representing the total of selected 2 offices from each of the 25-estate surveying and valuation firms in the study area) were sampled for ease of coverage. In the questionnaire administration, 2 office properties were purposively sampled from the portfolio of each sampled estate surveying and valuation firm. In each selected office property, 2 tenants were purposively selected from each sampled office property. Therefore, a total of 100 tenants in 50 office properties were selected for sampling. The paper adopts a quantitative method of data analysis. Descriptive techniques were adopted; it includes the tabular analysis of data using percentages and frequencies. The relative Preference Indexes were also determined. From the empirical studies, it was discovered that most of the respondents have the highest preference for Executive suites type of office space (50.0%), even though a larger percentage of them are occupying Traditional office spaces due to the fact that they cannot afford Executive suites as it is always more expensive as compared to other categories. They, however, have the lowest preference for the Contiguous office category of office space.

Keywords: Users' Preferences, Office Spaces, Akure, Relative Preference Index, Executive suites, Traditional office spaces, Contiguous office.

1. Introduction

Currently, the world is experiencing an extreme growth in building sector. The building or space development targets the improvement of various commercial activities as well as enhancing the availability of public facilities [1-2]. According to [3], what usually lead to an organization seeking for more optimal use of facilities and space, positive image, better use of resources, improved performance, increased flexibility, and increased users' satisfaction is the allocation of different categories of space for various type of office activities.

However, in office space studies, we have two major points agreed upon by most researchers, which are cost and the utilization of space. [4] said effective utilization of office space can help in reducing an organizational cost apart from the daily work activities support. However, there is difference between the government sector office space utilization and that the private sector. In some instances, there can be overutilization of space or underutilization of space due to the present working environment changing pattern [5].

Office space has a direct response to a person's relationship with work and his involvement in work processes. Several authors [6-7] have noted how the physical properties of work setting and environment has brought about better organizational performance. The office space can be used to increase the productivity of the employees. As stated by [8], a tool that can help to achieve a corporation's goals and can be used to improve business outcomes is an office space.

The development of new kinds of office properties have been as a result of several market changes. Some of these new developments includes; more use of public spaces as work spaces [9], new working ways [10], more need for flexibility [11]; [12], the economy sharing [13]. more number of self-employed workers, development in technology use, and the decreasing and changing request for office space [14]; [12].

More research on users' preferences for office space is required so that office property owners or managers can effectively attend to these preferences by creating office spaces in an increasingly competitive development market that will attract more tenants. Therefore, this study is aimed towards analyzing the users' preferences for office spaces with a view to providing office property owners or managers with tools, skills and competencies to improve their competitive position.

2. Review of Relevant Literature

Studies that majorly focus on office space users mostly examine what motivate the users to occupy and work in different office spaces. For example, [15] found that the main factors users consider in making the choice of their office spaces are related to location. The report gave by [16] shows that rental costs are the most crucial factors that determine the users' preference for office space for about 47% of the respondents. In addition, other important motivations that determine the users' preference for office space were the amazing and nice environment found in the particular spaces [17], and the fact that they felt part of an environment [18].

However, there are still limited research on users' preferences for office spaces. One of the limited studies which is related to user preferences by [19] is on the features of multi-tenanted office properties, and it's generally based on users' satisfaction. Several physical features of multi-tenanted office properties were grouped into ten essential multi-tenanted office properties factors, which includes: office exterior and division, location, office decoration, services and facilities, office leisure, seclusion rooms, information and communication technology (ICT) and equipment, office climate and privacy. According to the results obtained, the multi-tenanted office properties users are the most satisfied with the availability of fixed workspaces and general accessibility and the least satisfied with the individual personal control of the indoor climate.

Besides the features of the office property spaces, past studies also revealed proof for the influence of individual features on users' preferences. For instance, [20] revealed that what majorly influence preferences for several parts of single-tenanted office property workspaces is the individual differences (i.e., gender, age, time spent working individually, time spent at the office). They revealed, for instance, that the category of people that prefer personal control of the indoor climate are the older workers while a workplace that induces teamwork are being preferred the younger workers. Also, they revealed that respondents who value most the ability of the work environment to support the values and image of their organization are those who spend most of their working hours at the office [20].

According to [21], another thing that influences users' preferences is the sector of the organization. They revealed, for instance, that the creative industry workers prefer shared areas with flexible layout, representative interior and meeting spaces for the organizations they work for.

Studies by [22] reveal that higher environmental satisfaction and higher privacy ratings is associated with increased enclosure. Users seem to prioritize a private office work space over a non-private office work space. One of the most frequently mentioned problems in open office spaces is lack of privacy. Due to the close proximity in which employees are seated, they can become over-stimulated. It is more difficult for employees to maintain a desired level of privacy and avoid contact with one another under these circumstances.

In office design, an important factor to be noted is the ability to work individually without distractions. More than 50% of the workers in open-plan office spaces report that during work, they are usually disturbed by noise from conversations between others, from telephones, office automation and air conditioning systems. Disturbance among colleagues and subsequently increased communication can cause workers to find it difficult to concentrate in open plan offices [23].

What seems to lead to higher levels of job satisfaction is the ability to choose an office space based on personal preferences [24]. According to [25], people experience a considerable amount of control as it is possible to sit anywhere in an office with flexible workspaces.

This paper is very important for two main reasons. First, it covers how owners/managers of office properties can create office spaces that attract more tenants in an increasingly competitive growth market and optimally respond to these users' preferences for office spaces. Second, in order to provide owners/managers of office properties with tools, skills and competencies to improve their competitive position, it analyzes the users' preferences for office spaces and the influence of users' characteristics on these preferences.

3. Methodology

In order to investigate the users' preferences for office spaces, data was collected through questionnaires from the occupants/tenants of office properties in Akure, Nigeria, estate surveying and valuation firms' management portfolio. A total of 50 offices (representing the total of selected 2 offices from each of the 25-estate surveying and valuation firms in the study area) were sampled for ease of coverage. In the questionnaire administration, 2 office properties were purposively sampled from the portfolio of each sampled estate surveying and valuation firms. Purposive method of sample selection was adopted to select offices from the portfolio of estate surveying and valuation firms in order to cover different locations and gather data about users' preferences for office spaces. In each selected office space, 2 tenants were purposively selected from each sampled office space. Therefore, a total of 100 tenants in 50 office spaces were selected for sampling.

In the Section A of the questionnaire, questions on the socio-economic characteristics of the respondents and the reasons for their choice of office space were asked. The respondents were asked further in Section B of the questionnaire to rate the level of their preferences for office spaces using Likert's scale.

For the data analysis, descriptive technique was adopted to assess users' preferences for office spaces. It involves the tabular analysis of data using percentages and frequencies and Relative Preference Index (RPI).

4. Analysis and Results

One-hundred (100) questionnaires were administered to the tenants of office properties in Akure Metropolis. Fifty-Four (94) questionnaires were collected and found useful, which represents 94% rate of response, 6 questionnaires were not returned which represent 6% of the response rate. Tables 1-3 below presented the socio-economic characteristics of respondents who are tenants of office properties in Akure Metropolis. In this section, they supplied the data needed for this survey in terms of; Age of respondent, academic qualification of respondent, Type of Office Space etc. This was done so as to ascertain the reliability and validity of the data collected for the study and also for the researcher to familiarise himself with the respondents for the study.

Table 1: Ages of Tenants of Office Properties in Akure Metropolis

Age	Frequency	Percentage
20 – 30	19	20.2
31 – 40	22	23.4
41 – 50	35	37.2
51 – 60	15	15.9
61 – 70	3	3.2
70 and above	0	0
Total	94	100.0

Source: Authors' field survey, 2021

With respect to ages of the respondents in the study area, most of the office properties tenants are between the ages of 41 and 50 (i.e., 37.2%). This is followed by those within the ages of 31 and 40 (i.e., 23.4%). 16.7% of the tenants are between the ages of 20 and 30. Some are between 51 and 60 years of age (i.e., 15.9%) while we only have one of the respondents which is between 61 and 70 years of age (i.e., 3.2%) and none of the respondents are 70 years and above. Most of the respondents are in their mid-adulthood. So, they are matured enough to take office spaces and also to respond adequately to the questions provided in the questionnaires.

Table 2: Academic Qualification of Tenants of Office Properties in Akure Metropolis

Academic Qualification	Frequency	Percentage
OND	21	22.3
HND	33	35.1
B. Sc.	18	19.1
M. Sc.	14	14.9
Others	8	8.5
Total	94	100.0

Source: Authors' field survey, 2021

From the table, it can be inferred that with respect to their academic qualification, 35.1% of the study population are HND holders, 22.3% are OND holders, and 19.1% are B. Sc. holders while 14.9% are M.Sc. holders. Holders of other certificate of education such as the SSCE are 8.5%. This revealed that the most of the respondents are well educated and academically qualified to respond adequately to the questionnaires. This response revealed that the data gathered for this study could be reliable as per the respondents' educational levels

Table 3: Types of Office Spaces Occupied by Tenants in Akure metropolis

Type of Office Spaces	**Frequency**	**Percentage**
Traditional Office Space	26	27.7
Creative Office Space	8	8.5
Co-working Space	17	18.1
Executive suites	9	9.6
Flex Space	6	6.4
Contiguous Office Space	12	12.8
Other Types of Office Space	16	17.0
Total	94	100.0

Source: Authors' field survey, 2021

The table reveals that most of the Office Spaces occupied by tenants in the study area are Traditional Office Spaces (i.e., 27.7%). 18.1% are Co-working Spaces. 8.5% are Creative Office Spaces. 9.6% are Executive suites. 12.8% are for Contiguous Office Spaces, while 17.0% are for other categories of office spaces that are not on the questionnaire. The lowest percentage of Office Spaces occupied by respondents in the study area is Flex Space with 6.4%. This indicates that Traditional Office Spaces dominates the study area.

4.1 Users' Preferences for Office Spaces in Akure metropolis

The following Likert scale was used in the questionnaire to measure the level of users' preferences for office spaces in Akure metropolis: 1 as Not prefer (NP), 2 as Indifferent (I), 3 as Prefer (P), 4 as More prefer (MP_1), and 5 as Most prefer (MP_2). Their frequency and percentages of responses are as presented in the table below. The responses were subsequently analysed using descriptive statistical techniques (frequency percentage) and the results were ranked accordingly in ascending order using Relative Preference Index (RPI).

Table 4: Relative Preference Index (RPI) of the Users' Preferences for Office Spaces in Akure metropolis

Users' Preferences for Office Spaces	NP (1) Freq. (%)	I (2) Freq. (%)	P (3) Freq. (%)	MP1 (4) Freq. (%)	MP2 (5) Freq. (%)	RPI	RANK
Traditional Office Space	13 (13.8)	17 (18.1)	21 (22.3)	20 (21.3)	23 (24.5)	0.65	3rd
Creative Office Space	20 (21.3)	16 (17.0)	19 (20.2)	22 (23.4)	17 (18.1)	0.60	6th
Co-working Space	15 (15.9)	18 (19.1)	14 (14.9)	23 (24.5)	24 (25.5)	0.65	3rd
Executive suites	2 (2.1)	13 (13.8)	12 (12.8)	20 (21.3)	47 (50.0)	0.81	1st
Flex Space	11 (11.7)	21 (22.3)	23 (24.5)	18 (19.1)	21 (22.3)	0.64	5th
Contiguous Office Space	17 (12.9)	25 (27.8)	18 (5.6)	15 (27.8)	19 (25.9)	0.58	7th
Other Types of Office Space	10 (11.1)	14 (14.9)	26 (29.6)	24 (25.5)	20 (21.3)	0.66	2nd

Source: Authors' field survey, 2021

In order to better understand the Users' Preferences for Office Space in Akure metropolis, the various responses obtained were analysed and ranked. Relative Preference Index (RPI) (see Table 4) pointed to the fact that Executive Office Space with RPI of 0.81 has the highest level of most prefer with 50.0%. It is followed by Co-working Space with 25.5%. With a RPI of 0.58, Contiguous Office Space has the lowest level of preference by office space users. Traditional Office Space and Co-working Space have the same RPI of 0.65, which means that the Users preferences for these categories of office spaces are relatively the same. These were the rank of users' preferences for different categories of office spaces. Therefore, tenants prefer office spaces in this order with the Executive suites as the greatest or most prefer office space.

5. Conclusion

The paper examined the users' preferences for office space in Akure. The users of office spaces in Akure, Nigeria have given their preferences for office space in this area. Through questionnaires served on these respondents and personal interviews, it was discovered that most of the respondents have the highest preference for Executive suites type of office space, even though larger percentage of them are occupying Traditional office spaces due to the fact that they cannot afford Executive suites as it is always more expensive as compared to other categories. They however have the lowest preference for the Contiguous office space category of office space. It can therefore be concluded that most of the office space users in Akure are occupying Traditional type of office space, they however desired to take and give highest preference for Executive Suite type of office space but most of them are majorly hindered by financial commitment to take and occupy this type of office space.

Conflict of Interests

The authors declare that there is no conflict of interests.

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Active and Participatory User Contribution to Inclusive Design For Net Zero Homes in the United Arab Emirates

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Abstract: United Arab Emirates (UAE) National Agenda, National Legal Framework & Policies, and Technology leads in multidisciplinary topics such as Human Computer Interaction (HCI), Ergonomics of human-system interaction, Housing Models such as Solar Decathlon Middle East (SDME), has led to short-term and long-term Strategies and Initiatives for Energy by the Electricity and Water Authorities of the UAE Government. There are various Operational, Infrastructure and Economic, usually heuristic impediments, not to mention the nascent nature of the HCI and User Experience / User Interface (UX/UI) work in this area that must be considered. The aim, objective and focus of the research below is garnering the above information and relating it together by identifying the missing inclusivity elements, local legalities, and partners. This is required for effectively deploying User Behavior/Engagement to promote User Empowerment and Participatory Governance for the active and participatory contribution of Inclusive Design -to meet Societal requirements in context with Net Zero Energy Building (nZEB) and Housing, for meeting the ZEMCH Objectives of Inclusive and sustainable Built Environments in UAE. The results sdrawn indicates that User Behavior and Engagement is the key to success for Cost to Benefit percolation and Return on Investments, thereby promoting User Empowerment through Inclusive Design for All (Age-Friendly, Disabled Friendly, and Special Needs Friendly). Using Computer Science and Engineering in UX and UI Design, HCI, Artificial Intelligence (AI), Machine Learning (ML) and Deep Learning (DL), and Internet of Things (IoT) seems the best way forward to the success of all such Engagements and Empowerments. Municipal Questionnaire(s) when combined with applied UX Methodology for Inclusive Housings, interpret/result in Inclusive Designs. Potential improvements and further design and development requirements for success can be related to the emerging fields of technology and aiming them to make Users Contribute towards making nZEB and Housing Inclusive and Livable.

Keywords: Inclusive Design ; Citizen Contribution ; User Experience (UX) ; User Interface (UI) ; Participatory Design ; Interaction Design (IxD) ; Human Computer Interaction (HCI); Artificial Intelligence (AI)

1. Introduction

"A calm and modest life brings more happiness than the pursuit of success combined with constant restlessness." - Albert Einstein [1].

Happiness mentioned by Dr. Albert Einstein as a virtue is subjective, and all Governments and related Institutional Policies are aimed at mining this Happiness. Once the Policies are outlined, they get executed to achieve the desired results. Calm and Modesty, as Dr. Einstein muses, is analogous to serenity combined with sustainability, which is what the world is in dire need of today. Dr. Einstein in his capacity as a successful scientist, rightly points out that while the pursuit of success provides purpose to human life, it does not always bring happiness. One needs to go beyond the codes into the lives of the users and see where happiness lies for them, what makes them tick, and what gives them more of the happiness. It needs to be ascertained whether happiness index measures the nation's strength, and if it is sufficient to track and explain the quality of lives of the Citizens of a Nation. Given that there is a Legislative Basis for Inclusion - internationally, nationally (in the UAE), and provincially (in the seven Emirates of the UAE), evolution of law and policy has led to ideological shifts that result in the promotion of inclusion and belonging:

- Dubai Universal Design Code (2017)
- UAE Federal Law, No. 29 (2006) In Respect of the Rights of People with Special Needs
- Dubai Law, No. 2 (2014) concerning the 'Protection of the rights of those with disabilities in the Emirate of Dubai.'
- Article 27 of the Dubai Municipality – Building Regulations
- UAE Fire & Life Safety Code of Practice
- Ministerial decree No 43 of 2018 for private sector firms to create accessible working environments for People of Determination.

Housing is a sector, that not only garners a level of trust and investment, but the market also inherits the need to keep the needs and wants of its inhabitants, and the society [2]. The higher ratio of expats, as compared to the nationals in the United Arab Emirates, makes the market diverse and dynamic. Due to ever changing and churning facets of modern technology, housing needs to be automated, and walk arm in arm with technological advancements. The needs are now being normalized by the authorities, and behind the scenes individuals, i.e., the primary stakeholders, like the Rulers, Regulatory Bodies, Law and Policy makers. On the other hand, all the additions of comfort that are needed to make a house homely and customized, are defined by the end-users of the house, and the builders. 'Zero Energy Mass Custom Homes' now uphold the merits of a reduced cost architecture with ameliorated sustainability performance, keeping in mind energy efficiency, and environmental safety and protection. This can be achieved through a degreed organizational framework, wherein the design processes have a convergent goal, with supplementary features, monitored by the Primary Stakeholders with active and participatory contribution from the Secondary Stakeholders in the inclusive design for net zero homes in UAE. Addressing the engagement statement prepared, in this study [3] - UAE, especially Dubai and Abu Dhabi as smart cities invests in modernization and fuel efficiency, to boost economic development bolstered through environmentally friendly practices, paving way for a higher quality of sustainable life, one that only increases, with banes being minimized. This is achieved through user-involvement, user interaction and their engagement and awareness throughout the tenure of the project, and after [4]. Due to increase in the transformation of the UAE's architectural scenario, and increase in affordable housing, road congestion, and larger populations living in, and expiating to populated cities like Dubai and Abu Dhabi, the coming decades will be very crucial to the housing market. Infrastructural elements like mobility, buildings and energy will all be impacted. Information and communication technology shall be interwoven into the connected networks of cities all over the world, and will become so ingrained into modern architecture, that users shall forget life before this integration, making them an essential to living and working. UAE has already taken a step towards digital dependency and has modernized its governance and way of functioning. From ambient lighting in parking lots to the introduction of accessibility features in RTA Road buses, enabled just through a touch of the fingers, UAE has efficiently incorporated technology into everyday life. Such technologies, have a plethora of applications and uses, from improving traffic flow to ensuring public safety and reduced space consumption, through the application of automata, whether it be for buildings, or for the vehicles required to get to that building [5].

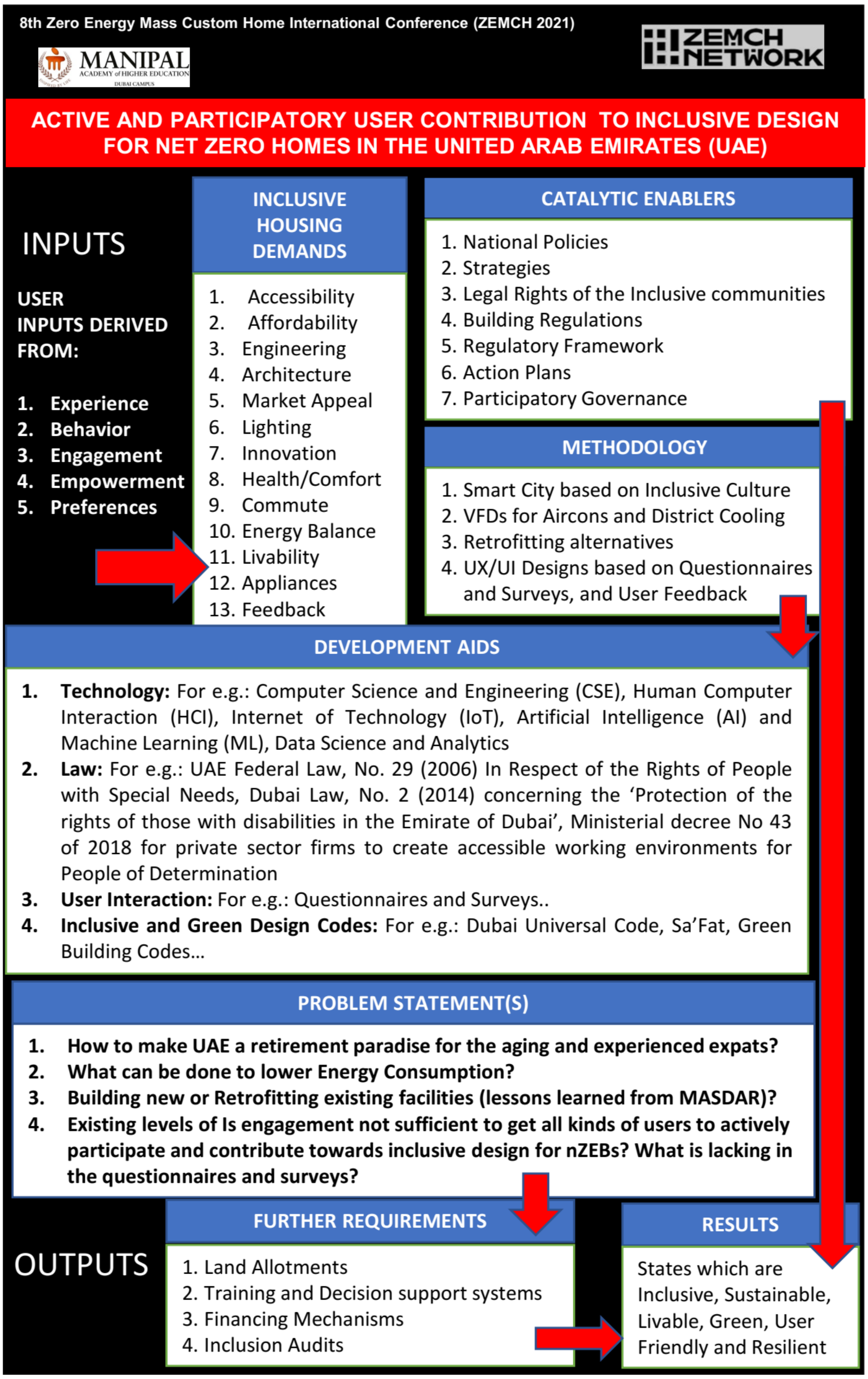

Figure 1. Framework and Inputs – Identifying and Shortlisting the Problem for the Purpose of this study. Is engagement sufficient to get all kinds of users to actively participate and contribute towards inclusive design for nZEBs? [6]

For the purpose and functioning of this housing demand study:

1. "Are any Inclusive Elements lacking in the questionnaires and surveys associated with this study", and
2. "What is being done to make innovation, design and technology inclusive"

By figuring out what is lacking in the surveys, the focus of the limelight is shed on the user, who is fundamentally the reason for engendering products, and thereby technology.

By questioning the result and underlying principle of the study, one creates more room for improvement by constantly enhancing and upgrading existing standards of living and working.

2. Materials and Methods

This research uses a diversified approach, which consists of a literature review and subsequent analysis of various aspects. The literature review was used to study local and worldwide findings in similar conditions and understand the nature of the Problem Stated.

Data collection involved gathering statistics (majorly surveys conducted: a viable option due to the large user group) from internet/websites of concerned authorities, research papers and direct observation of life and housing in the Emirates over the past one year, and analysis of technical documents. It must be recognized that surveys are a method for quantitative overviewed collection of data which is not essentially open-ended, which makes it paint just half the picture. Hence, considering it as exhaustively representative, might be a folly. This shall be exemplified as below.

Inclusive Design is used as a methodology, has enabled including a large group of socially and economically diverse people and catering to all their needs, by learning their pain-points and understanding what is required by them in a product or device. Inclusive Design believes in including all user groups, but it might not be able to branch out to thinner edge cases, which might be catered to by agile thinking practices, which focus on the user and help designers modulate their thinking according to the demand of the situation [7]. Although qualitative methods give an all-round understanding of the subject being studied, there has been a historical precedent of quantitative methods being used to study the development and improvement modifications of nZEBs starting from the 1970s, up until now in the 21st century [8].

Every person will have their own issues and quirks, which leads to the need for many permutations and combinations of questionnaires. To keep research succinct, effective, and most importantly inclusive, the paper further analyzes a sample of an existing questionnaire, and adding to it missing Inclusivity Elements, so that Active, Contributory and Participatory User feedback can be obtained for the final decision-making strategies.

The point of User Research is to understand user problems and create an effective methodology to generate themes and subsequently solutions to those themes. As aforementioned, the presence of a large user group to cater to, does not permit hand-picking and solving edge case users. Hence, the best strategy would be to cluster users into categories to which they belong through their walk of life, which gives a fair idea of their lifestyle, if not an in-depth analysis, a general overview that shall help generate data that might be helpful in creating elucidations to provide them with a sustainable régime and make their lives remarkably tranquil.

After User Interaction, one can identify the aspects of design that are negatively impacting the user. This shall help improve the existing version of that technology and ameliorate it's working. User Interaction and feedback shall also help in data collection and analysis which helps recuperate supposedly obsolete technology and bring it back to life by adopting sustainable methodologies of development, production and finally working by employing current research and advancements in the field of Artificial Intelligence, Cloud and Machine Learning.

The user groups will be linked to technology as well as other stakeholders as seen in Figure 2 below, which shall succor attainment of not only a perception of the operation chain but also an understanding of the social chain which the user is a key link of. This insight and its accurate comprehension shall enable upward mobility of sustenance through the required expenditure wherewithal.

On the next page, relations are depicted using User Input(s) to Feedback Mechanisms of all possible Inclusive Users indicating how Human intervention and User Experience corresponding to User Satisfaction can contribute towards Active and Participatory Utility Design; a logic thereby generated along with benefits of user interaction positively affecting the listed aspects, not exhaustive, of utility design and consumption.

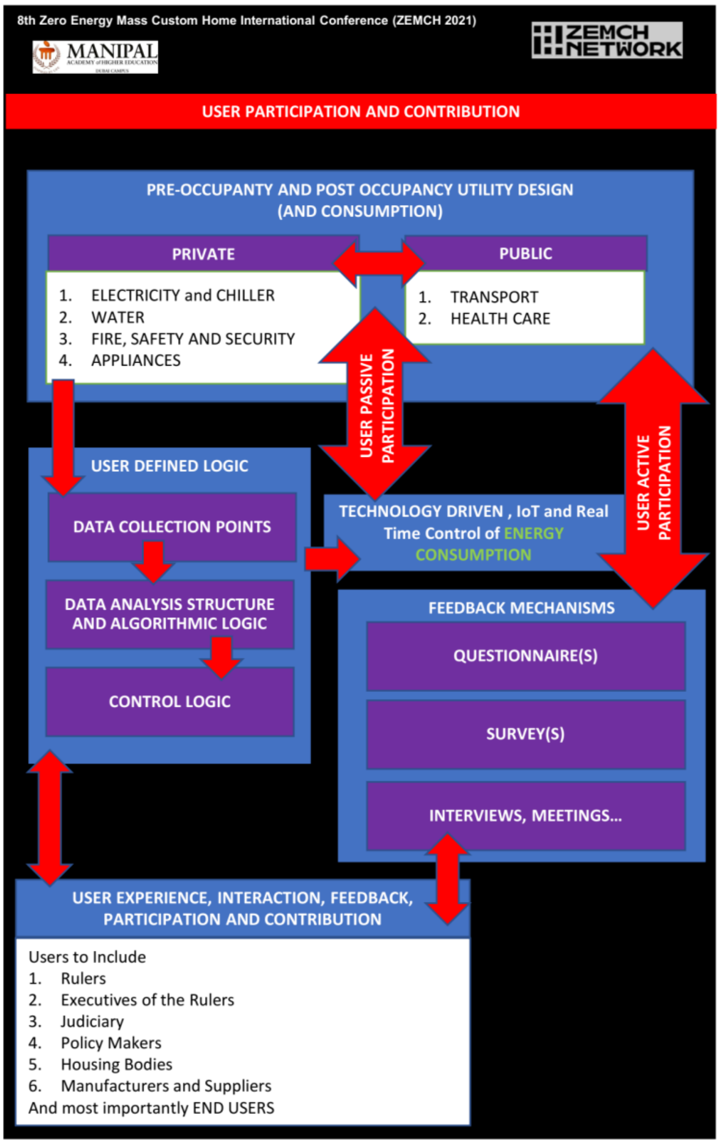

Figure 2. Outlining User Inputs, Inclusive Users, Human intervention, and User Experience corresponding to User Satisfaction towards Utility Design - without which Cities may become Ghost Towns

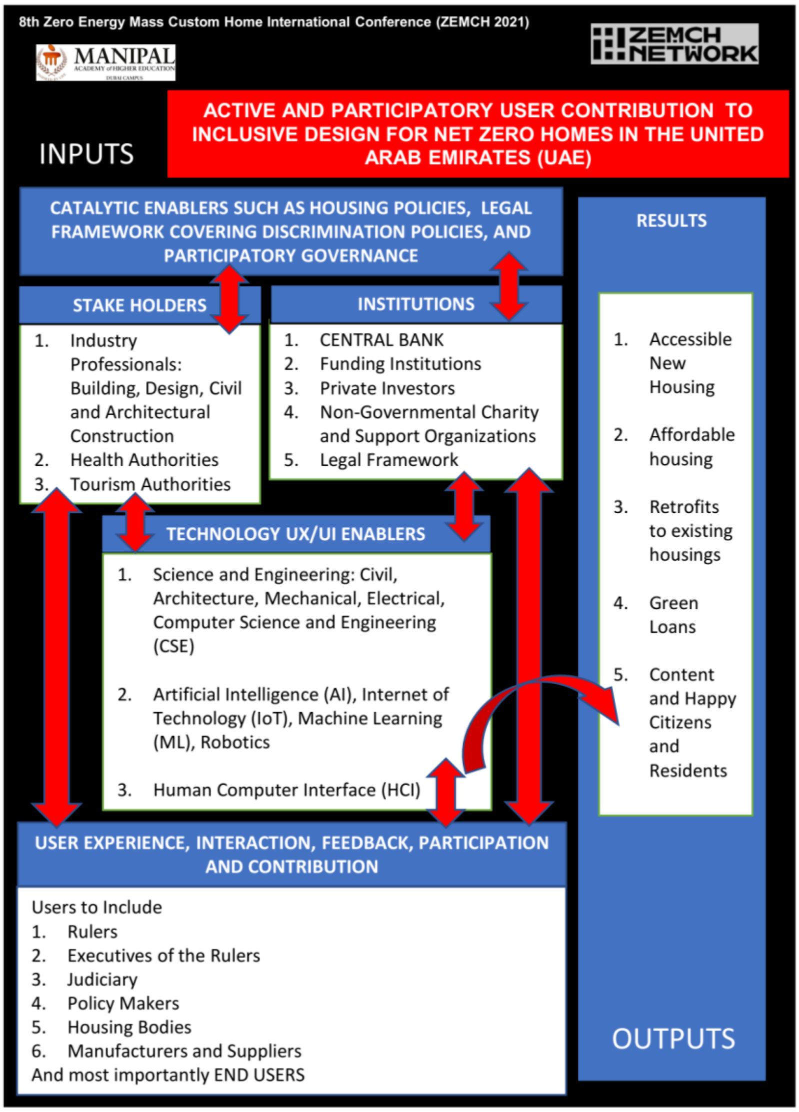

Figure 3. Technology UX/UI Enablers at the epicenter of the process for enabling Users Contribution to Inclusive Design for nZEBs

One will be able to identify the challenge posed by this topic, by relating the situation of getting a consensus on any controversial topic while at home. The amount of debate and the number of arguments will be well worth once a decision is arrived at after considering everyone's opinion.

Public participation is a catalyst to any decision-making process since people partake active and interested involvement in results and choices that format the quality of life they shall live in the vicinity of that decision [9]. “Principles of empowerment” guides the citizen participation process through the following [10]:

Political: that encompasses “rights of all citizens to future decisions”; touching upon the residences they live, relax, and operate from.

Humanistic: marks responsibility to design usable automated architecture, keeping in mind the location of the building for developing neighborhoods that integrate communities and build a pacific culture [11].

2.1. Scientific elaboration of methodology behind implementation of Inclusive Design

The Research methods used within the Inclusive Design Methodology can be scientifically elaborated on and gets clarified by:

1. Identifying the existing User Problems, Analyzing the Method(s) used presently to address the issues or problems.

2. Including what is found missing (qualitatively and quantitatively: mixed methods of research).
3. Identifying the local legalities involved.
4. Identifying the various partners, entities and associations required to implement the opportunities discovered with new findings from the questionnaire(s) in a socially inclusive, sustainable, accessible, affordable, and adaptable manner.
5. Maintaining consistency within the testing framework to understand user pain points [12].

This paper uses randomly sampled Municipal survey(s) as a benchmark and compares it with Internationally used Inclusive Survey Questionnaire(s). Therefore, it must consider that the analysis done encompasses the deterioration of response amongst individuals and households. This undermines the validity of surveys as a method of data collection. Due to the changing structure of the society and the pressure an individual must face at all fronts, it is likely, that they would not spend a lot of thought answering surveys, and many won't even answer them. What needs to be taken away from this is that these surveys are social interactions, and as abovesaid, almost the only way of reaching a large population, and having close to complete data representation [13]. Also, while processing the data received, one must hold into account, that the answers on surveys are just instinctive replies, that users have not placed much thought into, a bane of surveys that might have been resolved through rigorous interviewing, subsequently reducing the user pool. One can observe that this is a conundrum that tips neither way.

- Problem Statement: Case for UX/UI:

"I remind myself every morning: Nothing I say this day will teach me anything. So, if I'm going to learn, I must do it by listening." - Larry King, TV and radio interviewer and host [14].

Whatever we do, we cannot learn without being open to feedback as observed pertinently by King. Sustainability gets incorporated into our daily lives through devices and services we use. Hence the experience associated with the product must be optimal. To improve it, one must engage in User Research, to increase loyalty, engagement, usability, and equitability of the product/service.

2.2. User cases

Consider the following cases:

1. Parents of students in the age group of 5-25 years finding accommodation so that they do not have to spend hours in commuting between their house and school / college / place of work.

2. Youngsters in the age group of 20-40 years trying to find housing solutions which are low in rent, energy efficient, near to their place of work and entertainment hubs.

3. Aging people in the age group of 30-60 years, trying to maintain their health, and wanting to stay in houses which are near to parks, jogging tracks, and in the vicinity of public health centers.

4. Aged people above the age of 60 years wanting to spend the rest of their lives without having to do anything and spend their time enjoying the fruits of their labor till date.

5. Disabled, Handicapped and Social determination people hoping to find a place which will be compliant to meet their daily requirements.

6. Planning Authorities of Developing Smart Cities trying to find/develop a technical standard or code OR Legal framework which best suits their requirements.

7. Implementing Authorities of Developing Smart Cities coping with the gap between the plan, availability and the as Built Environments

8. Building/Constructing Industry trying to find a solution to meet customer requirements at the least possible cost.

9. Research and Development Universities/Institutes trying to keep up with the National Agenda of Inclusiveness and Sustainability

All the above categories are Users, whose active and participatory contribution can go a long way in arriving at successful Inclusive designs for nZEBs and Homes in UAE. In business, when everyone comes together, that's when ideas become reality. For the engagement to be sufficient one needs to get all kinds of users to actively participate and contribute towards inclusive design for nZEBs. As mentioned before, it needs to be determined what is (are) the missing inclusivity elements in the surveys.

2.3. Municipal Work

Dubai Municipality is an Authority which Permits, Monitors and Approves Buildings in Dubai. It recently launched campaigns for public feedback: "Questionnaire Form for Community Engagement in the future of construction" and "Questionnaire Form for Urban Expansion", and asked questions to Citizens/Residents/Visitors in the Emirates of Dubai for involving the concerned. As for an authority, Municipal work revolves around Policies, Permits and Approvals. The Questionnaires outlined are sufficient and adequate for the purpose. Going one step further, from a holistic point of view, for achieving target User Involvement, Participation, Contribution and Empowerment, some more information is required to be addressed, maybe not by the Municipality. A brief outline and summary of the same follows below, with the Municipal Questionnaire as the base. These surveys help gain perspective on the current usability and sustainability scenario(s). Sustainable infrastructure can be termed as successful when it is appropriately implemented for use by the common masses.

A Rhetorical Analysis follows in the next couple of pages of this research:

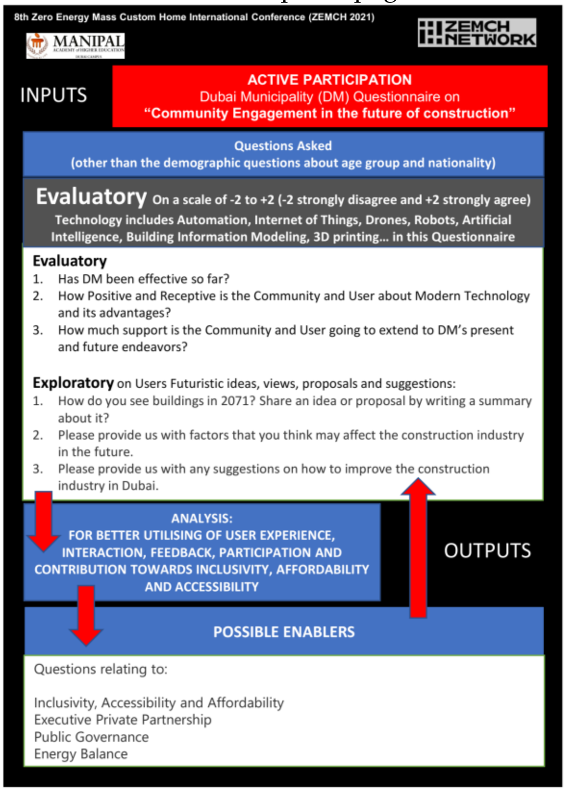

Figure 4. Analysis of one Municipal Questionnaire [15]

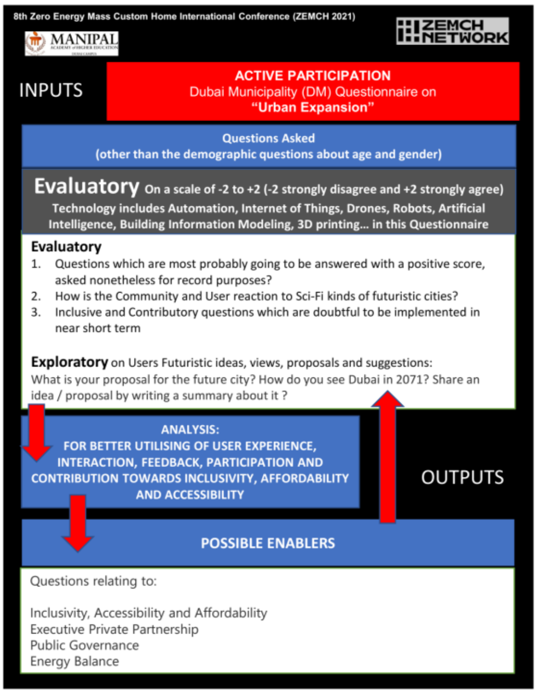

Figure 5. Analysis of another Municipal Questionnaire [16]

2.4. User Engagement

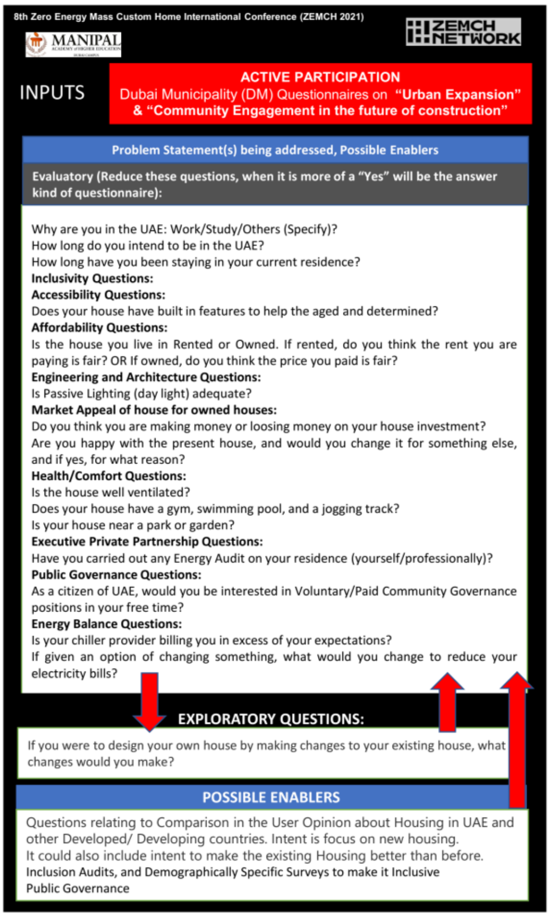

Figure 6. Enabling Questions for Active Participation of Inclusive Users

8th Zero Energy Mass Custom Home International Conference (ZEMCH 2021)

MANIPAL ACADEMY of HIGHER EDUCATION DUBAI CAMPUS

ZEMCH NETWORK

USER EXPERIENCE / USER INTERACTION FEEDBACK FORMS

USER FEEDBACK	Specific and Open Ended Questions						
Demographic							
Age	15-20	21-40	41-50	51-60	Above 60		
	☐	☐	☐	☐	☐		
Gender	Male	Female					
	☐	☐					
Income … AED per year	<60K	60k-120k	120k-240k	240-480k	480k-960k	960k-1500k	>1500k
	☐	☐	☐	☐	☐	☐	☐
Source of Income:	Business	Employment	Others				
	☐	☐	☐				
Lived in UAE … years	<5	5-10	10-20	20-40	>40		
	☐	☐	☐	☐	☐		
Want to live in UAE for another … years	<5	5-10	10-20	20-40	>40		
	☐	☐	☐	☐	☐		
Do you live in an rented or owned apartment	Rented	Own					
	☐	☐					
How long have you been living in your current accomodation … years	<1	1-2	2-3	3-4	4-5	>5	
	☐	☐	☐	☐	☐	☐	
Qualifications	Nil	Commercial	Technical	Area of expertise			
	☐	☐	☐				
Would you be interested in volunteer work	Yes	No	Maybe				
	☐	☐	☐				

Figure 7. Questionnaire that will enable determination of the interest demonstrated by the User in participating actively [17]

8th Zero Energy Mass Custom Home International Conference (ZEMCH 2021)

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ZEMCH NETWORK

USER EXPERIENCE / USER INTERACTION FEEDBACK FORMS

USER FEEDBACK	Principle in Place		Principle Implemented			Target Area for Change Effort	
Housing Principles	Yes	No	Yes	No	Somewhat	Yes	No
Housing is suitable for residents of all ages and abilities (i.e. incorporates Universal Design or visitability principles)	☐	☐	☐	☐	☐	☐	☐
Housing incorporates some kind of Green Building Code	☐	☐	☐	☐	☐	☐	☐
Housing Recognizes local and regional housing needs	☐	☐	☐	☐	☐	☐	☐
Ensure that housing is available for people at all economic levels	☐	☐	☐	☐	☐	☐	☐
Identify underrated buildings - not of market or people appeal	☐	☐	☐	☐	☐	☐	☐
Explore the feasibility of transforming excess parking areas into new housing or alternatively explore feasibility to provide more parking areas	☐	☐	☐	☐	☐	☐	☐
Prioritize development in pedestrian-friendly neighborhoods and commercial districts	☐	☐	☐	☐	☐	☐	☐
Ease of access to Parks and Gardens	☐	☐	☐	☐	☐	☐	☐
Going out for a walk or cycling possible	☐	☐	☐	☐	☐	☐	☐
Can get around without a car	☐	☐	☐	☐	☐	☐	☐
Spending time outdoors / Entertainment	☐	☐	☐	☐	☐	☐	☐
Ease in crossing streets	☐	☐	☐	☐	☐	☐	☐
Passive Lighting (Daylight) adequacy	☐	☐	☐	☐	☐	☐	☐
Socialising areas	☐	☐	☐	☐	☐	☐	☐
Heat loss Facades	☐	☐	☐	☐	☐	☐	☐
Adequate Ventilation	☐	☐	☐	☐	☐	☐	☐
Can live safely and comfortably	☐	☐	☐	☐	☐	☐	☐
Availability of friendly neighbours or Volunteers to help in need	☐	☐	☐	☐	☐	☐	☐
Availability of Facilities such as Gym, Swimming Pool, Jogging Track	☐	☐	☐	☐	☐	☐	☐
Near to Public Health Facilities, Salons and other services needed periodically	☐	☐	☐	☐	☐	☐	☐
Near to Shopping Mall, Groceries, Restaurant..	☐	☐	☐	☐	☐	☐	☐
Energy Audit Results available	☐	☐	☐	☐	☐	☐	☐

Figure 8. Questions that will probe users existing problems, conditions, expectations, and Target Areas for directing efforts [18]

3. Results

As aforesaid, one needs to maintain consistency in the testing methods in order to derive an optimum conclusion. Surveys, despite being quantitative, if cleverly designed, can ask a substantial expanse of users just the right questions to understand their tribulations. While individually using surveys, one should do it for only gauging the bugs that need to be fixed in the product/service being surveyed. They are an initial level, that gives clues to improve, and make the product as flawless as it can be made, to aid in user-engagement.

User Research on the other hand, brings empathy into the equation and allows to customize and optimize every aspect of a person's home: from closets and cabinets to moving space and house alignment that has an impact on the users' thoughts, feelings, needs and habits. The best way to do this, would be to conduct one-to-one interviews, that helps collect data that can be utilized in creating a final product admissible and appreciated by the user. Hence it helps connect developers/builders of a property, easily with their end user [19].

Time as a cost factor is normally overlooked. When calculating ROI with User Experience, Participation and Contribution involved, if time were to be provided with monetary value, ROI will increase and Costs will automatically get reduced, as development time reduces with improved Customer Engagement, because designers will know what to design in advance of the projects, allowing them to focus on the other important aspects of the project.

3.1. Legality Involved

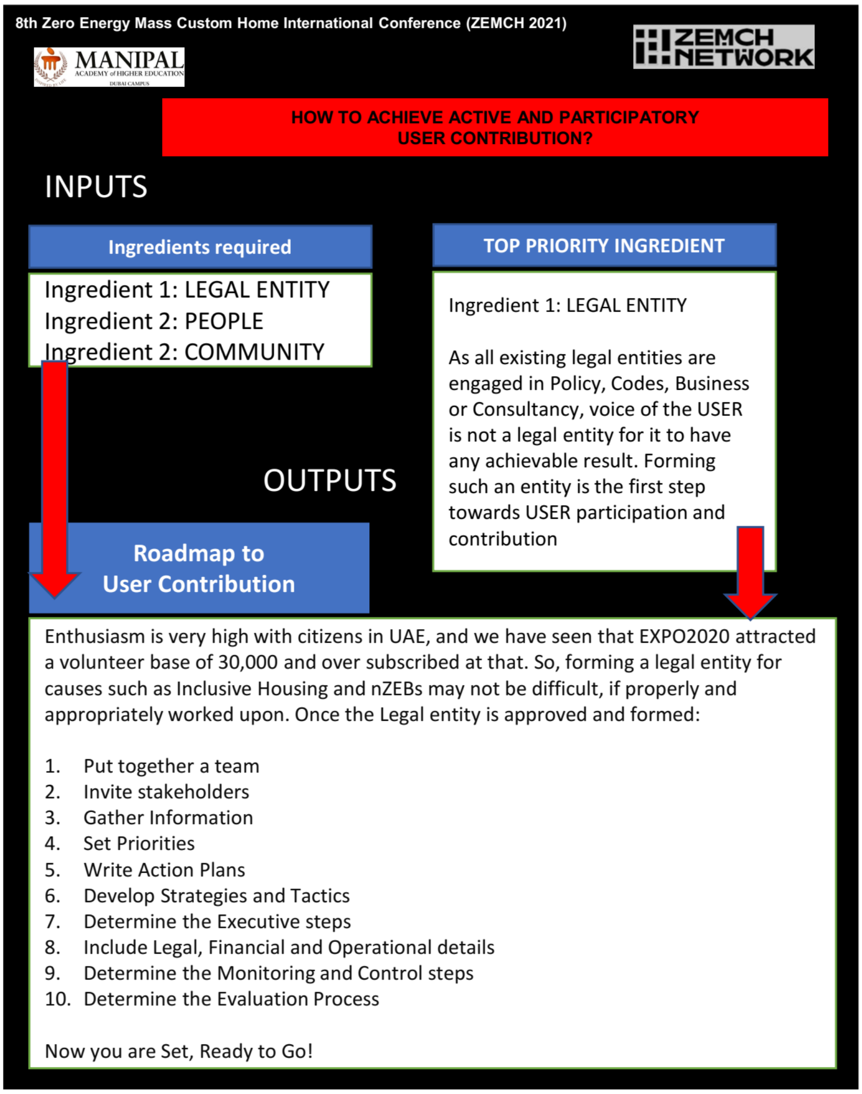

Figure 9. Forming a Legal Association – a step forward [20]

3.2. Identifying entities

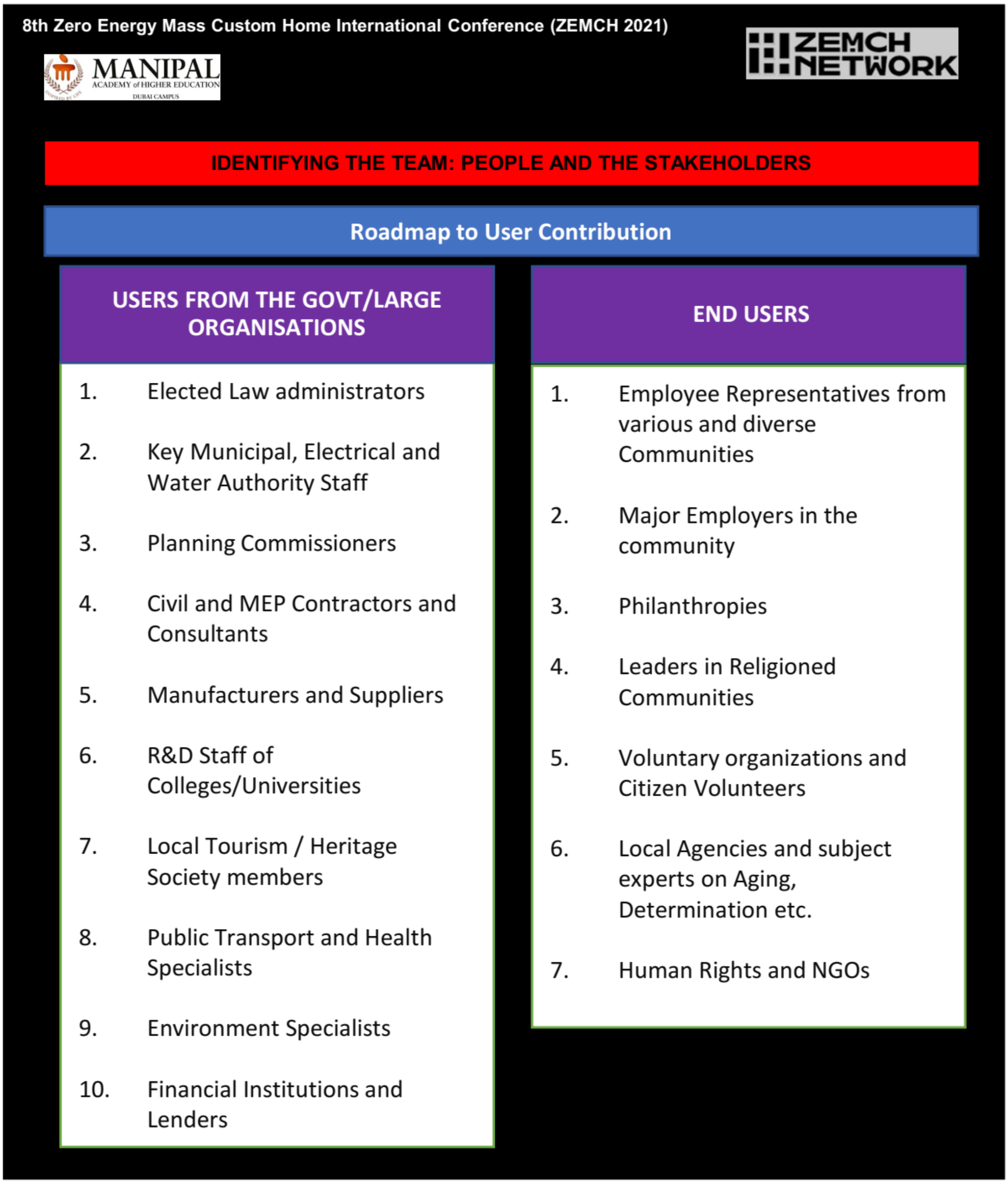

Figure 10. Identifying the team members – Roadmap to user contribution

Create a manual for the process - start with the forms to be filled, describe the process, prepare the policies in an ISO-9001 Quality Management System (QMS) fashion.

3.3. Accessibility

Accessibility, an aspect coming into prominence with HCI and User Interaction, is something, the housing cannot forsake. Every item/appliance, that is perfect for the average user, should be easily modified into an item equally perfect for the societally deemed "Special-Needs" category of people. Every person must be able to enjoy that product and reap benefit from it.

A small example would be the feature of Talk-Back in Android [21] and Spoken Content in iOS, that reads to a Blind user, everything written on the screen, making the website accessible and usable to all [22]. Even within the Spoken Content, there are different dialects associated with the region of the device's usage. This is more inviting to users, helping them easily connect with the content, and increasing product loyalty.

3.4. Smart Cities: Using AI, ML, DL, and Blockchain

Now, moving to smart cities, something that Dubai is on the path of becoming, the fields the city might be interested in implementing, is mixed reality. A whitepaper from the IEEE has wonderfully expressed this concept. Mixed reality is the middle road, between real environment, and virtual one, creating the perfect blend for environmental preservation, sustainability, automated technology, to make human life efficient [23]. Planning, actions, and scheduling, not only for personal uses, but for governmental operation, can be easily automated and enhanced via this technology. Superimposing reality with 3D vision, like a virtual personal assistant, or a virtual house manager, that can not only assist with daily functions, but can also monitor actions, remember them, and optimize its function according to the user's work/relaxing schedule.

By implementation of sensory and perceptron technology which shall change environment through virtual interaction, which will take up all clinical requirements needed for a multi-functional, affordable, automated, sustainable housing [24].

In a household, it is very important for every member to be aware of the changes that their lifestyles require, to transpose an efficient sustainable energy transition. This change is supplemented by upliftment and modification of technology, that optimizes energy flow and reducing dependency on fossil fuel [25], which is the main source of energy for the UAE currently and is currently under transformation with the shift to exploiting of the renewable solar energy, which the UAE receives in abundance. The introduction of The Dubai Clean Energy Strategy 2050 is a prominent step towards a sustainability churning, extremely important to the milieu looking at the current habitat and scenario [26]. Also, the affiliations created through IEEE Smart Cities [27], is another important step taken to create a consortium of aware nations moving towards creation of durable, non-contaminating technology.

The lack of knowledge is the root reason of the stagnancy in sustainability and environment fortification. Ergo, discontinuing irrational methods of functioning, and moving to sustainability is the cog required in the making headway for humanity. The using of energy efficient rated domestic appliances might seem like a small start but is the initiation of a transformation in the current operating situation. While increasing knowledge, user expectations must also be considered, as has been exemplified above. Artificial Intelligence, Machine Learning, and Deep Learning, are aspects, commonly associated with modern technology aimed at making human life easier. But as explained above, they can also be utilized to make technology environmentally friendly and sustainable. Cyber Physical Systems, that incorporate these facets of technology, are the closest to being able to create non-expendable technology [28].

Using Blockchain a currently booming field which can change the landscape of technology, is a way to boost smart city development, by incorporating immutability, transparency, end-to-end trust, a decentralized distributed method of working, that shall make the current management and development scenario, not only inefficient in comparison, but also obsolete; paving way for the Industrial Revolution 4.0 [29].

3.5. Affordability

Affordability can be achieved by developing:

Governmental plans that lay emphasis on land-usage strategies to ameliorate current landscaping scenario, from over-crowding to centralization of real estate pricing by providing inducements to authorities closely associated with distribution of property among the general public, such as land subventions, to increase affordability for the end user.

Development with land-administration programs in new Dubai: where the governmental-developers sell land at exorbitant rates to smaller developers, who shall be left with no other choice but to build luxury-developments that are comfortable and user-friendly to convalesce that high cost that comes tagged with the land. Bachelor accommodations are best affordable when shared, ergo, the government must arrive at strategies to make this possible for the population, and take care that development is carried out by citizens. Adopting a multistakeholder approach to make housing affordable and meet the production with the increasing demand, leaves room for sustainable practices that are environment friendly. The UAE government could come up with an approachable "long-term land usage plan" that concurs with its urbanization strategies. In contrast to other developing or developed countries in the West or East, housing in Dubai is principally the responsible of the end user, being able to start development at a much faster and technologically advanced scale [30].

4. Discussion

All said and done Human Behavior is responsible for Energy Consumption.

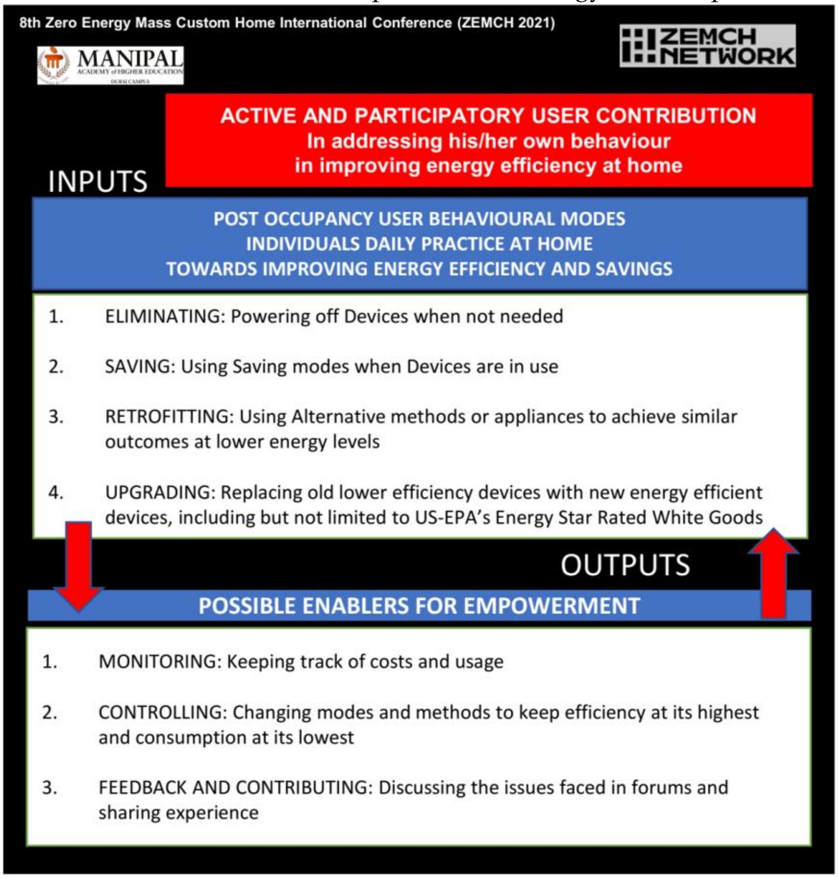

Figure 11. Revisiting the basics of individual contributions to reduce energy consumption

4.1. Questionnaire usage

Questionnaires are a very efficient market research tool, that easily gives a pool of information, in a fastidious manner. Due to a lack of context and differing user personae and lack of user stories surveys generally do not provide for a holistic method of research:

- Surveys tend to become quantitative, which does not match the objective UX research that tends to be qualitative, insightful, and not number dependent.
- UX Research, by talking to people, understands the context of experience: What? Why? How? When? Where? etc. A survey can only answer the question of 'What'.
- User behavioral observation and empathy gathering is important to every process; making it analogous to surveys creates a hotch-potch.

Teams use surveys exclusively, which tends to blind them to actual user's wants, and feelings, missing the whole point of going through User Interaction and User research. Surveys can be brought to optimal use in conjunction with qualitative user research. They provide quantitative contrast to data (contextual), motivated by user emotions. They provide an all-round insight, that is cost-effective. Through User backgrounds and stories, the "why's" are easily answered, though one must not keep asking the user questions which make them alter their original chain of thought, and they might start giving adulterated and convergent one-word answers instead of stories [31].

4.2. Formulating Decision Making Strategies for UX/UI

How user feedback will be analyzed to final decision-making strategies for UX/UI: The questionnaire(s) seek data on affordability, qualifications, accessibility, and lifestyle. All these facets of life are extremely important to the user and will determine how the user interacts with the survey questionnaire. Some users might be more distracted while answering the survey, while others might be less inclined to answer it at all. By understanding what the user does one can have a coding scheme which shall tell how far the survey results are reliable, or in-depth [32]. That is the reason, these municipal surveys have been chosen to analyze the connection between user engagement, and sustainability.

4.3. Combinatory Questionnaires

There may be a lot of questionnaire patterns, and there are a lot of things that can be said and done for achieving Inclusive and Sustainable Built Environments. The UX/UI Questionnaire(s) have to be a series of Questions, just like adjusting the frequency of a radio. One uses the coarse tuning to get to a nearby frequency, and then fine tunes it to get the right frequency. So, for combining all of them while being practical, the least one can do is acknowledge the existing shortcomings and bring it to a platform where it can be addressed effectively for narrowing down the shortcomings in the next steps - beginning with the problems associated with the masses who are the primary users and majority of them are listed at 2.2. in this paper.

Collecting data is the first step towards analysis and defining the shortcomings if any in the systems and processes:

1. Visitability research brings forth evolution of the accessible design strategy [33] but no research has enumerated the psychological as well as social benefits of Visitability or other approaches to accessible housing and neighborhoods. Persuasive research clarifying any aims of a universal design, is an extensive area where research must be conducted.
2. Inclusion Training / awareness training can be a real eye-opener helping teams to see the day-to-day challenges for a Person of Determination that may otherwise not be noticed.
3. Revised and Align planning, policy, and legislation to ensure that all new housing units (and not alone commercial/government units) are built to be inclusive.
4. Include these inclusive design elements as part of the curriculum for Schools/Universities.

4.4. Research Needs:

The needs found can then be addressed with further operational research. As buildings evolve over time, so do the needs of users. Inclusion Audits to review the physical ingress and egress of buildings benchmarking against the Dubai Universal Design Code and international standards.

5. Conclusions

Co-relating the Problem Statements, Results and Discussion, as seen in the previous sections, User Research assists in bringing empathy, allowing customization, providing solutions to the Problem Statements, identifying key partners and legalities involved, and making leeway for providing sustainability, accessibility, affordability, and adaptability to the Inclusivity Elements in a Technically advanced manner, while enabling Improvements in Energy Efficiency and Savings for

Housings in the UAE. This when unleashed and combined with the powers of the State for Housing Legislations, will help bring about order and balance to the Housing Sector In the UAE.

If user participation and contribution is obtained, then the specs are available during the planning stages. This is evident and proved by the success of social housing in Brazil, My House My Life (MHML) Program using the ZEMCH approach. The function analysis guides the design decisions, corresponding to the evaluation criteria scoring matrix results of each group.

Pre-Covid-19 belief existed that Luxury is rare, exclusive, and expensive. With the advent of the COVID-19 pandemic realization has dawned that luxury is those little things that unknowing are already inherited and not valued till it is gone. Extravagance is being healthy. Indulgence is never going to a medical center, but trekking mountains, enjoying safaris, and living peacefully. Luxury is being able to socialize. It simply means living life to the fullest, and to heart's content, in an Inclusive Manner.

To conclude, this document has investigated the Municipal Questionnaire(s) and applied UX Methodology. The inputs were taken for a base model for survey questionnaires for Inclusive Housings. Several recommended enablers would further result in Human Involvement, most importantly, controlled, and monitored human behavior and regulated end-use patterns.

Stay Blessed. Stay Healthy. Stay Grateful.

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Analysis of Indoor Environment Quality (IEQ) in UAE University Campus Building, UAE

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Abstract: In accordance with a recent climate change report by IPCC, temperatures in UAE will rise and harsh weather will occur more often, increasing the time spent in the buildings. The Study of buildings' indoor environments is important due to the fact that people spend more than 90% of their time in buildings, which increases the likelihood of exposure to unhealthy environments as well as some physical and psychological problems such as sick building syndrome. As evidenced by previous studies, the indoor environment of a building has a significant impact on the productivity of a user's work. furthermore, occupants working in a comfortable indoor environment will reduce the rate of absenteeism and incidental costs such as medical expenses, improve work efficiency, and productivity. The study will conduct an indoor environmental quality assessment of UAE University's building. Based on the assessment, it will prepare strategies to improve indoor environment quality for case study building to reduce the occupants' discomfort and to improve the occupants' work productivity. To perform the study, one lecture building is selected. To determine the level of indoor environmental quality of case study, POE study as occupancy survey, monitoring study by using data loggers will carry for selected classrooms, and the level of indoor environmental quality will be analyzed based on standards. It will provide an overview of IEQ level in the case study building, and the problems of the case study building based on POE and monitoring study. The research findings will be discussed in this paper in detail. The following step for this research will be simulation using DesignBuilder software to find more gaps in the building and see the difference before and after adding the suggested changes.

Keywords: IEQ; POE; Sick Building Syndrome; User Comfort; Health & Wellbeing; University Buildings Design Standards

1. Introduction

Wellbeing in the built environment can be defined as space's performance in improving or at least not reducing the emotional, mental, and physical health of the buildings' occupants [1]. The World Health Organization (WHO) defined health as the "*State of complete physical, mental and social well-being and not merely the absence of disease or infirmity*." These definitions show the importance of studying health and wellbeing in the built environment, since it can affect the occupants' productivity, health, and satisfaction, and this could have an impact on the society and economic growth of the country.

The buildings were made to meet a specific goal, and these goals cannot be achieved if the occupants of these buildings are affected negatively by the indoor environment quality (IEQ). The fact that the daily tasks been done inside the buildings using electronic devices, and to escape the outside high temperatures, people nowadays stay more than 90% of their time in buildings, especially at houses. For students, the second-highest time spends in educational buildings [2].

One of the main reasons that make people stay more time inside the buildings is the climate change and the hot outdoors, especially in hot countries. In UAE the situation even worst, because it has a desert climate, which means a very hot and sunny summer season. Moreover, the heat is unbearable because of the Arabian Gulf's humidity. UAE considered as one of the countries that has the highest possibility to be affected by the climate change, which will result in warmer weather. The warmer weather is showed by the increasing of the temperature from past to recent years, and the maximum temperature record has been changed as well. There is a prediction by Emirates Wildlife Society and World Wildlife Fund (EWS-WWF) that there will be increase in temperatures by 2°C by 2050 with a rise in the humidity by 10% in a report titled by "UAE Climate Change: Risks and Resilience".

In addition to what been said above, the growing economy of the UAE will be affected by the performance of the workers and students. Buildings' Occupants' wellbeing has direct and indirect-health related economic issues; The direct is related to the increase of the diseases and tiredness from the indoor environmental issues, which will cause the overuse of the health sector resources, and so that will require a high cost from the government to give the needed treatment to the people. On the other hand, the indirect impact is made by the reduction of the productivity of the work or study from the buildings' users.

This study will mainly answer these two questions:

- What are the current issues of the case study building?
- What are the suggestions to improve the IEQ and reduce energy consumption inside the building? (the part related with simulation will be answered in another research paper)

1.2. Indoor Environment Quality (IEQ)

IEQ involving the situations inside the building (such as Indoor Air Quality, Thermal, visual, and acoustic conditions) and their influences on people' wellbeing and satisfaction. Since the sustainable building concept become more viral to include not only the environment issues but also the wellbeing of the residents, the methods to classify the IEQ become various as well. The main way to address such a concept (IEQ) is by ensure people health, safety, and comfort, as well as enhancing the quality of life, and make spaces that can reduce the chance of having any physical and psycho issues for the users. A better IEQ can result in a better productivity and performance levels since that will make the experience of using and interacting with indoor environment of the building more fun and professional [3].

1.2.1. International and National Level of IEQ

Both locally and worldwide air related issues seems to be the most popular out of all of the other issues (thermal, acoustic, and visual), and that mainly because the diverse illnesses that resulted from the polluted indoor air. The air pollution issue is not only considered as a health related, but also as social and economic issue [4].

As mentioned by [Olesen, B. W.] in International Standards for The Indoor Environment, with relation to health there are around 5000 people who die each day because of the bad Indoor Air Quality (IAQ) in the developing regions, in addition of the increasing numbers of people who get asthma and allergy for the same reason [5].

Diverse range of health problem might be caused due to the exposition of bad IEQ, most known ones is those related with poor IAQ such as lung cancer, respiratory syndrome, legionnaires' disease and many others. While a good IEQ can improve occupants' health, productivity, and their learning or working performance. [6].

Taking todays situation during COVID-19 pandemic, most of the people are working and studying from inside the buildings, mainly from their houses, which mean the world use the houses (or the small spaces that can keep them secure from other and from outside) as a shelter, but that actually make more exposition to the indoors pollutions and issues mostly to the indoor air pollution with the fact that the indoor air is almost 2.5 more polluted than the outdoor air [7].

1.3. IEQ Related Terms and Aspects

There are different terms related with indoor environment, those terms are the aspects that shape the indoor environment. Parameters including (indoor air, thermal, acoustic, and visual) need to be taken into consideration when studying the indoor environment for a building and the wellbeing issues related to it, some of those will be defined below.

1.3.1. Sick Building Syndrome (SBS)

SBS can be defined as the matter that people in a specific building or space feel unwell or sick due to their exposure to the indoor environment. The caused can be related to the furniture type and the toxics that come out from it, as well as the materials that been used inside such as paints, lighting, or even from gasses that are in the indoor air, such as volatile organic compounds (VOC). These can cause some simple types of tiredness and fatigue or some serious diseases. So, as a conclusion for different researches related to IEQ, designers and engineers need to design the buildings in a way that will reduce occupants' exposure to the indoor toxic chemicals, and this can be done by monitoring indoor air and water piping in the building, as well as choosing the best materials for the interiors [8].

1.3.2. Indoor Air Quality (IAQ)

According to USEPA, IAQ refers to "*the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants*". It defined the elements of a good IAQ as:

- Ensuring adequate ventilation (introduction and distribution of clean indoor air).
- Controlling contaminants traveling in the air.
- Maintaining acceptable thermal comfort.

The air that people breathe inside the buildings can lead to a range of short- and long-term health problems, and these can be range from simple health problems to serious ones. The IAQ can be improved by raising the rate of ventilation inside the buildings, this will decrease the pollution level in the indoor air. Another way is to decrease the pollution sources in, out and within the building, this can be done by providing some filters, air cleaners, and other equipment that will deal with this issue [8].

Air pollution conditions may have acute and adverse effects on students' health which can indirectly affect performance, through impaired attendance and discomfort. Additionally, low outdoor air ventilation rates and thus high indoor concentrations of CO_2 impairs attention span and increases concentration loss and tiredness. The higher indoor CO_2 levels have been associated with an increased probability of communicable infection, asthmatic symptoms, absenteeism, and impaired academic performance. Every decrease in indoor CO_2 level by 1000 ppm was associated with at least 1.0% to 2.5% relative decrease in illness absence of students [9].

1.3.3. Thermal Environment

According to ASHRAE, thermal comfort is defined as "*that condition of mind that expresses satisfaction with the thermal environment*".

The thermal comfort is one of the most factors that can affect the occupants' productivity, and at the same time, it is easy to be achieved if a specific procedure has followed. There is a comfort zone for each factor, it can be different based on age and gender [8].

The thermal comfort has been also related to energy saving which been in the focus for the previous few years. Previous studies on thermal environment in educational buildings showed that there are many buildings that not following the standards for thermal comfort. If the suitable temperatures value not achieved, it might impact the health due to the high density of occupants who occupy the same environment or a certain hyper-sensitivity of students to higher temperatures [10].

In addition, thermal comfort is linked to our health, well-being, and productivity and is ranked as one of the highest contributing factors influencing overall human satisfaction in buildings. Due to its influence on the integumentary, endocrine, and respiratory body systems, thermal comfort can impact multiple health outcomes. For example, exposure to cold air and sudden temperature change can trigger asthma in adults. Thermal discomfort is also known to play a role in sick building syndrome symptoms, which will similarly cause decreases in productivity [11].

1.3.4. Acoustic Comfort

Acoustic comfort can be achieved by taking into consideration the different ways to protect the buildings' occupants from any noise that come from outside such as the traffic noise, as well as to prevent the noises in the inside from transferring from place to another or to outside [8]. This can be done by choosing the right construction materials and to follow some standards. Furthermore, to ensure the acoustic performance and specification for the insulation that is used for the different building elements such as for the walls, roof, and windows [12].

The noise causes irritability, and fatigue of the whole body, especially of a hearing. The noise has a negative action on human health [13]. In addition, poor acoustics in classrooms can directly impact student health and behavior. It can stimulate hearing loss, changes in heart rate, higher blood pressure, higher stress responses, and Attention Deficit Hyperactivity Disorder (ADHD). Moreover, poor acoustics results in lower student achievement [14].

1.3.5. Visual Comfort

Visual comfort can affect the occupant's productivity in the educational buildings, especially where they have to use computers or any electronic devices to complete their works, because of factors such as glare and reflection. Visual comfort can also have an impact on occupants' wellbeing, because it may cause them some sorts of eye discomfort and tiredness which can lead to headaches and other related vision diseases and issues [8].

The poor lighting in schools could negatively affect students' health and academic performance. For example, it might affect their sleep/wake cycles and circadian rhythm.

1.4. Occupants' Wellbeing in Green Building Rating System in UAE

Sustainability become one of the most important topics in the world, and that because people want to have a better environment to live in, and since the buildings are one of the most factors that affect human and environment in the local, regional, national and global average the focus becomes bigger on them. For that, the UAE's government start to import as well as publishing some regulations and standards for buildings, so that these buildings will be safer for the user and will have less negative impact on the environment. There are standards and regulations that only made to show designers and engineers how to provide better living spaces and areas for people. Some of the used rating systems in UAE are ESTIDAMA, LEED, Well Standards, and ASHRAE. Based on those, the results from monitoring experiments will be judged (poor or good).

Table 1. The Different Indoor Environment's Parameters Standards.

IEQ's Parameters	Standards
Temperature (^oC)	- Based on ASHRAE 62.1 2007: 21 - 25 ^oC
Relative Humidity (%)	- Based on ASHRAE 62.1 2007 section 4.2: 65% or less - Based on WELL Standard: Minimum of 30%
CO_2 (PPM)	- Based on ESTIDAMA: Must not exceed 1000 ppm
PM2.5 ($\mu g/m^3$)	- Based on ASHRAE 62.1 2007: 15 $\mu g/m^3$ or less
PM10 ($\mu g/m^3$)	- Based on ASHRAE 62.1 2007: 50 $\mu g/m^3$ or less
TVOC (PPB)	- Based on WELL Standards: 312 ppb or lower.
Noise Level (dB)	- Based on ESTIDAMA: 35-40 dB
Light Level (lux)	- Based On ESTIDAMA: A minimum illuminance of 300 Lux. - Based on ASHRAE 90.1 2016: 300 – 500 Lux.

2. Materials and Methods

2.1. Case Study Building

The studied building is the C6 Building (College of Engineering, Food and Agriculture, and Science Building). The focus will be on the classrooms which are been used by the students mostly in the daytime (8 Am to 5 Pm). The building located in the female side in the UAE University in Al Ain, UAE. It is three floors building (with the ground floor and the first floors are mostly classrooms and computer labs, while the second floor is offices). The building shape is almost look like a triangle with an open courtyard in the middle. The building cover with lots of glasses and have an additional layer of glasses on the windows and curtain walls from the outside for extra shading, and it is surrounded with some trees and other shading objects as well.

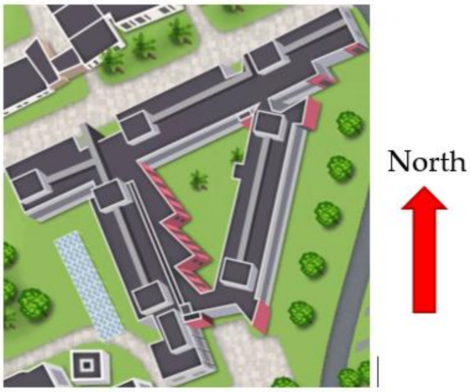

Figure 1. Female Faculty of Engineering, Science, Food and Agriculture [C6 Building], UAEU, Al Ain, UAE.

2.2. Methods

The research depends on the quantitative and qualitative research methods for the data collection, because relating the real values from monitoring experiments and reading people answers in questionnaires will give a bigger understanding of the current situation.

Table 2. Research Methods

Research Methods	The Purpose
Online Resources: journal papers, books,	- Journal Papers and Books: Information gathering - Standards: Parameters limitations
Online Questionnaire	- Users' Perception and satisfaction level
Monitoring Experiments	- Air Mentor Pro: Measuring PM2.5, PM10, CO_2, TVOC, Temperature and Humidity - Multi-Function Environment Meter: Measuring lighting level

3. Results

There are two main methods as discussed before, so the results section will be divided into two main sections to discuss the results of each method.

3.1. Online Questionnaire

The online questionnaire was created in April 2021 and was active till August 2021. The number of participants is 217 only, due to the COVID-19 pandemic most of the students did not come to university in a long time, which makes them not able to remember the indoor environment of the building, that's why the number of participated students in the questionnaire is little.

The questionnaire focusing on the satisfaction level of the different indoor environment parameters, as well as the student comfort and wellbeing inside the classrooms. The students who answered the questionnaire are all under the age ranges of 15-20 (43.32%) and 21-25 (56.68%).

The following tables and graphs will show the results.

Table 3. Part 1 Of The Questionnaire.

Parameters	Q. How Often Do You Feel Annoyed By The Followings?			
	Often	Regularly	Sometimes	Never
Dry Air	16.59%	23.5%	40.55%	19.35%
Stuffy Air	15.67%	29.49%	35.02%	19.82%
Too Cold Temperatures	13.82%	19.35%	50.23%	16.59%
	When? (82.38% Winter), (3.33% Spring), (11.43% Summer), and (2.86% Autumn)			
Too Warm Temperatures	26.73%	27.19%	29.95%	16.13%
	When? (3.85% Winter), (5.77% Spring), (86.54% Summer), and (3.85% Autumn)			
Temperature Changes Through the Day	11.98%	28.11%	36.87%	23.04%
Cold Feet	14.29%	24.42%	36.87%	24.42%
Warm Surface	9.22%	19.35%	39.63%	31.8%
	Where? (6.21% Ceiling), (35.86% Windows), (20.34% Walls Facing Outdoor), (10.69% Walls Facing Indoor), (20.69% Floor), (6.21% Other such as Chairs and Tables)			
Too Much or Too Strong Light	13.36%	18.43%	39.17%	29.03%
	Why? (48.84% Too Much Artificial Light), (38.6% Too Much Daylight, (12.56% Other)			
Insufficient Light	5.99%	17.51%	39.63%	36.87%
	Why? (24.39% Too Little Artificial Light), (29.76% Bad Quality Lighting System), (31.71% Too Little Daylight), (14.15% Other)			
Reflections or Glare	8.29%	10.6%	51.15%	29.95%
	The Cause? (58.82% Windows), (30.88% Artificial Lighting System), (10.29% Other)			
Noise	16.59%	25.81%	43.32%	14.29%
	From Where? (44.92% Outside), (20.66% Adjacent Room), (16.07% Mechanical Systems), (11.8% Equipment), (6.56% Other such as People)			
Odor/Bad Smell	11.06%	15.21%	37.79%	35.94%
	From Where? (40.62% Outside), (15.18% Adjacent Room), (9.82% Mechanical Systems), (13.84% Equipment), (20.54% Other such as carpet)			

From Table 3, students mostly annoyed from variables related to temperature, and some annoyed with air quality. For lighting factors, glare and reflection sometimes occur and made the students feel uncomfortable. Students feel that the noise from outside affect them sometimes. Lastly, students seem to feel good about the place' smell.

Table 4. Part 2 Of The Questionnaire.

Parameters	Very Unsatisfied	Unsatisfied	Neutral	Satisfied	Very Satisfied
Thermal Comfort	4%	10.14%	44.24%	35.48%	8.29%
Indoor Air Quality	3.69%	11.52%	36.87%	37.79%	10.14%
Acoustic Comfort	3.69%	7.83%	44.7%	31.8%	11.98%
Visual Comfort	3.69%	6.91%	42.86%	35.48%	11.06%
Overall Indoor Environment	2.76%	6.45%	34.56%	41.01%	15.21%

From Table 4, people seem to feel neutral about most of the parameters, and some are satisfied. Later on, these answers will be compared to the results from the monitoring experiments to see if the occupants' perception meets the actual situation of the building.

Table 5. Part 3 Of The Questionnaire.

Parameters	-2	-1	0	1	2
Temperature	16.59% Cold	40.09% Cool	35.94% Neutral	6.45% Warm	0.92% Hot
Temperature Preference	2.76% Much Cooler	44.7% Cooler	35.02% No Change	17.51% Warmer	0% Much Warmer
Relative Humidity	2.3% Very Dry	21.2% Dry	66.82% Neutral	8.29% humid	1.38% Very Humid
Relative Humidity Preference	1.38% Much Drier	12.44% Drier	74.19% No Change	11.52% More Humid	0.46% Much More Humid
Air Movement	3.69% Very Weak	23.5% Weak	59.91% Neutral	11.52% Strong	1.38% Very Strong
Air Quality	3.69% Very Stuffy	17.05% Stuffy	57.14% Neutral	19.82% Fresh	2.3% Very Fresh
Air Quality	1.84% Very Dusty	6.91% Dusty	54.84% Neutral	30.41% Clean	5.99% Very Clean
Odor/Smell	2.3% Very Smelly	9.22% Smelly	52.53% Neutral	30.88% Good	5.07% Very Good
Noise Level	2.3% Very Noise	10.6% Noisy	59.91% Neutral	22.58% Silence	4.61% Too Silence
Ability to Hear Teacher	1.38% Very Difficult	4.83% Difficult	38.25% Ok	35.94% Easy	16.59% Very Easy
Light Level	0.46% Very Dark	5.99% Dark	64.52% Neutral	26.73% Bright	2.3% Very Bright
Glare	1.84% Too much Glare	9.68% Glare	64.98% Neutral	19.35% Little Glare	4.15% No Glare At All
Daylight	2.3% No Daylight	17.97% Little Daylight	40.09% Neutral	35.02% Satisfied	4.61% Very Satisfied

As Table 5 shows, how people feel and prefer the indoor are differ from one to another, for example 44.7% prefer the temperature to be cooler while 17.51% prefer it to be warmer, this shows two main things one that design the indoors need a detailed study about the occupants (genders, age ranges, etc.), and secondly the importance of having controllers inside the classrooms so that people can change it based on their preference. The table also conclude that students has not much of complains on the relative humidity and 74.19% prefer to keep it as it is. The air movement answers are varying, and this is can be due to the used type of AC inside the classrooms (strip shape – 2 inlets and 2 outlets), which make students who set under it feel colder, drier, and annoyed more about air movement while the rest of the students can feel comfortable or totally opposite. The results also show that the students feel good about the indoor air quality, odor/smell, and noise level. For the lighting and glare parts, students mostly answered based on the known situation inside the classrooms (closing the blinds and turn on all the lights), but this is bad because it can affect both energy consumption and the circadian rhythm of the students. The dependence in the daytime must be on the daylighting, because the amount of natural light that enter the classrooms is able to light up at least half of the classroom (rows near the windows).

Table 6. Part 4 Of The Questionnaire.

Parameters	Q. If You Are At The Classrooms For Long Time, Do You Experience Any Of These Symptoms?			
	Often	**Regularly**	**Sometimes**	**Never**
Dry Eyes	11.06%	13.36%	33.64%	41.94%
Watering Eyes	4.61%	17.51%	20.74%	57.14%
Blocked Nose	5.07%	15.21%	29.49%	50.23%
Runny Nose	5.99%	15.21%	41.01%	37.79%
Dry Throat	6.91%	12.44%	35.94%	44.7%
Irritated Throat	4.61%	6.45%	29.49%	59.45%
Chest Tightness	4.61%	11.52%	26.27%	57.6%
Dry Skin	9.22%	13.82%	38.71%	38.25%
Irritated Skin	5.07%	9.68%	24.42%	60.83%
Headache	14.29%	21.2%	41.47%	23.04%
Tiredness	15.21%	22.58%	45.62%	16.59%

Based on Table 6, some health issues such as runny nose, dry skin, headache and tiredness is occurring sometimes, but generally there are not much complains about students' health issue.

Finally, the participants were asked to write some suggestions to make the classrooms indoor environment better for them. Some of the answers were changing the classrooms layout (such as the boards shouldn't face the windows to reduce the glare), adding air diffusers and air humidifiers, change the AC type, increase the daylight instead of the artificial lights, increase the number of windows or their sizes and make them operable to enter fresh air from outside, change the glass type, re-distribute the artificial lights, add a better noise isolation, and get rid of the carpet (for smell and dust purposes).

3.2. Monitoring Experiments

The monitoring experiments were done using two main devices, which are Air Mentor Pro and Multi-Function Environment Meter.

3.2.1. Using Air Mentor

Several devices (of the Air Mentor) were placed in different areas across the building, such as (classrooms 0006, 0021, 0032, 0033, 0034, 0035, 1015, 1037, and 1059 as well as two students sitting areas). The monitoring done in two periods, the first one was from Monday 15/02/2021 till Thursday 15/04/2021, while the second one was from Sunday 18/04/2021 till Thursday 29/04/2021. The gathered data were taken from 8:00 am till 4:00 pm. The Air Mentor devices helped in collecting data about the Particles ($PM_{2.5}$ and PM_{10}), carbon dioxide (CO_2), total volatile organic compound (TVOC), Temperature, and humidity.

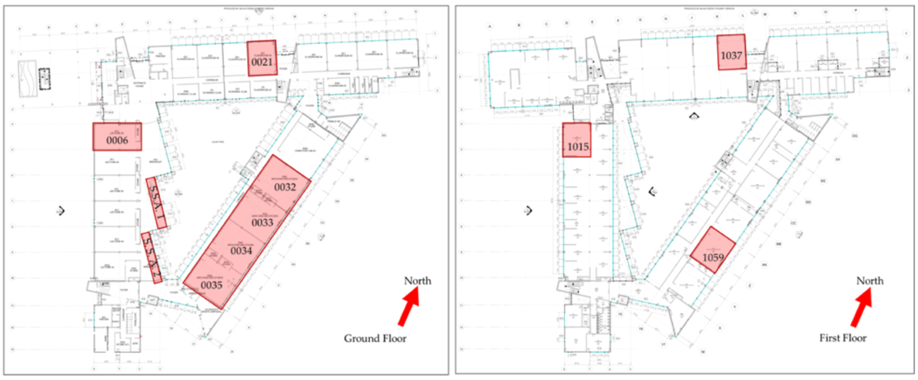

Figure 2. Selected Classrooms and Areas (Shaded in Red) At The Ground and First Floors, C6 Building.

Samples of the results that were gathered presented below using graphs.

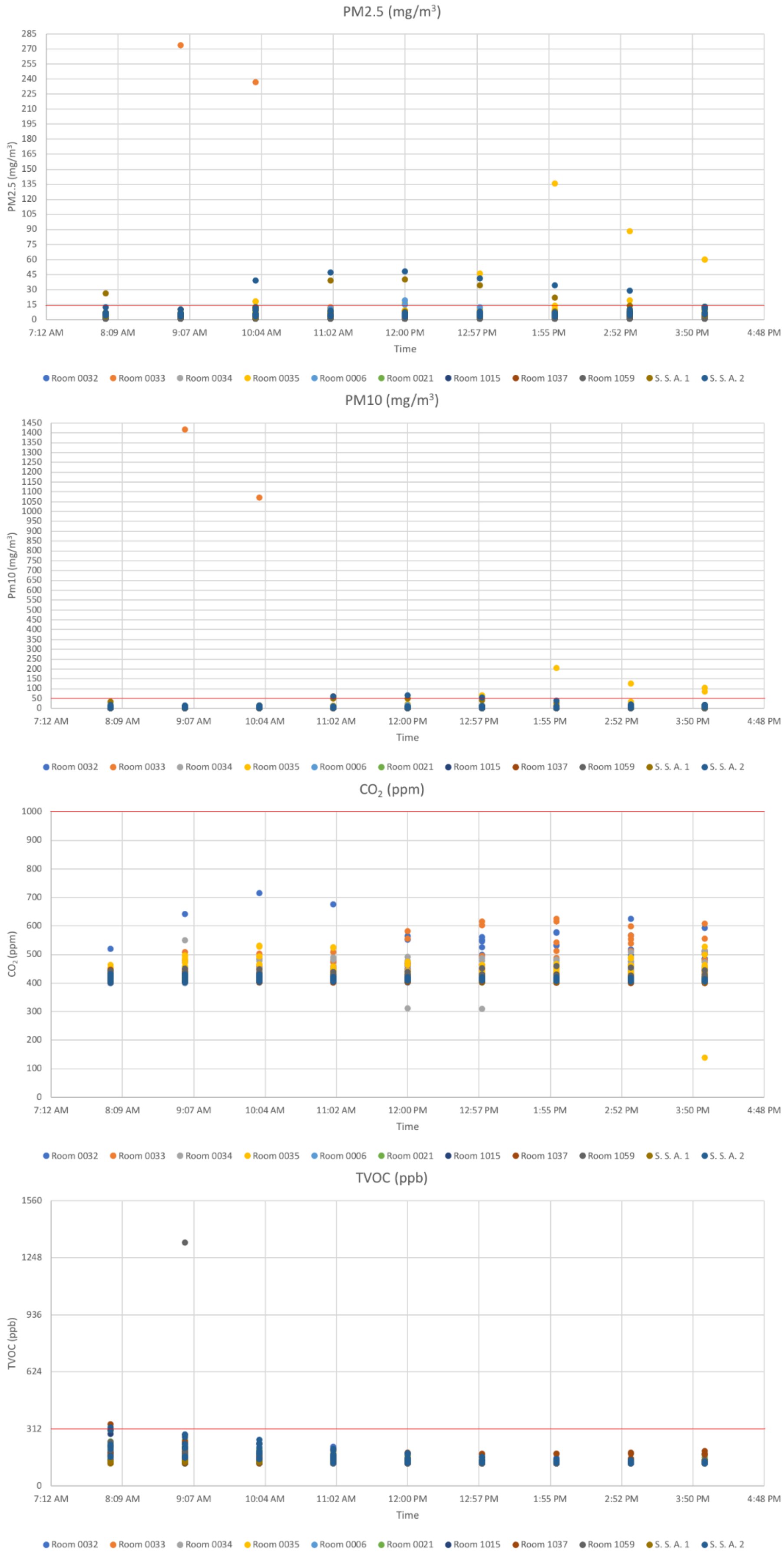

Figure 3. Hourly Based Indoor Air Quality Parameters (PM2.5, PM10, CO2, and TVOC).

From Figure 3, it is clear that there are some issues with particles (PM2.5 and PM10) in the classrooms 0033 and 0035 as well as in the students sitting areas. For PM2.5, the highest results were 274 and 237 both in classroom 0033. For PM10, the highest results were 1416 and 1072 both in classroom 0033. The CO2 seem to be good everywhere. The TVOC is good as well except for three readings, the highest one was 1331 in classroom 1059. All of those measurements were done in a time the building was almost empty, so in the normal situation (the building being fully occupied) the readings might change.

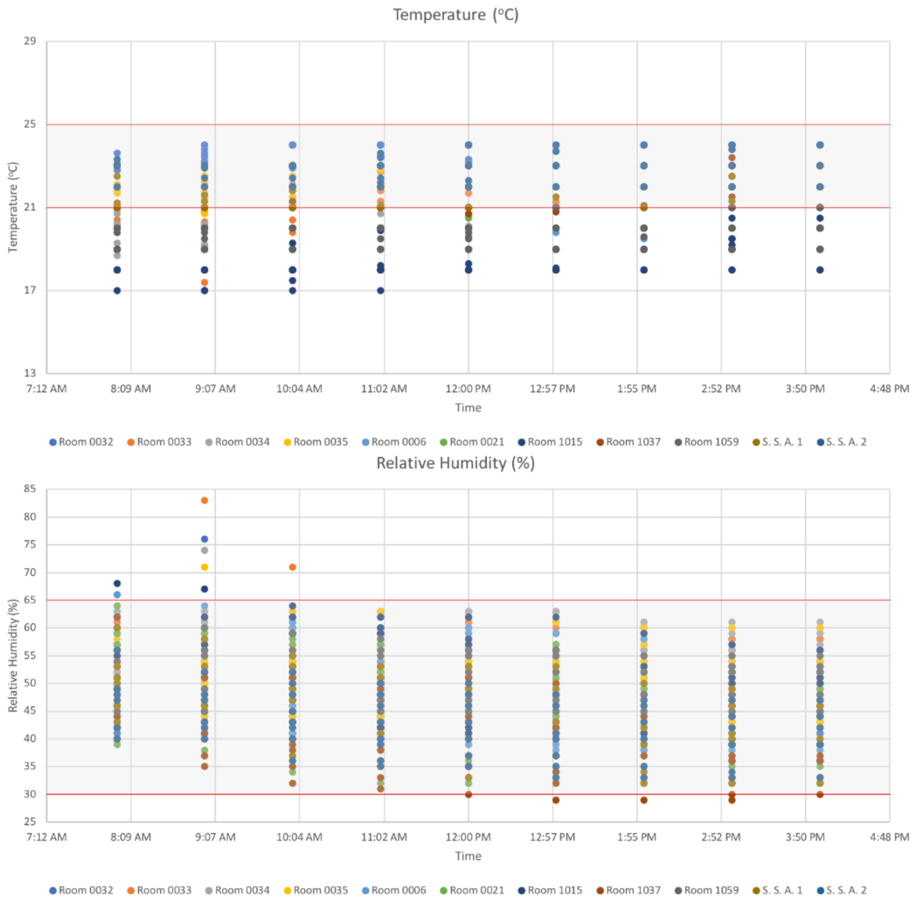

Figure 4. Hourly Based Thermal Environment Parameters (Temperature and Relative Humidity).

As seen in Figure 4, there are several readings under the comfort level (21 – 25 °C) for temperature, and those are mainly in the early mornings, the lowest readings were 17 °C in 1015 and 17.4 °C in 0033, followed by 19.2 °C in 0032 and 0034, 19.3 °C in 0034, and 19.8 °C in 0033. None of the readings for above the comfort level for the temperature. For the relative humidity, there only three readings below the standard and that were 29% all in room 1037, there are also some readings above the standards, the highest readings were 83% in room 0033 followed by 76% in room 0032.

3.2.2. Using Multi-Function Environment Meter

Multi- Function Environment Meter used to measure lighting inside the classrooms. The classrooms that were selected are located in different directions and floors of the building. The measurements for each classroom were taken four times, each time with changing a variable that affect the indoor visual comfort; (1) blinds open and lights on, (2) blinds open and lights off, (3) blinds closed and lights on, and (4) blinds closed and lights off. These different situations helped in concluding if the natural lighting is enough, or if it is used well, as well as it helped in seeing if the layout of the classrooms is good or need to be changed. Figure 5 shows the selected classrooms for conducting the lighting monitoring experiments.

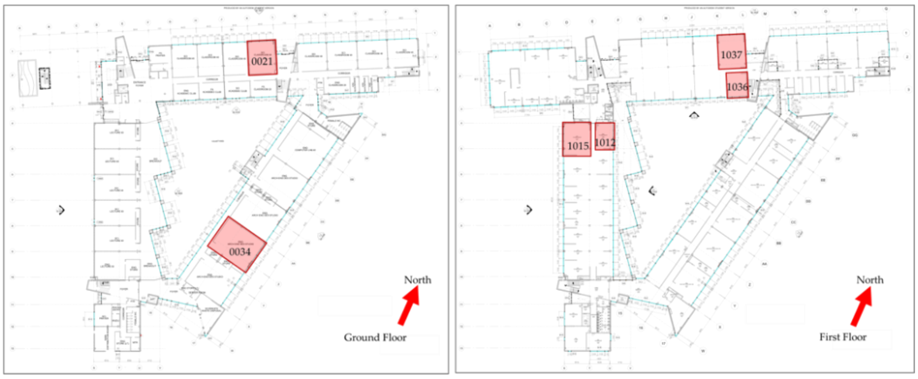

Figure 5. Selected Classrooms (Shaded in Red) At The (LEFT) Ground Floor and (RIGHT) First Floor.

As mentioned in Table 1, the lighting level for classrooms based on ESTIDAMA should not be less than 300 lux, and based on ASHRAE 90.1 2016 should be between 300 and 500 Lux. Following are the lux level showed in colors based, the light green color means the light level are in the preferred range (300 – 500 Lux).

Lux Level

- < 100
- 100 - 299
- 300 - 500
- 501 - 800
- 801 - 1100
- 1101 - 1400
- 1401 - 1700
- 1701 - 2000
- > 2001

In each of the classrooms the device was placed based on the classrooms' layouts (students tables). The readings for each classroom were taken at three different times (9 am, 12 noon, and 3 pm). In each time there were four different situations related to blinds (open/close) and lights (on/off).

The readings for class 0034 (Architectural Engineering Design Studio) are shown in Figure 6 as an example of the gathered data using the device. This classroom can be divided into 7 rows and 4 columns (based on the classrooms layout). Where the 7th row is the nearest to the wall covered with windows, and first row is the far away one (near the wall that contain the smart boards). From figure 6 it is clear that when the (blinds opens and lights off) almost half of the rows can depend on the daylighting from 9 am till 12 noon, while at 3 pm it is hard to do so.

9:00 AM		Blinds Open And Lights Off			12 Noon		Blinds Open And Lights Off			3:00 PM		Blinds Open And Lights Off		
	Column 1	Column 2	Column 3	Column 4		Column 1	Column 2	Column 3	Column 4		Column 1	Column 2	Column 3	Column 4
Row 1	No Table	No Table	No Table	76	Row 1	No Table	No Table	No Table	33	Row 1	No Table	No Table	No Table	15
Row 2	65	No Table	83	93	Row 2	37	No Table	40	43	Row 2	17	No Table	15	16
Row 3	89	106	130	146	Row 3	51	55	67	68	Row 3	20	20	21	21
Row 4	187	242	273	340	Row 4	101	126	124	133	Row 4	34	52	48	50
Row 5	520	550	1900	2200	Row 5	240	350	417	316	Row 5	80	106	119	119
Row 6	1180	780	1430	1780	Row 6	511	550	841	787	Row 6	133	172	226	213
Row 7	No Table	8700	2300	2090	Row 7	No Table	1392	1578	1460	Row 7	No Table	441	470	427
9:00 AM		Blinds Open And Lights On			12 Noon		Blinds Open And Lights On			3:00 PM		Blinds Open And Lights On		
	Column 1	Column 2	Column 3	Column 4		Column 1	Column 2	Column 3	Column 4		Column 1	Column 2	Column 3	Column 4
Row 1	No Table	No Table	No Table	697	Row 1	No Table	No Table	No Table	655	Row 1	No Table	No Table	No Table	625
Row 2	737	No Table	780	780	Row 2	724	No Table	738	756	Row 2	696	No Table	715	686
Row 3	750	790	830	880	Row 3	726	748	755	785	Row 3	696	704	732	758
Row 4	890	980	1010	1090	Row 4	803	861	853	897	Row 4	738	778	762	792
Row 5	1280	1250	1690	1800	Row 5	923	1028	1108	1149	Row 5	741	793	797	823
Row 6	1730	1470	2220	2360	Row 6	1060	1147	1380	1375	Row 6	725	799	856	864
Row 7	No Table	8500	7600	7180	Row 7	No Table	1468	1595	1548	Row 7	No Table	690	713	684
9:00 AM		Blinds Closed And Lights Off			12 Noon		Blinds Closed And Lights Off			3:00 PM		Blinds Closed And Lights Off		
	Column 1	Column 2	Column 3	Column 4		Column 1	Column 2	Column 3	Column 4		Column 1	Column 2	Column 3	Column 4
Row 1	No Table	No Table	No Table	14	Row 1	No Table	No Table	No Table	6	Row 1	No Table	No Table	No Table	2
Row 2	14	No Table	15	17	Row 2	10	No Table	6	6	Row 2	9	No Table	3	3
Row 3	17	20	22	23	Row 3	8	7	8	8	Row 3	5	4	4	4
Row 4	39	40	42	52	Row 4	14	15	13	15	Row 4	7	7	5	6
Row 5	120	89	142	157	Row 5	35	34	39	38	Row 5	10	11	12	13
Row 6	760	127	832	671	Row 6	53	50	70	67	Row 6	14	18	21	20
Row 7	No Table	800	323	720	Row 7	No Table	112	110	141	Row 7	No Table	32	36	37
9:00 AM		Blinds Closed And Lights On			12 Noon		Blinds Closed And Lights On			3:00 PM		Blinds Closed And Lights On		
	Column 1	Column 2	Column 3	Column 4		Column 1	Column 2	Column 3	Column 4		Column 1	Column 2	Column 3	Column 4
Row 1	No Table	No Table	No Table	633	Row 1	No Table	No Table	No Table	626	Row 1	No Table	No Table	No Table	633
Row 2	694	No Table	716	730	Row 2	688	No Table	710	655	Row 2	704	No Table	711	723
Row 3	694	709	734	762	Row 3	680	697	717	743	Row 3	686	696	719	743
Row 4	734	775	761	801	Row 4	714	753	739	769	Row 4	710	744	735	760
Row 5	1203	789	1239	1284	Row 5	706	744	750	774	Row 5	685	724	727	745
Row 6	781	780	863	896	Row 6	668	708	727	747	Row 6	629	670	676	697
Row 7	No Table	1000	930	968	Row 7	No Table	400	430	478	Row 7	No Table	352	354	379

Figure 6. Lighting Levels Measurements For The Classroom 0034 In The Ground Floor.

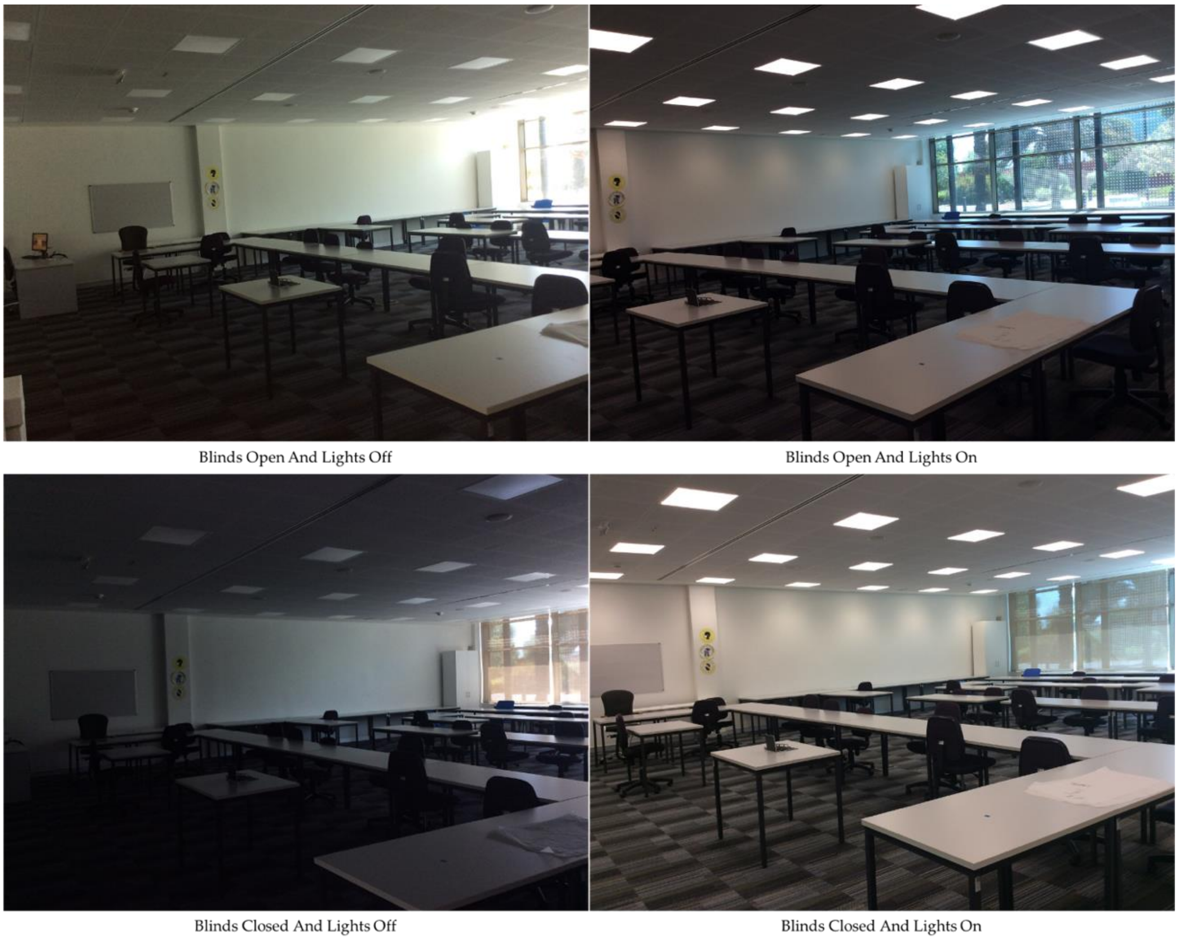

Figure 7. Blinds And Artificial Lights Different Cases In Classroom 0034, Ground Floor.

As seen from Figure 7, it is clear that the windows can provide enough daylight for almost half of the class in daytime; so, this can give an idea of changing class layout or provide different controls for lightings. All the other measurements for the classrooms showed that they got good (but varying) amounts of daylight each based on the classroom' location in the building.

4. Discussion

Using mixing methods (qualitative and quantitative) are helpful to understand the indoor environment and how the occupant's percept it.

The questionnaire itself shows that the people can have different opinion for each of the parameters of indoor environment. When comparing the questionnaire to the monitoring experiments it is also showed that not all people will get annoyed or affected by the indoor environment in the same way or at the same level. Because even when the readings weren't good some of the students still find the indoor environment good for them, while others not.

Table 7 will show the minimum and maximum measured readings for each of the parameter, as well as the average based on all of the readings. Then it will calculate the percentage difference (above or below) between the average and the standard.

Table 7. Summary Of The Measured Parameters And Related Standards (Based On -Hourly-Measured Data).

Parameters		Standard	Minimum	Maximum	% Difference
Indoor Air Quality	PM2.5	=< 15 μg/m^3	1	274	1727% Above Standard
	PM10	=< 50 μg/m^3	1	1416	2732% Above Standard
	CO2	=< 1000 ppm	400	625	0%
	TVOC	=< 312 ppb	125	1331	327% Above Standard
Thermal Comfort	Temperature	21 - 25 ^{o}C	17	24	19% Below Standard
	Humidity	30 – 65 %	29	83	3%Below Standard 28% Above Standard
Visual Comfort - Light Level (For Classroom 0034 Only)	Artificial Light Only	300 – 500 lux	352	1284	157% Above Standard
	Daylight Only		15	8700	95% Below Standard 1640% Above Standard
	Mixing Mode		625	8500	From 25% to 1600% Above Standards

There are some suggestions based on the results from both methods, some of these are:

- Changing the classroom layout, in a way that will make it use the most of daylighting, and in some classrooms the students' tables are perpendicular to the windows which cause glare and reflections so making it parallel to the windows will reduce this issue.
- Making the artificial lighting controlled by rows, this will reduce the energy consumption, because the rows that has enough daylighting will not need to turn on the artificial lights and so on.
- Changing the AC type (strip type) to type that can distribute the air evenly in the classroom, because the students that set under the supply feel colder and drier than the others, while the ones who set far away from it could feel warmer or comfortable.

5. Conclusions

This paper focus on studying the indoor environment quality for a university building by conducting a survey and monitoring experiments. It is clear from the results that there are some issues inside the classrooms, also that sometimes what users' percept is not the same for all of them. Moreover, the monitoring experiments showed more issues that what occupants can feel, which mean it is better to do different types of analysis when studying the IEQ.

This research will be continued by doing a simulation using DesignBuilder software, the first module will be the current state of the building and the average of cooling and heating load, daylighting and artificial lighting, and the energy consumption will be discussed. After that some changes will be added to the module, such as changing the classrooms layout, windows types, provide lighting controls and others, and the difference between the pre- and post-changes will be discussed.

The main limitation was the (COVID-19 situation), it is affected this study a lot. At the beginning, this research was supposed to consider three of the university buildings, two of them lecture buildings (one in female side and the other in male side) and the third one is the female residence building, but because the buildings were almost empty and not used a lot since most of the classes are online, as well as some safety purposes (especially at the female residence building), this study focused on only one building. Adding on that, some of the parameters were ignored for the current time (such as measuring the noise level) inside the classrooms, because the building supposed to be normally occupied so that the readings will be accurate.

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Daylight, View-Out, and Windows: The Sensorial-Based Design of Ottoman-Era Mosques.

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Abstract: Daylighting and outside view, as window design parameters, are often the main ambience-generating design factors that connect the users' sensorial relationship to their external environment. These relationships and their resulting ambiences vary by building type and carry a heightened value in some specific typologies of which, religious buildings hold a paramount place. Indeed, the sophistication of openings' design strategies applied throughout centuries in religious buildings, are good learning grounds on the use of daylighting and its resulting sensorial impact on users. In addition to a literature review related to Ottoman religious architecture, this paper reports on an in-situ field investigation that explored these relationships in a corpus of forty-five (45) mosques in Bursa, Edirne, and Istanbul, dating back to the Ottoman era (1299-1923). Breaking with past schemes, the new design paradigm introduced drastic changes in plans, openings, windows, views, and daylight, which resulted in unique ambiences. The variables investigated in this study include: i) the window location within the mosque envelope (zenithal and/or lateral), ii) the window location concerning the conventional prayer direction referred to as "Qibla" wall, and iii) the window transparency that permits or stops/blocks the outside view. In addition, the view content encompasses the identification and categorization of the objects, as seen by the worshipers while performing their prayers, through the ground-level windows. The collected information was converted into a database for statistical analysis. By focusing on the human sensorial-based design in the Ottoman mosques, the results revealed the daylighting design specificities of the building envelope and the windows as well as the nature of the view out content
Both of them attested to the human-centered design by Ottoman builders offering worshipers a strong connection to the external environment, thus creating ambiences conducive to spiritual fervor and beatitude.

Keywords: Daylighting; Window design; View out; Heritage Ambience; Ottoman Mosques.

1. Introduction

Environmental design could not be undertaken without considering the users [1, 2]. Significant research substantiates the inadequacy of building design as a result of failure to meet users' needs, resulting in discomfort, energy performance gap, alteration of buildings, and/or reduced productivity [3-5]. Hence, several approaches have been established by researchers to set up ways that would allow the consideration of the users during the architectural design process. Going beyond the functional aspects, researchers are increasingly focusing on the psychological and behavioral effects including emotions and feelings.

In the architectural research field, "Ambiences" or "Atmospheres" is a widely known theme highlighting the human sensorial relationships towards urban and architectural environments [6].

Such relationships are limited to what the built environment transmits, through the most common human senses, to its users. This research work belongs to the same thematic context of scientific research. It investigates the luminous ambience in the Turkish Ottoman mosques through the study of window openings design strategies, with a focus on daylight admission and the provision of a view out. Both parameters are considered as important factors for human physical and psychological well-being within the built environment realm.

The investigation of such aspects within historical buildings remains inherent to the fact that these ambiences constitute an intangible heritage needing to be studied, advertised, and preserved [7, 8]. Additionally, contemporary users' needs, as well as building techniques development, must be carefully adapted to the specific constraints of such historical buildings. This will also allow the constitution of a set of architectural daylighting design references for the contemporary restoration of Ottoman architectural religious buildings. It must be reminded here, that the design order in question is present in most of the Muslim and non-Muslim parts of the former Ottoman Empire and is an inherent part of the local architectural heritage [9].

2. Ambience, natural light, view out, and Islamic architecture

From the conceptual point of view, ambience is modeled as a temporally evolving condition that expresses the interaction between four components: i) the Context (climatic, cultural, and social), where the investigated built environment is located (building and/or urban space), ii) the Architectural space (shape and usage), iii) the Sensorial stimulus-related physical environment previously enumerated, and iv) the Users through perceptual and behavioral conducts towards the spaces [10,11].

Equally valorized by Islamic builders and writers, while enjoying a manifest presence in several Quran verses, natural and artificial lighting are epitomized as an inherent component of ‘Beautiful’ [12]. From an artistic point of view, artificial lighting artifacts such as chandeliers are considered a unique craft field of a high caliber. Besides, and similarly to geometry and rhythm, light is one of the artistic tools expressing the 'unity of existence' or 'unity of the real' in the architectural composition.

Natural light is a critical stimulus historically recognized as the main design component in Islamic architecture. The Islamic art and architectural historian Oleg Grabar indicated that the contrast between light and shadow in the first Islamic palace architecture was different than the one inherited from Roman classical buildings [13]. Moreover, the archeologist J. Bonnéric also attested that in medieval Islamic architecture, the light created an intangible architecture that comes to be superimposed to the material one [14]. Beyond the mosque's roofs, walls, and finish materials, natural light plays a major topological-based functionality in addition to the divine symbol it represents [15]. Respectively, natural light indicates distinct areas inside the prayer hall such as: i) the Mihrab and Minbar zone from which the Imam leads the community prayer and the Friday sermon, and ii) the other parts of this space reserved for the regular prayers. Moreover, as it is the case for any sacred space, Muslim worshippers are also not insensitive to the divine symbolic effect of light [12, 16, 17]. Inside the mosque, the perceiving process has been revealed as a sensing function type involving the five senses (vision, touch, smell, taste and hearing). These senses are driven by the details and people focus first on them before defining an impression. In addition, it has been pointed out that the mosque’s physical environment provides that outer physical and social stimuli in favor of the worshippers’ extraversion, preferred orientation in terms of spiritual relationships with God [18]. Therefore, natural light constitutes one of the most powerful external physical environments that: i) are sensorially perceived by means of human vision, ii) make worshippers focus on the mosque envelope's details, in particular its various openings and the views contents they provide, and iii) offer that extraverted environment linking spiritually the worshippers to their creator.

Natural light, as an immaterial stimulus, was at the basis of the creation of numerous and rich Islamic architectural components varying from the larger urban scale to the minute construction detail [19, 20]. For the special case of Ottoman religious architecture, a previous study by one of this study’s authors highlighted such daylighting design-related architectural variety in the case of Ottoman mosques in Tunisia and Algeria [21]. In and closely associated with natural lighting, the provision of a view outside the prayer hall seems to be a supplementary character distinguishing Ottoman religious architecture from other preceding sacred buildings including Islamic ones. The lower windows in the Ottoman mosques' prayer hall provide a view to the outside. This is not; however, the case of the mosques built during the Ottoman's earlier dynasties. Additionally, these windows are unscreened and differ from the upper ones in the same wall. For, the view content is considered as sources of latent signals including skylight, sunlight, gardens' colors and odors as well as the carved tombstones' shapes. These latter participate powerfully in the prayer hall's inner ambience.

This study aims to explore, identify and survey window openings design in the Ottoman mosques in Turkey. These ambient components are considered as the architectural devices transmitting the luminous and other latent signals towards the mosque's users (worshippers and travelers as well). Users receive these various signals sensorially. Describing the inner luminous ambience of Istanbul's Fatih Mosque, F. Babinger said:

> *"The interior of the mosque is of almost overpowering puritanical simplicity. The unobscured light enters through numerous windows ordered in superimposed rows"* [22, p. 177].

The windows' provision of an outside view seems to be another important function as it was cited by the traveler Stratten:

> *"The eye, from inside or from out, sees clear through the building. ...He (Sinan) glazed those at floor level with clear glass and grilled with the Ottoman rectilinear iron bars..."* [22, p. 187].

It must be pointed out that using such sensorial signals to affect the worshippers is a key design strategy for Ottoman architects; for, art is a means to bring humans closer to their Creator. Rather than a geometric shape order, the designed dynamic, changing, and unexpected visual qualities of spatial experiences are based on distinct and/or associated effects of color and light among others. Such sensorial-based relationships between the mosque's inner spaces and its natural and/or urban exterior environment are treated from the most general to the smallest of conceptual details [23].

In order to undertake this investigation, an extensive literature review and a large in-situ fieldwork were carried out. Additionally, an analytical protocol was developed.

3. Study Corpus

In his book entitled "Mosques of Istanbul including the mosques of Bursa and Edirne", Matthews [24] sets chronological groupings of Ottoman mosques as they historically evolved from the early to the latest stages of the Ottoman Empire. Hence, the architectural historian defined six main eras; i) Period before the conquest of Constantinople (mosques in Bursa and Edirne), ii) Early period after the conquest of Constantinople, iii) Classical period (Sinan's mosques), iv) Late classical period, v) Baroque period, and vi) Late Nineteenth-century period.

In addition to three Christian churches converted into mosques, Matthews enumerates forty-six (46) mosques constructed during these periods and located in Bursa, Edirne, and Istanbul. Among this collection, forty-one (41) mosques were visited and selected as the study corpus of this investigation. In addition, four (4) mosques located in Istanbul and not cited by H. Matthews [24] were visited and added to the study corpus; i) Firuz Aga Mosque (Early period after the conquest of Constantinople), ii) Seb Sefa Hatun Mosque (Baroque period), iii) Pertevniyal Valide Sultan Mosque, (Late Nineteenth-century period), and iv) Ertuğrul Tekke Mosque, (Late Nineteenth-century period)

As a result, forty-five (45) mosques constituted the study corpus, spanning though the various eras as defined by H. Matthews [24], and located in the three most important Ottoman cities of Bursa, Edirne, and Istanbul (Table 1).

Table 1. The in-situ investigated study corpus mosques in Bursa, Edirne and Istanbul.

N°	Name	City	Era	Style -Matthews's Classification
1	Alâeddin Mosque	Bursa	1335	Bef. Constan. Conq.
2	Orhan Gazi Mosque	Bursa	1339	Bef. Constan. Conq.
3	Yildrim Beyazit Mosque	Bursa	1391-95	Bef. Constan. Conq.
4	Ulu (Great Mosque)	Bursa	1396-1400	Bef. Constan. Conq.
5	Yeşil (Green Mosque)	Bursa	1412-22	Bef. Constan. Conq.
6	Muradiye Mosque	Bursa	1424-26	Bef. Constan. Conq.
7	Eski (Old Mosque)	Edirne	1403	Bef. Constan. Conq.
8	Muradiye Mosque	Edirne	1435	Bef. Constan. Conq.
9	Üç Şerefeli Mosque	Edirne	1438-47	Bef. Constan. Conq.
10	Murat Paşa	Istanbul	1469	Early M. Aft. Conq.
11	Beyazit II	Edirne	1484-88	Early M. Aft. Conq.
12	Firuz Aga	Istanbul	1491	Early M. Aft. Conq.
13	Gazi Atik Ali Paşa	Istanbul	1496	Early M. Aft. Conq.
14	Sultan Selim	Istanbul	1522	Early M. Aft. Conq.
15	Haseki	Istanbul	1550-51	Classical Sinan
16	Mihirmah Sultan Iskele	Istanbul	1543/44-48	Classical Sinan
17	Şehzade	Istanbul	1543-48	Classical Sinan
18	Süleymaniye	Istanbul	1550-57	Classical Sinan
19	Kara Ahmet Paşa	Istanbul	1565-71	Classical Sinan
20	Sinan Paşa	Istanbul	1554-55/56	Classical Sinan
21	Rüstem Paşa	Istanbul	1561-63	Classical Sinan
22	Mihirmah Sultan	Istanbul	1563-70	Classical Sinan
23	Molla Çelebi	Istanbul	1570-84	Classical Sinan
24	Selimiye	Edirne	1568-75	Classical Sinan
25	Sokollu Mehmet Paşa and Ismahan Sultan	Istanbul	1567/68-71-72	Classical Sinan
26	Piyale Paşa	Istanbul	1565-73	Classical Sinan
27	Zal Mahmut Paşa and Şahsultan	Istanbul	1577-90	Classical Sinan
28	Sokollu Mehmet Paşa	Istanbul	1573-77/78	Classical Sinan
29	Atik Valid Sultan	Istanbul	1571-83	Classical Sinan
30	Kiliç Ali Paşa	Istanbul	1578-81	Classical Sinan
31	Şemsi Ahmet Paşa	Istanbul	1580-81	Classical Sinan
32	Nişanci Mehmet Paşa	Istanbul	1584/85-88/89	Classical Sinan
33	Yeni Valid Emi	Istanbul	1597-1663	Late Classical
34	Sultan Ahmet (also called Blue Mosque)	Istanbul	1609-16	Late Classical
35	Yeni Valid Usk	Istanbul	1708-10	Baroque
36	Nuruosmaniye	Istanbul	1748-55	Baroque
37	Laleli	Istanbul	1759-63	Baroque
38	Fatih	Istanbul	1767	Baroque
39	Seb Sefa Hatun	Istanbul	1787-88	Baroque
40	Eyüp Sultan	Istanbul	1798-1800	Baroque
41	Dolombahçe	Istanbul	1853	Late 19th Century
42	Mecidiye	Istanbul	1854	Late 19th Century
43	Pertevniyal Valide Sultan	Istanbul	1871	Late 19th Century
44	Hamidiye	Istanbul	1880	Late 19th Century
45	Ertuğrul Tekke	Istanbul	1887	Late 19th Century

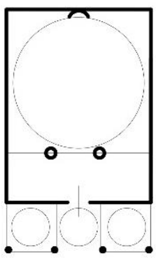
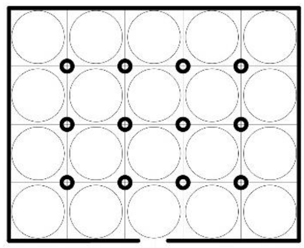
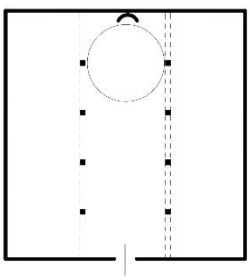
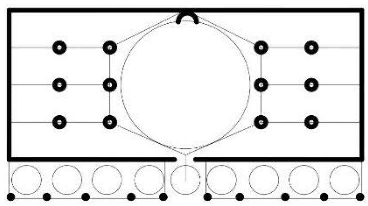
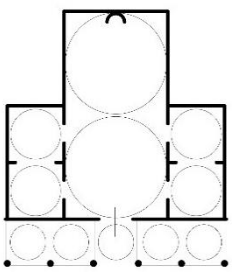
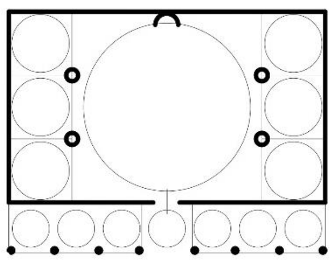
4. Methodology

From an architectural point of view, daylighting is primarily provided in a lateral and/or zenithal way, regardless of the used means [25]. Hence, this research considers openings located in roofs and walls. This study presents specifically the investigation of the Qibla wall's openings and its resulting ambiences. The Qibla wall, always oriented towards the Kaaba in Mecca, is the wall faced by all worshippers during their prayers. However, the space characteristics are still crucial parameters in terms of daylighting design [26]. Thus, the mosque's prayer hall is examined to set up a series of daylighting-related morphological indicators. The methodological approach is; therefore, based on an in-situ detailed survey of the parameters and characteristics of the daylighting strategies in each considered component, roof and wall, followed by a statically analysis of the data collected.

4.1. Ottoman mosques' prayer hall characteristics

The Ottoman Mosque has been and remains an attractive architectural research topic and several publications, as well as scientific events, are devoted to it. For this investigation, the Ottoman mosque typology is based on an adaptation of Oney's classification, who divided the XIVth-XVth century era of Ottoman mosques into seven types [27]. This investigation; however, considers six types instead of seven with type 5 and type 6 being combined to form the inverted T-shape mosque type (also called mosque with "Tabbanes/Zaouias" which are two additional prayer areas located laterally and set back from the main prayer hall). The six resulting types are: i) The cubical buildings with a unique cupola, ii) the hypostyle mosques, iii) the basilica-style mosque, iv) the mosque with a transept, v) the inverted T shape mosque, vi) the mosque with a central dome (Table 2). In addition, the location of a mosque within a religious urban complex and the resulting landscaped setting remains into consideration due to its link to the view-out content.

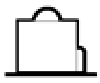
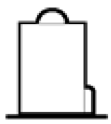
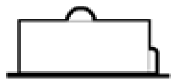
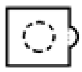
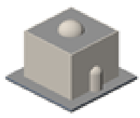
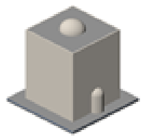
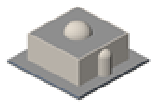
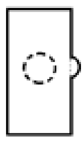
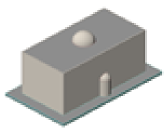
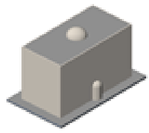
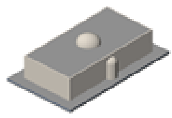
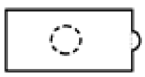
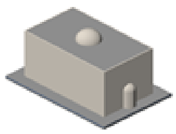
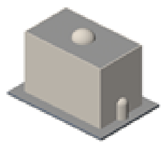
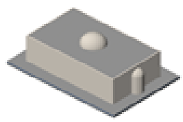
Table 2. The six types of mosques' prayer halls (Variants' examples).

	
The cubical building with a unique cupola	The hypostyle mosque
	
The cubical building with a unique cupola	The hypostyle mosque
	
The inverted T shape mosque	The mosque with a central dome

In addition to this architectural-historical classification, the prayer hall size needs to be considered in daylighting design. Hence, the width, length, and height of the prayer hall are considered in this study. They are distinctively divided in categories per their width/length ratio and include: i) square (width = length), ii) large (width > length), and iii) deep (width < length). The categories defined in respect to the prayer room height are: i) regular (height = length), ii) high (height > length), and iii) low (height < length).

To set up a more daylight-related classification that is independent of the effective (metric) area of the prayer hall, the inner volume of this latter has been categorized in respect of its height, length, and width. This synthetically inner volume-based classification emerges from the crossing of the previous categories and results in three kinds of prayer hall inner volumes: i) cubical, ii) slender, and iii) flattened (Table 3).

Table 3: Categories of the Ottoman mosque's inner prayer hall volume.

			Section		
Plan			Regular	High	Low
					
	Square		 *Cubical*	 *Slender*	 *Flattened*
	Large		 *Flattened*	 *Slender*	 *Flattened*
	Deep		 *Flattened*	 *Slender*	 *Flattened*

4.2. Domes and cupolas openings

Typically, in an Ottoman mosque design, zenithal daylighting occurs through apertures in cupolas and domes. These openings vary in number and location according to the building construction era. This research refers to the classification established in R. Günay's book entitled "*Sinan. The architect and his works*" which identified five base types of Ottoman mosques [28]: i) square-based single-domed mosques, ii) square-based semi-domed mosques, iii) hexagon-based mosques, iv) octagon-based mosques, v) multi-based multi-domed mosques. This typology was extended to the entire corpus' mosques and applied to those built before and after Sinan's era as well as by other builders.

4.3. Qibla wall openings

The characteristics of both vertical and horizontal distributions of windows within the Qibla wall may be analyzed as follows [28]. Horizontally, the windows are divided into series depending on their openness/closeness as they relate to the absence/presence of a screen. The screens are also distinguished as inside, outside, or double (inside and outside screens). The absence of a screen provides the prayers with a view out through the window. Its presence allows sunlight and/or daylight admission as well as a play of a mixture of colored sunrays. This division of window screens is quantified as a quotient defining the number of screened windows' rows per the total number of rows of windows in the whole Qibla wall.

Vertically, attention is paid to the presence/absence of windows in the Mihrab's axis (Figure 1). This axis is prominent in all mosque designs as it indicates the direction of the Qibla inside the prayer hall, and consequently, the location of the windows highlights such importance. Additionally, it is argued that the location of windows on both sides of the Mihrab will have a similar but less expressed importance. The number of window stacks (or vertical series) within the Qibla wall is considered. However, this division is quantitatively limited to the number of those located on either side of the Mihrab's axis.

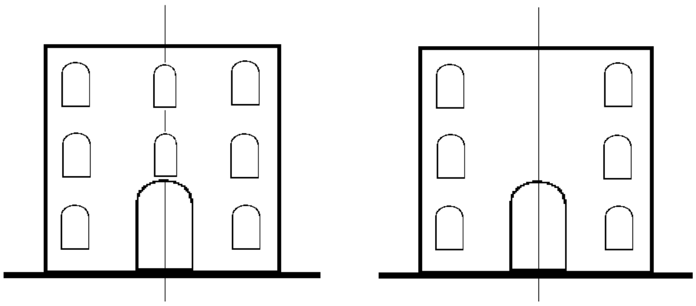


Figure 1. Presence or Absence of the Quibla wall's windows in the Mihrab's axis (Respectively on the left and right).

5. Results and Analysis

The surveyed characteristics of the investigated Ottoman mosques formed a database which was then examined through a statistical descriptive and multivariate analysis using the "Statistica" 7.1 version program [30]. This constituted corpus indicates that mosques with a central dome are predominant (76%). The cubical mosques with a unique cupola, the hypostyle mosques, and the mosques with "tabbanes / Zaouias" (inverted T) are less present; respectively accounting for 9%, 9%, and 7%. The results and analysis that follows addresses each component (prayer hall, roofing system and Qibla wall).

5.1. Prayer hall characteristics

The prayer hall characteristics highlighted predominant categories. The inner volume-based classification of the prayer hall allows the identification of the most dominant categories as the flattened (49%) and slender (40%) prayer halls, while the cubic one was less frequent (11%) (Figure 2).

5.2. Prayer hall's roofing system characteristics

As an integral part of the roof design, most of the principal domes (84%) include windows. They are distributed as follows: i) the square-based single-domed mosques (24%), ii) the square-based semi-domed mosques (18%), and iii) the octagon-based mosques (18%) (Figure 3). The double in-depth square-based domed mosques, the hexagon-based mosques, and the multi-based multi-domed mosques are less present (respectively 13%, 13%, and 7%). Besides, few cases (representing 2%) are:

i) double in large square-based domed mosques, ii) single eccentric-based mosques, and iii) windowless octagonal-based domed mosques.

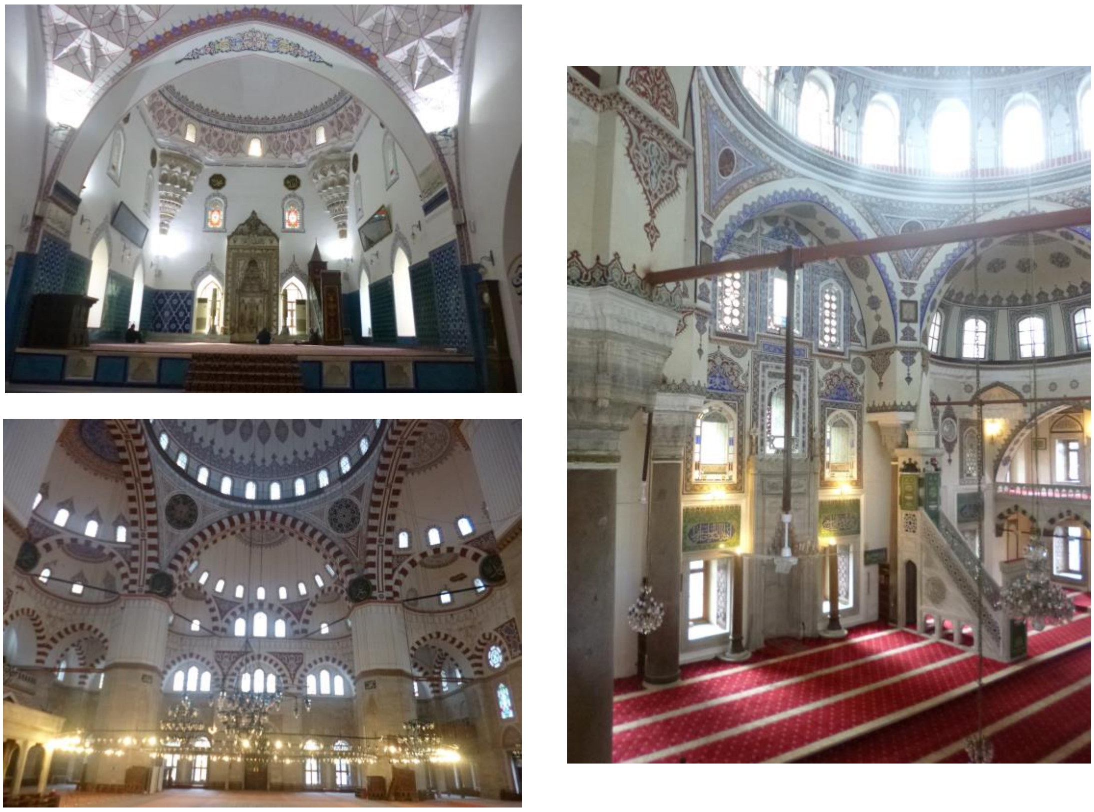


Figure **2.** The presence degree of the studied mosques' prayer hall inner volume categories: i) Left top: Flattened (49 %), ii) Right: Slender (40 %), and iii) Left down: Cubical (11 %).

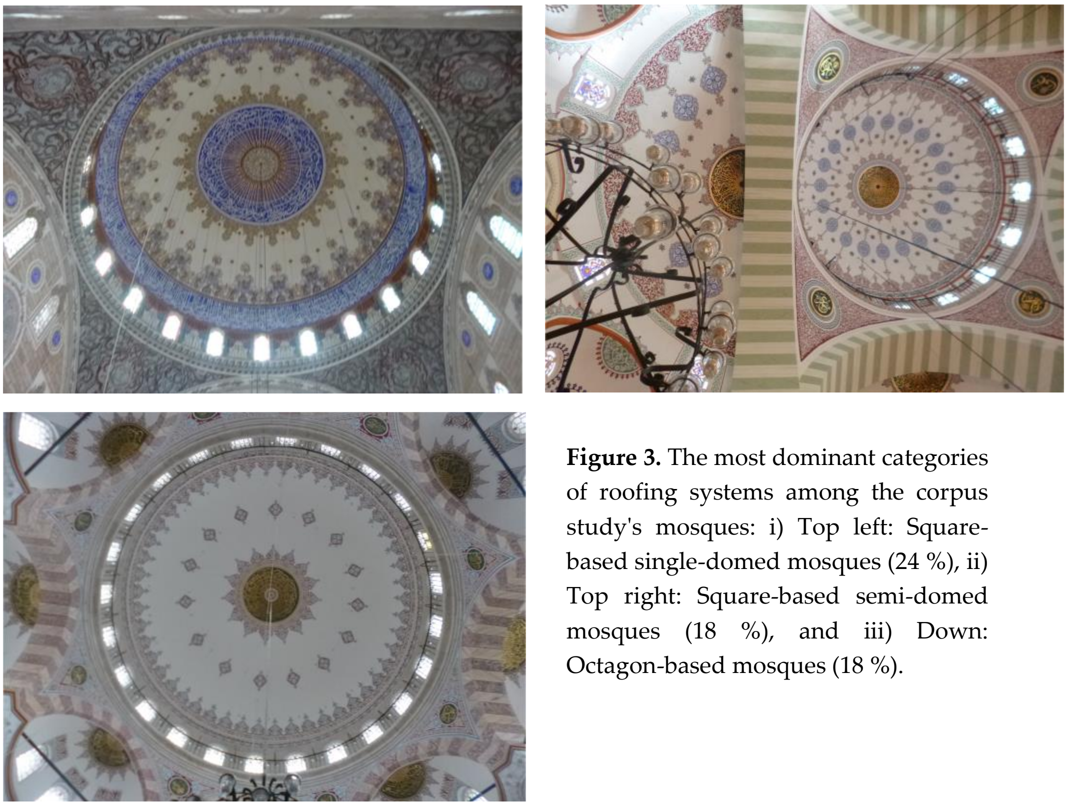


Figure 3. The most dominant categories of roofing systems among the corpus study's mosques: i) Top left: Square-based single-domed mosques (24 %), ii) Top right: Square-based semi-domed mosques (18 %), and iii) Down: Octagon-based mosques (18 %).

5.3. Characteristics of the Qibla wall windows

The Ottoman mosques' Qibla wall is largely windowed as identified by the statistical analysis. In the studied mosques, the window horizontal distribution varies greatly from 2 to 5 rows (31%, 20%, 24%, and 18%). Nearly all the mosques have a low-level row of unscreened windows (96 %) whilst only five mosques (11%) have no screened windows rows altogether (Figure 4).

Figure 4. Example of a mosque with a unique unscreened ground level windows' row (Left) and another with all unscreened windows' rows (Right), respectively Mourad Pacha Mosque and Dolmabahce Mosque, Istanbul.

In the Qibla wall, the Mihrab constitutes a focal point for the prayers that gave it a topological character inside the prayer hall [20]. Utilizing daylighting design, the Ottoman mosque highlights such a character through various daylighting-based architectural compositions: i) windows located along the Mihrab axis/span in more than three quarters of the mosques (78%), ii) from one to four columns of windows positioned on both lateral sides of the Mihrab (respectively 29%, 13%, 16%, and 22%) (Figure 5). Moreover, the Mihrab span is designed as a specifically windowed cantilevered volume in more than three-quarters (78%) of the mosques (Figure 6).

Figure 5. The Mihrab's luminous topology by means of: i) Windows' columns located on the its axix and/or span (Left), and ii) Windows' columns located only on its both lateral (Right), respectively, Sehazade Mosque, Istanbul and Yildrim Beyazit mosque, Bursa.

Figure 6. The Mihrab's luminous topology by means of semi-domed cantilevered volume. Example: Molla Çelebi Mosque, Istanbul.

6. Discussion

6.1. Daylighting design-based correspondences between the multiple characteristics of the prayer hall

Three multivariate statistical analyses were undertaken to identify the daylighting-based features that should correspond to the prayer hall characteristics. The first Multiple Correspondences Analysis (MCA) informed that each category of the prayer hall inner volumes is related to specific roof design and a precise total number of the Qibla wall windows' rows (Table 4).

The second MCA revealed that the absence of windows at the principal dome base occurs for the case of the square-based single-domed mosques with a single row of windows and mostly characterized by a slender inner volume and less by a cubic one (Figure 7). By contrast, the presence of windows in this zenithal daylighting component is common to the mosques with the other characteristics.

The corresponding relationships between the type of mosque and the prayer hall's inner volume as well as its roof design were also investigated. The third MCA showed that each type of mosque, as categorized by G. Oney [27], has specific characteristics (Table 5). However, it must be noted that the hypostyle mosque is not specifically characterized by any prayer hall inner volume or a precise number of window rows. Similarly, the mosques with a central dome are not associated with a unique kind of prayer hall inner volume. Additionally, the cubic prayer hall inner volume is not limited to any mosque architectural type.

6.2. Window, Daylight and View out

The Ottoman mosque's openness towards the outside contrasts with the previous mosque examples and, for that matter with Christian sacred buildings as well [31]. Whilst the first opposition could be related to the different climatic conditions between Anatolia and the other hot arid regions of the Muslim world, the second one could be considered from the divergence of meanings of the whole sacred space and light, particularly from the Christianity and Islam points of view.

Table 4. Correspondences between Prayer hall's inner volume categorizes and its characteristics as resulted from the first Multiple Correspondences Analysis.

N°	Prayer hall inner volume category	Variant	Prayer hall characteristics
01	Slender	1	Total windows number series : ▪ Three (3) Prayer hall roofing systems: ▪ Double square-based domed Large mosque ▪ Hexagon-based mosque ▪ Octagon-based mosque
		2	Total windows number series : ▪ Six (6) Prayer hall roofing systems: ▪ Square-based Single-domed mosque
02	Flattened	1	Total windows number series : ▪ Two (2) Prayer hall roofing systems: ▪ Double square-based domed Deep mosque ▪ Single Eccentric domed mosque ▪ Multi-based Multi-domed mosque
03	Cubical	1	Total windows number series : ▪ Four (4) ▪ Five (5) Prayer hall roofing systems: ▪ Square-based Semi-domed mosque

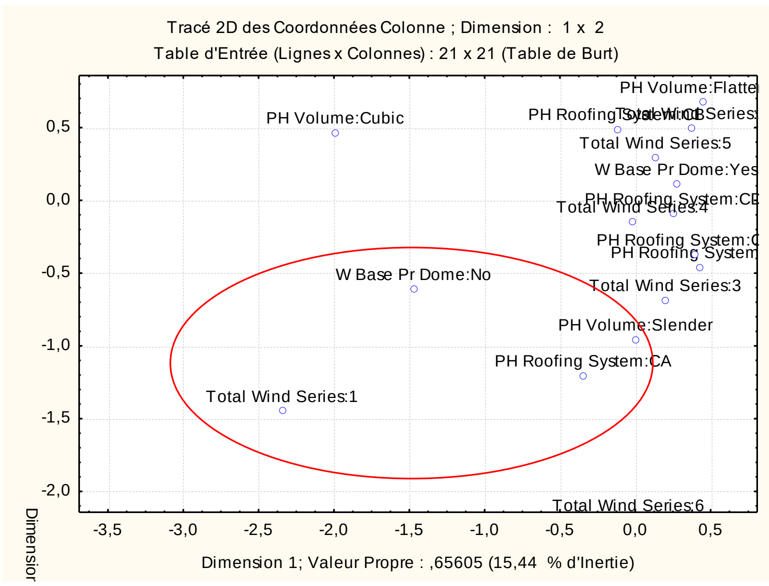


Figure 7. The graphical outcome of the second multiple correspondences analysis revealing the prayer hall's characteristics associated to the case of central dome without windows at its base (Statistica 7.1 program).

Table 5. Correspondences between Prayer hall's inner volume categorizes and its characteristics as resulted from the first Multiple Correspondences Analysis.

N°	Mosque Type in respect to G. Oney's categorization [27]	Prayer hall characteristics
01	Type i: The cubical mosque with a single cupola	Total windows number series : ▪ Three (3) or Six (6) Prayer hall roofing systems: ▪ Square-based single-domed mosque Prayer hall inner volume: Slender
02	Type ii: The hypostyle mosque	Prayer hall roofing systems: ▪ Double square-based domed Large mosque ▪ Multi-based Multi-domed mosque
03	Type v: Mosque wiith 'Tabbanes' (Inverted T)	Total windows number series : ▪ Two (2) Prayer hall roofing systems: ▪ Double Square-based Single-domed Deep mosque Prayer hall inner volume: Flattened
04	Type vi: Mosque with a central dome	Total windows number series : ▪ Four (4) or Five (5) Prayer hall roofing systems: ▪ Octagon-based mosque

Moreover, this character illustrated by the row of a low-level window, which is largely present in the Ottoman mosques, influences powerfully the worshippers inside the mosque and then, the general ambience of the prayer hall. In addition to the travelers, architectural historians and writers also described the luminous ambience within the Ottoman mosques and used a rich poetical vocabulary in their narratives. Inside the prayer hall, the Qibla, right and left walls' ground level unscreened windows are mainly oriented towards green intermediary spaces and/or cemetery gardens [23, 32]. By intended contrast, the ground level windows located in the wall behind the prior provide views on the open-to-sky courtyard.

In terms of view out through the low-level windows, the points of view diverge in terms of the influence they have on the user's behavior during prayer. For C. E. Arseven [33], the worshipper is entertained and focuses less on religious duty when looking outside through windows. In contrast, H. Matthews [24] considers the content of view to the outside and sees that the worshipper will be reminded of human mortality when seeing the garden cemetery located near the prayer hall. When observing on-site, the very high degree of decoration and sculpture of these tombstones, it is inevitable that the contemplation of the divine imposes itself on the human being and affects his or her piety (Figure 8).

Moreover, these windows are designed in such a way that they provide a specific place for devotion. Following an ancestral tradition and until the present time, the worshippers still use mosques to read the Muslim holy book, the Koran, while being in visual contact with the outside (Figure 9). It must be noted here that this location is the most comfortable in the Mosque from the daylighting point of view. However, the magnificence of the outside landscape is not to be ignored.

Figure 8. Various views through low level row windows as well as outside the prayer hall showing the cemetery gardens decorated with sculptural tombstones.

The Ottoman designers included this aspect by the creation of an urban complex which encompassed the mosque and allowed the creation of various outdoor greenery scenes (Figure 10). Both cemeteries and gardens belong to paradise. So, rather than just admitting light inside the prayer hall, the introduction of greenery through unscreened ground-level windows meant death and paradise, in opposition to the open-to-sky courtyard which provided social communion and represented the earth [24, 32].

6.3. The users' point of view: From the inherited luminous ambience to the daylight-based contemporary architectural design.

At the present time, Ottoman mosques in Turkey are used by worshippers and visitors. The impact of natural lighting on both groups is manifestly contained within the mosques' description by old travelers and/or renowned architectural experts. In this respect, the traveler E. Celebi described the ambience of a religious event (the Ashura night during August 1630) inside a mosque in Istanbul:

"…the door was opened, and the light-filled mosque was crowded with a luminous congregation, who were busy performing the dawn prayer" [34, p.4].

A similar encounter involved one of the Modern Masters, Le Corbusier who in 1911, marveled about the Suleymanie Mosque in Istanbul:

"It must be a silent place facing toward Mecca. It needs to be spacious so that the heart may feel at ease, and so high that the prayers may breathe here. There must be ample diffused light as to have no shadows; the whole should be perfectly simple; and a kind of immensity must be encompassed by these forms...At a glance

one sees the four corners, distinctively feels their presence and then construes the great cube perforated by small windows...overhead is a vast space whose size one cannot grasp, for the half sphere has the charm of eluding measurement... All these things are clothed by a majestic coat of whitewash. The forms stand out clearly, the impeccable construction displays all its boldness" [35, p. 363].

An in-progress research work investigates such textual data with the aim to identify the most cited daylighting devices by travelers and their associated effects as they described them. Further, a morphological study will focus on those dominant apertures.

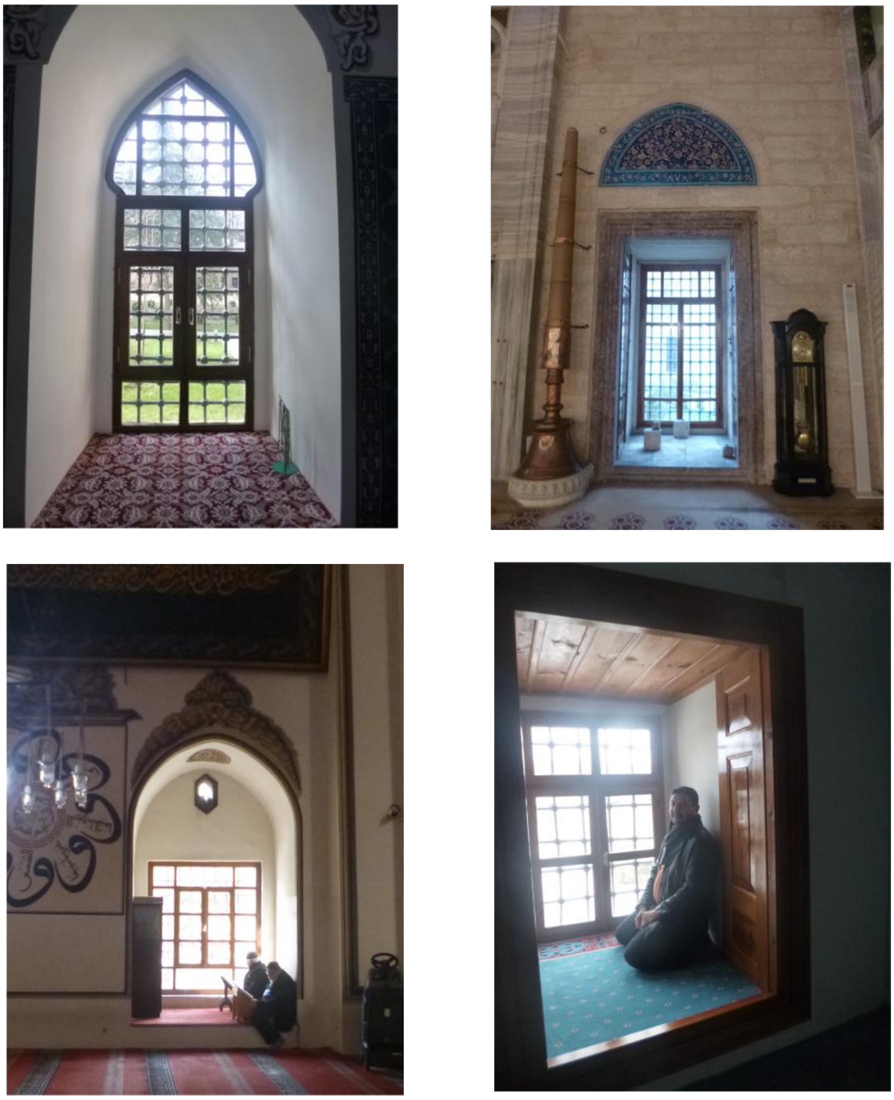


Figure 9. The devotional use of the human scale designed ground level windows by the priors for the reading of the Koran and worship using the rosary.

The users' point of view about this sensory experience is still important nowadays, and for several reasons. Besides the current life within the historical mosque and its luminous ambience impact on the worshippers, the restoration of these heritage buildings requires a careful undertaking in the preservation of such human based environmental and authentic character while responding to the current requirements for indoor comfort. Effectively, the users of some of Bursa historical mosques attest that the noticeable visual discomfort is due to the new but inappropriate artificial lighting used [36]. Among these mosques, two were restored, mainly after the numerous earthquakes, and the inadequate artificial lighting features could have been adopted as part of these restoration projects.

Figure 10. The mosque's outside garden and cemetery landscaping as well as the scenes perceived from inside through the prayer hall's low level windows.

In addition, the specificity of this sensory design related legacy induces its scientific overall and detailed knowledge in order to take a new look towards the still undisclosed Ottoman architecture [35]. Finally, such investigations will allow identify the degree this heritage ambience has been and/or could be used as a reference for the contemporary mosque design and, thus, constitute a permanent architectural identity feature [37]. Effectively, the recent built Turkish mosques' designers used widely the natural light as a main creative tool in reference/or not to the Ottoman architectural heritage [38-41] (Figure 11).

7. Conclusions

This research aimed to investigate the sensorial-based environmental relationships inside the Ottoman mosques in three main Turkish cities, Bursa, Edirne, and Istanbul. The data collected during the extensive fieldwork as well as from an extensive literature review were statistically analyzed to satisfy a large degree of objectivity.

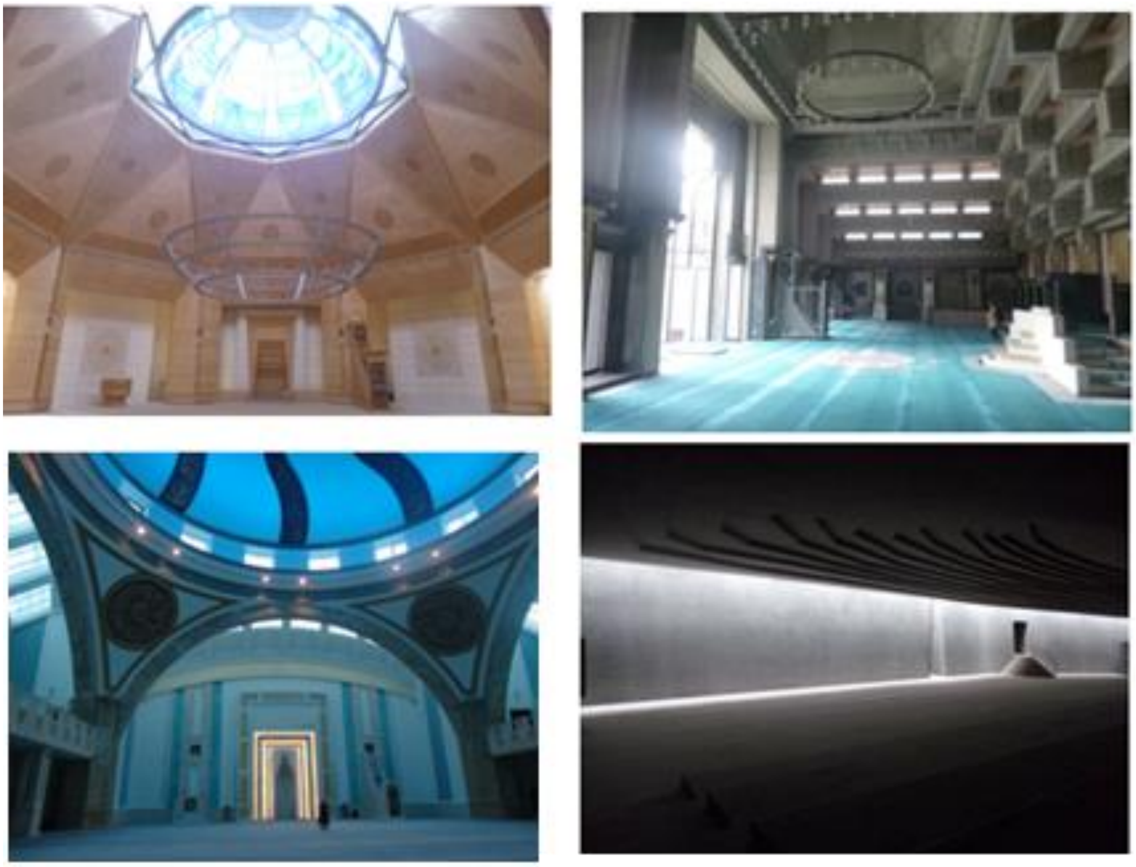


Figure 11. Examples of natural lighting architectural components in the Turkish contemporary mosques revealing the reference (left) or not (right) to the Ottoman old daylighting design.

The preliminary outcomes of this analysis revealed that slender and flattened inner volumes of the prayer hall are more present among the mosques' study corpus than the cubic ones. These most prominent volumes are generally covered by a windowed central dome to which could be added semi-domes and smaller cupolas.

In the history of the Ottoman Empire, the mosques' Qibla wall is progressively windowed. In the later structures, it became almost transparent with large rows of fully unscreened windows. Further, this wall attests to a particular luminous spatial topology. The Mihrab itself is a blind focal point that is brought to light by the windows located above and/or on either side of it. This specific important and symbolic area was elevated as a cantilevered volume added to the general envelope of the mosque. Both lateral and zenithal daylighting are used to enhance the luminosity of the place by respectively employing rows of windows and a windowed semi-dome.

The mosques' inner volume daylighting design attests to a development that is respectful of the architectural style evolution, whilst some characters occurred throughout the various Ottoman eras. In addition to the daylight admission inside the prayer hall, the view out through ground-level windows constitutes a specific Ottoman attribute for the sacred space. The view orientation and contents include several signals that powerfully impact the worshippers' perceptions and behaviors while they distinctively characterize the Ottoman mosques' ambiences.

This research work will be extended in the future to include more case studies representing the production of all the Ottoman Empire's eras. On the other hand, the ambient-based architectural design will be investigated at both the designer's intentions and the levels of users' perceptions and behaviors. It is intended that content analysis will be applied to historical narrative sources and contemporary literary productions. Finally, an exhaustive analysis will be undertaken to define the morphological characters of the windows-envelope relationships in terms of lateral (walls) and zenithal (roof design) daylighting design.

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Conflicts of Interest: The authors declare no conflict of interest.

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Affordable Heating System Exploration for a Net Zero Energy Experimental Home in Melbourne, Australia

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Abstract: This research explores affordable heating for hydronic systems of a net zero energy experiment home built in Melbourne, Australia. For this research purpose, a 3m-wide 6m-long outbuilding is built next to a backyard garage. Inexpensive 12mm-dia poly tubes are spaced 100mm inside the 55mm-thick tiled concrete which rests on 100mmT (R2.5 $m^2 \cdot K/W$) recycled cold-room panels laid on ground. This hydronic floor and ground is insulated from the outdoors by 400mm-deep 40mm-thick (R1 $m^2 \cdot K/W$) polystyrene. Simulations show that heating this hydronic floor by a vertical ground heat exchanger with 17°C bottom temperature, together with a hydronic wall radiator heated by 30 evacuated tubes and a 2-cubic meter thermal storage, the indoors could reach the Nationwide House Energy Rating Scheme (NatHERS) respective night and day heating thermostats of 15°C and 20°C across winter. This assumes that the indoor had been at NatHERS temperatures for 5-6 years for the temperature at the bottom surface of the floor to stabilize. Since this warmup period has not been met, the results in this paper show the temperatures with water heated by a sawdust/wood burner. An experiment was also conducted with a compost pile. Two months after its initial 1-month exothermic phase, the temperature at the center was still 32°C. Thus, compost piles will be located outside external walls to help keep the perimeter of the floor warm. To obtain affordable hot water for the indoors to reach 20°C, a 6m-long 750mm-wide flat-belt collector was boxed up and covered with glass. In late autumn, it could only heat water by only 1-2°C and was thus not used in winter. However, by late spring, the empty poly belt had melted, indicating that, the temperature under the glass had reached above 50°C. Typical meteorological year data shows that the solar radiation has tripled that in autumn. Therefore, for future winter experiments, the weak solar radiation would be concentrated, by say, a north-facing parabolic trough with an aperture three times the area of a glazed metallic collector

Keywords: Renewable heat, Affordable hydronic radiator, Compost piles, Concentrated solar collector.

1. Introduction

Hydronic heating systems make homes in cool/cold climates comfortable quietly. This project explores affordable renewable sources to heat water for a hydronic floor. The experimental building in Melbourne Australia has an inexpensive 3m x 6m hydronic concrete floor which rests on recycled cold room panels laid on ground. As the temperature of the ground below the floor takes years to stabilize against the variations in the outdoor temperature, this paper reports the results to warm up the floor with a wood/sawdust burner.

It also reports test results for the exothermic decomposition of organic waste and the effect of glazing a flat belt solar collector that heats water for swimming pools. Test results are discussed and plans for future experimentation are presented.

This project is spurred by past 2-decade data from the US which shows that in winter, the energy use by the residential sector is nearly twice that by its commercial sector.

The vertical axes of Figure 1 show the Yearly Energy Consumption in the US for the last 2 decades. The scale in the top figure, by the commercial sector, is half of that in the bottom figure, which is that for the residential sector.

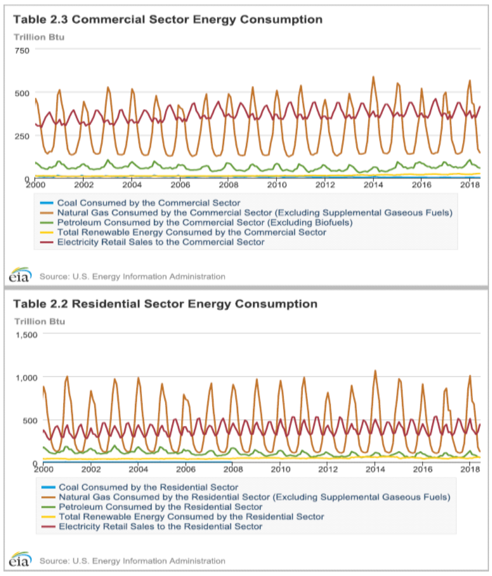

Figure 1. Energy consumption. 2-decade US data

2. Literature Review

2.1. Low Temperature Hydronic Radiators

Qian Wang et al (2015) [1] showed that low temperature hydronic can improve the thermal performance of five retrofits to an acceptable level. Dietrich Schmidt et al (2017) [2] pointed out that currently 12 research institutions from 8 countries are participating in the research to use low temperatures in district heating. Mats Dahlblom et al (2018) [3] evaluated a feedback control method for hydronic heating systems based on indoor temperature measurements. Matjaž Prek and Gorazd Krese (2018) [4] presented an experimental validation of an improved heat output regulation concept for multi-panel radiators and showed that the implementation of the modified water flow arrangement significantly improves the transient response of heating radiators in terms of reduced time.

Petr Ovchinnikov et al (2017) [5] made a study that aims at evaluating practical application of low temperature hydronic space heating systems in residential buildings in Russia. M. Jangsten et al (2017) [6] stated that to maintain the competitiveness and improve the environmental performance of district heating, in the future, it is essential to transition to lower operating temperatures and suggested supply and return temperatures of 50–55 °C and 20–30 °C for low temperature radiators.

2.2 Solar Thermal – Limitations

Cüneyt Kurtay et al (2009) [7] reported that solar thermal systems supply 15-20% of the heating requirements of a building. They concluded that "at Ankara conditions it is not possible to provide thermal comfort conditions with thick clothing ensemble using solar energy" Ankara is the capital of Turkey and highest and lowest temperatures are like those in Melbourne Australia.

Solar domestic hot water systems with natural circulation are most favorable in areas with a mean annual sum of global radiation on a horizontal surface above 1800 $kWh^{-2}\ yr^{-1}$ and with collector areas up to 10 m^2, G. Faninger (2012) [8]. Representative Meteorological Year statistics show a much lower 48.439kWh. $m^{-2}\ yr^{-1}$ or 484.39kWh yr^{-1} for 10m^2 for Melbourne, Australia. This creates doubt on the use of solar thermal systems.

2.3. Simulated Results – Vertical Ground Heat Exchanger, heating floor to 15°C?

The heating performance of low temperature hydronic radiators was simulated by the EnergyPlus™ building simulation software. Ooi et al (2015) [9] showed the simulated results; the circulation of water in the U-tube of a 50m-deep VGHE to a floor-HR could heat the bedroom of a

60m² house to the Nationwide House Energy Rating Scheme (NatHERS) night heating thermostat of 15°C and the circulation of water, heated by 30 evacuated tubes and stored in a 2m³ indoor tank at 50°C at the end of summer, could heat the living area to NatHERS day heating thermostat of 20°C throughout winter.

Masa and Ooi (2020) [10] reported on the Melbourne experimental building. The 3mx6m hydronic floor (floor-HR) is constructed from affordable 5.8m long 13mm diameter irrigation tubing spaced at 100mm apart and laid on top of 100mm thick metallic-clad polystyrene laid on ground. At the rear of this 3mx6m building is a 50m-deep vertical ground heat exchanger (VGHE). The temperatures measured at the bottom of the VGHE is 17°C and the water conditioned by its U-tube is 15.5±1°C.

Messaoud Badache1 et al [11] reported on Ground-Coupled Natural Circulating Devices (Thermosiphons). To check if it could be possible to use zero energy to circulate water from this experiment building's 50m-deep VGHE to the floor, monthly averaged outdoor and ground temperatures are shown in Table 1. For April to June, the (4m-deep) ground temperature is hotter than the average, and is also above Australian National House Energy Rating Schemes (NatHERS) night heating thermostat of 15°C.

Table 1. Monthly Averaged Outdoor and Deep Ground Temperatures, 4m-deep

°°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	38.1	37.1	32.1	29.0	21.0	16.2	16.7	19.1	22.3	27.5	31.5	37.3
Min	11.6	10.3	8.9	5.8	4.8	4.4	3.7	2.5	2.6	5.2	8.2	8.9
Ave.	20.3	21.2	17.9	15.6	12.3	10.6	10.4	10.7	12.2	14.8	15.8	18.2
Ground	15.4	16.5	17.3	17.5	17.0	16.0	14.7	13.5	12.7	12.6	13.1	14.1

Representative Meteorological Year statistics for Melbourne, EnergyPlus™ (2020) [12]

Ooi and Masa (2017) [13] projected the higher ground temperatures at deeper depths and showed by simulation that 400m-deep VGHE could supply water temperatures up to 23°C. This is deemed sufficient for the day heating thermostat of 20°C. However, it was subsequently found that the cost of drilling is too exorbitant.

3. Method

Figure 2 shows the 3m-wide experimental outbuilding beside the 4.88m-wide 6m-long garage in the backyard of the 150m² experimental house. This 18m² outbuilding has 200mm thick ceiling with an R-value of 5 m².K/W, 150mm thick metallic-clad polystyrene walls (R-value 3.75 m².K/W) and 100mm thick metallic-clad polystyrene floor (R-value 2.5 m².K/W). This 48m² building is energy rated at the mandatory 6-stars by the Australian Nationwide House Energy Rating Scheme (NatHERS).

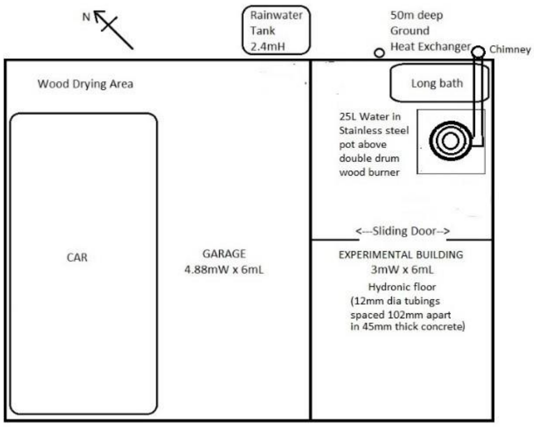

Figure 2 Experimental outbuilding

The hydronic floor (floor-HR) has 12mm diameter poly tubes embedded in 45mm thick concrete covered with 10mm thick ceramic tiles. This floor-HR is on top of 100mm thick recycled cold room panels, i.e., metallic clad polystyrene, that is laid on the ground.

Simulation results by Ooi et al (2015) [9] indicated that the direct circulation of water from the VGHE to the floor-HR could heat indoors to the night heating thermostat of 15°C. The assumption is that the temperature of the thermal mass in the ground under the floor has stabilized after a warmup of 5-6 years by keeping the indoors at the day and night heating thermostats of, respectively, 20°C and 15°C. Since the outbuilding has not satisfied this warmup period, the experiment was conducted with a wood/sawdust burner. At the same time, an affordable belt solar collector for swimming pool was tested with a glass cover. The external edge of the floor/ground is wrapped by 300mm deep R1 $m^2 \cdot K/W$ polystyrene to create an insulated thermal mass in the ground under the floor.

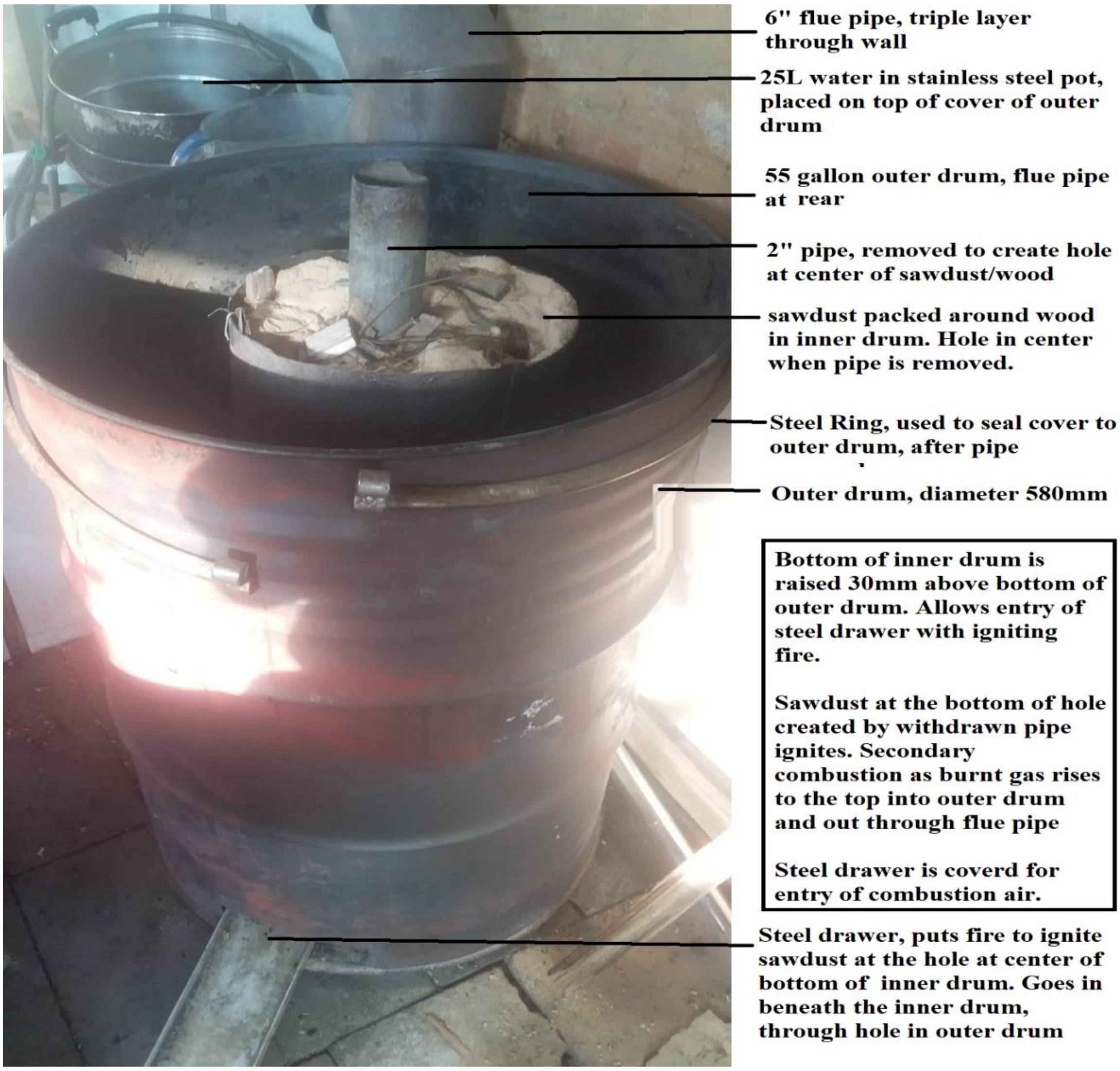

Figure 3. Sawdust/wood burner - hot water for floor-HR.

3.1. Sawdust/wood burner.

Figure 3 shows the sawdust/wood burning apparatus inside a 580mm diameter 44-gallon outer drum. The sawdust is packed, around a 50mm diameter pipe at its center, in the 480mm diameter inner drum. Beneath this inner drum is a 30mm-tall 150mm-wide, 350mm-long radial compartment that allows the entry of, a drawer with the igniting flame, and combustion air, into the central 50mm diameter hole, formed by the pipe after it is pulled out. Before ignition, the outer drum is sealed with a lid. On ignition, the flame rises through the central hole of the packed sawdust/wood. The burnt gases exit, via the gap between the inner and outer drums, through to a hole at back of the outer drum, to the chimney.

Figure 4 Wood Moisture Meter

The flue pipe exits the outer drum from behind. Its 45-degree penetration through the wall helps to draw the flue out to the vertical chimney, which is outside the building, to reduce the chances of particulates falling onto the roof. The roof is used to collect rainwater. Figure 4 shows the $20 wood moisture detector, to ensure the moisture in the wood is less than 20%, which is the standard used in UK. A carbon dioxide tester was also installed in the room. On top of the external drum is a 25-liter stainless-steel pot. The water in this pot heated by the fire in the inner drum. The fire can last for 8-10 hours. The hot water is circulated to the floor-HR.

3.2. Poly solar collector for swimming pool – cover with glass.

The 30 evacuated tubes used in simulations by Ooi et al (2015) [9] to heat the indoors to 20°C during the day is expensive and requires a 2 cubic meter indoor storage to buffer the winter coldness. An affordable 750mm-wide black polyethylene belt designed to heat swimming pool water is tested. There is no sign of deterioration after a few years' exposure, without water, to the sun. It is enclosed in a 6m-long 800mm-wide wooden box and placed over the 10-degree double-sloped garage roof. The bottom half of the belt rests on polycarbonate roofing sheets and the top half rests on 2" thick polystyrene. Glass sheets are placed on the wooden box to trap the longwave radiation.

3.3. Exothermic Decomposition of organic waste

Vegetable end cuttings and tea bags are piled together with alternate layers of grass cuttings (nitrogen) and paper or cardboard strips (carbon) at a corner of the backyard. Inside the pile are coils of perforated 4" diameter soft plastic pipe. Together with tilting, this enables aerobic decomposition so that methane gas is not produced. With air and water, the temperature of the compost pile can reach 45C as it undergoes the three phases of decomposition as shown in Figure 5.

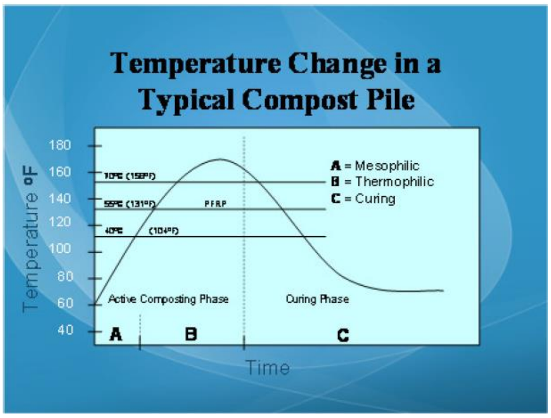

Figure 5. Three phases of aerobic decomposition

4. Results

4.1. Sawdust/wood burner – Results in the cold months, i.e. autumn, winter, spring.

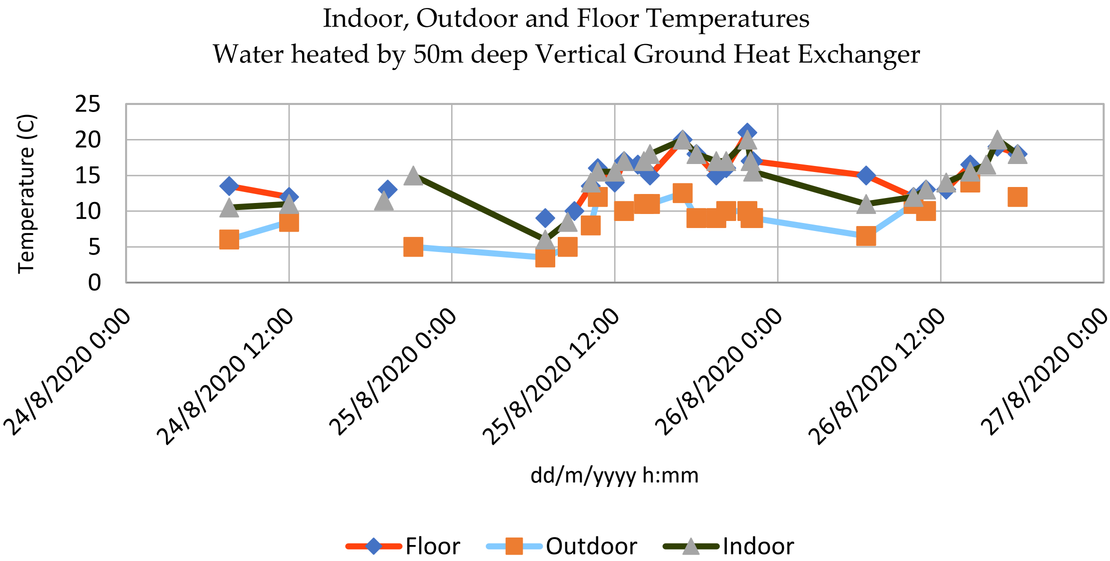

Figure 6. Temperatures during autumn

Figure 6 shows the temperatures during the autumn of 2020. The ground below the floor has heated up. The water is heated only by the 50m deep vertical ground heat exchanger and pumped directly to the floor-HR. The indoor temperature reaches the National House Energy Rating Scheme (NatHERS) daytime heating thermostat of 20°C only when the outdoor temperature is not less than 10°C.

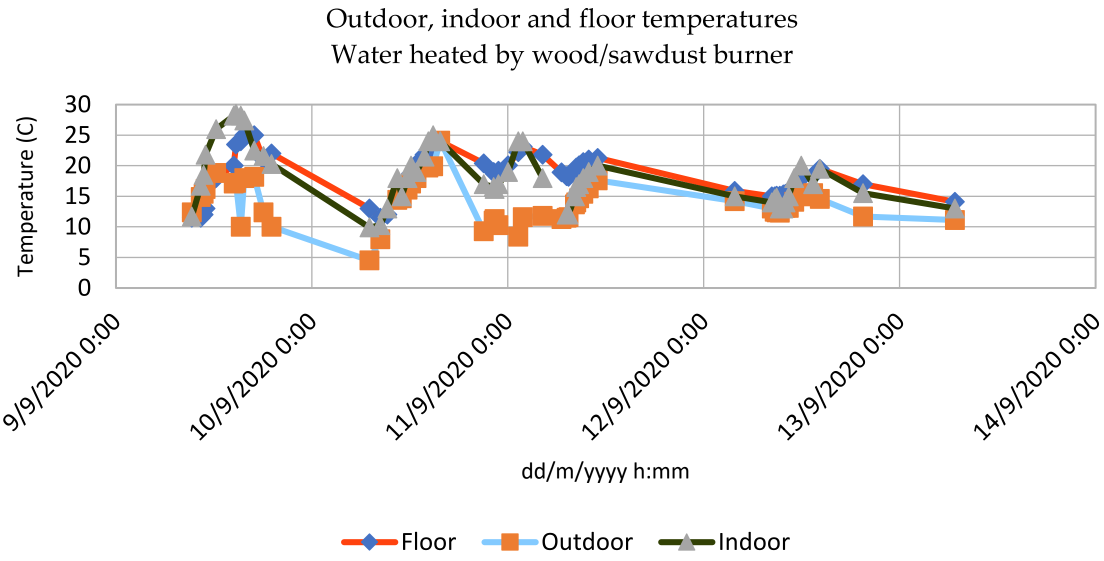

Figure 7 Temperatures during winter

Figure 7 shows the temperatures during winter 2020. The water is heated by the sawdust/wood burner and circulated to the floor-HR. The indoors could reach NatHERS day and night respective thermostats of 20°C and 15°C, even if the outdoor is cold.

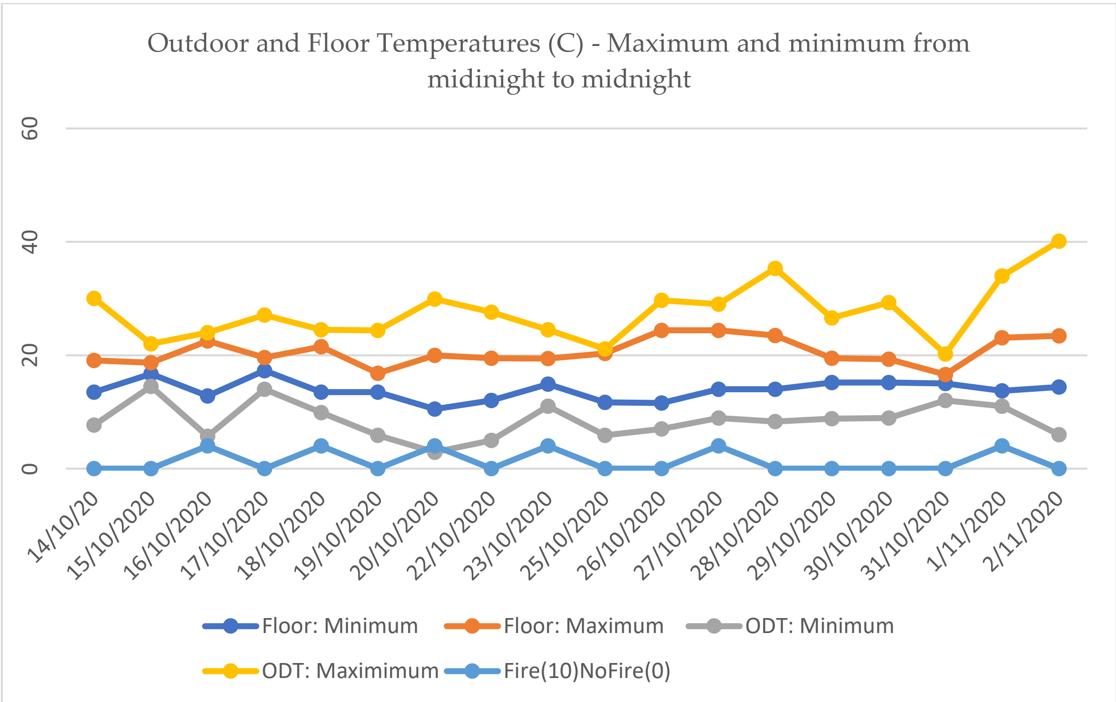

Figure 8. Temperatures during spring

Figure 8 shows the daily maximum and minimum outdoor and floor-HR temperatures in late cold months. Water is also heated by the sawdust/wood burner, mostly during the day. The author spent more time in the outbuilding than in the main house. The sawdust/wood and floor-HR provided more economical comfort than the central gas heater and ducted heating of the main house.

4.2. Results with glass covered poly solar collector

When the outdoor temperature was 26°C in the autumn of February 2020, the temperature below the polycarbonate, was 46°C. The water in a 200-liter indoor drum is circulated to this affordable flat panel at 6 liters per minute by a 40-watt pump. Measurement during sunny day of May 16th and 17th 2020, when the minimum and maximum outdoor temperatures are 4° C and 16°C respectively, show that the maximum temperature below the polycarbonate is 33°C and water temperature increases by only 1-2°C, similar to that claimed, without glazing, by manufacturer.
Water was not circulated through this belt during winter. On inspection in a spring day, the top half of the belt and the polystyrene had melted, i.e., a temperature of over 50°C. Before this inspection there was a hot November day. The glass is now wrapped with cloth. The cloth would also protect the glass from hail.

4.3. Results with compost pile

Kitchen and garden waste are piled up to enable entry of air, steam escapes from the center of the pile. Felt by hand, the temperature is estimated at about 50°C. This initial exothermic decomposition lasted for about a month. Whenever the height of this compost pile reduces, more organic material is added to maintain a 1-meter height. For the next two months, this compost pile cures. A compost thermometer indicates that during this curing stage, the temperature at the center of the pile is 32°C.

5. Discussion

5.1 Winter solar – Concentrate the weak radiation.

Ooi et al's simulation (2015) [9] used 30 evacuated tubes to heat the indoors to NatHERS daytime 20°C and a 2-cubic meter indoor storage to buffer across the three coldest months The test of glazing the flat belt collector, without vacuuming, shows that while in May, the water temperature is increased by 1-2°C, in November, the water temperature could reach above 50°C. The solar radiation in November is three times the average for the cold months of May/June/July, being about 180W/m2 for global horizontal radiation. A concentrator, probably a North facing parabolic trough, would be used for the next experiment. The aperture would be at least three times the area of the metallic collector.

5.2. Exothermic Heat from the Decomposition of organic waste

Matthew et al (2017) [14] did a comprehensive survey of how people have been trying to use the heat, from the exothermic decomposition of organic material by air/oxygen and water. The organic materials are green, nitrogen-rich material like kitchen waste, grass cut from the garden and brown, carbon-rich material like leaves, cardboard, paper, sawdust which can be obtained from most Melbourne homes. Cornell (2020) [15] reports that "Decomposition occurs most rapidly during the thermophilic stage of composting (40-60°C), which lasts for several weeks or months depending on the size of the system and the composition of the ingredients.

A compost pile in the backyard of the house has achieved this temperature. However, a review of the literature in the previous paragraph shows that the duration and transfer of this heat indoors, particularly for a small size compost for a residential building, must be investigated and experiments will be done in future winter 2021. Compost piles could be located beside the external walls of the experimental building. This will at least prevent the coldness from the outdoors from cooling the ground under the hydronic floor.

5.3. Ventilation Radiators, Lower Water temperatures for 20°C during the day

Besides getting the floor radiator to heat the indoors to the night heating thermostat of 15C, it is also necessary to get the indoors heated to 20°C during the day. We present some literature review below.

Jonn Are Myhren and Sture Holmberg (2013) [16] conducted laboratory experiments that confirmed CFD results that the energy efficiency in exhaust-ventilated buildings with warm water heating can be increased with a ventilation radiator; the heat output of ventilation radiators may be improved by at least 20% without sacrificing ventilation efficiency or thermal comfort. In future experiments, fins could be added to the wall radiators.

Ploskić. A and Sture Holmberg (2013) [17] found that combing air-heater with existing radiator heating systems. These systems operated at 20–22.5% lower temperatures than conventional systems Ploskić. A et. Al. (2019) [18] explored the importance of airflow rate and convector plate design on the operational performance of heating radiators equipped with an air device (ventilation radiators) With water supply/return temperatures of 45 °C/35 °C, the radiator was able to cover a room heat loss of 34 W/m² floor area. The results showed that ventilation radiators might cover a building heating load (kW) with a lower supply water temperature but not necessarily give a lower annual energy use (kWh) for the space heating of a building.

Hesaraki A. et. al. (2015) [19] tested floor heating, and ventilation radiator as very-low, and low-temperature heat emitter, respectively. They used a conventional radiator and found that floor heating required supply temperature of 30 °C and caused 22% energy savings

6. Conclusions

The sawdust/wood burner was able to heat up the hydronic floor to keep the small indoors thermally comfortable. Situating compost piles outside the walls would assist the hydronic floor particularly at the colder perimeter, warm. Sawdust and wood are factory waste material, thus will be used to warm up the ground below the hydronic floor. The 50m vertical ground heat exchanger will later be tested to see if it could heat the indoors to NatHERS night setting of 15°C. The next winter experiment would include the concentration of the weak winter solar radiation to heat water to above 20°C, for a hydronic wall, maybe with a radiator convector.

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From Work to User-Centered Design of Workplace Environments; a Rapid Literature Review

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Abstract: Workplaces in all their forms and shapes are being challenged drastically by the over yearlong Covid19 pandemic. Traditional work environments, as we know it, are being transformed with a heightened dependency on Information Communication Technology (ICT) systems to support remote virtual working. Organizations and employees are realizing new abilities and ways of incorporating the existing, but previously not yet fully adopted, ICT capabilities to perform work-related tasks efficiently, with contribution to a better work life balance being noted. In this context, this research aims first to explore the current debates around the shift happening in workplace. This task consisted of a rapid review to provide timely information through a synthesis of existing knowledge and current debates. The results focused on how work models have been disrupted by the pandemic, then look into work challenges during and post pandemic in work environments and finally explored the shift in how and why work spaces are being perceived and why. Findings suggest a major paradigm shift in workplace environments and the need for new thinking approaches to flexible work models and work environments in the future. It particularly highlights the fact that users miss socializing and face-to-face interactions; however, they expressed health concerns about going to previous physical work settings, indicating their need for working in ways outside these collocated settings. The discussion identified the opportunities for providing better work environments for employees and the future role of the workplace, along with the new needs from work places. This review paper opens venues for future studies investigating spatial design models for workplaces that are centered on needs, as well as integrated building technology systems to provide efficient, healthy and sustainable and resilient workplaces.

Keywords: Workplaces; Covid 19; Paradigm Shift; User's needs, Human-centered Design

1. Introduction

The infectious disease COVID-19 resulted in a pandemic that put the world in a public health crisis state since the early months of 2020 [1] [2] [3]. This is not the first epidemic to occur [4], however, the uncertainty that comes from Coronavirus being airborne [5] and fast spreading [6], affected how we live, study, interact with one another, and work [6] [7] [8]. When social distancing and confinement in our houses are the solutions to stay safe, what could possibly happen to the spaces that were part of our daily lives and how could we seek social interactions?

Hence, a change has accelerated, of how we plan and design spaces, as in shaping them within buildings and what are their role would be [4] [6]. This change is mainly driven by the need of today's architecture to be flexible and efficient in tackling rapid environmental, spatial, social, and economic changes while protecting their occupants during the COVID-19 surge or any other similar disruptive challenge [1] [6]. It is possible that an effective vaccine or therapeutic treatment becomes available quickly enough to limit the direct impacts of COVID-19 [9]. However, a look at human and architecture history of how cities are shaped by pandemics [10] [11] such as: Swine flu, Cholera and

Ebola [4], requires planning and design changes many of which previously introduced changes adopted policies to improve sustainable and health conditions [12]. Thus, researchers have called for analyzing the available body of knowledge in many affected fields including of urban planning [4], architecture and spatial program planning [13] [14].

Furthermore, there is a need for planning and establishing new design mindsets [6] [15] [16]; to help individuals and organizations manage health and work efficiency risks [7]. These mindsets should be characterized as: (1) effective solutions to be applied on existing and re-furbished buildings, (2) resilience to changes, (3) ability to respond rapidly to rising needs of potential future emergencies, (4) fulfillment of user's needs as well as the protection of their health and well-being [8] [17] [18].

In Koverman and Kalayil's paper, a logistic growth model was discussed to highlight the importance of understanding one user's journey experience to achieve physical distancing on campus during pandemic and to give priority to human-centered solutions in promoting physical and emotional well-being solutions [19]. Gruenwald, on the other hand, in his paper focusing on real estate economics concluded that cutting-edge research for the Covid-19 crisis requires looking at human-centered living environments through a solid science-based analysis [20]. Furthermore, in "Enhancement of human-centered workplace design and Optimization with Exoskeleton technology", the researchers argued the importance of integrating adaptive technological tools that help reduce physical stress and improve productivity in work places through systematic scientific approaches [21].

Evidently, from these new mindsets, design centered on users is gaining momentum and being investigated widely as a solution for spaces and buildings amid the challenges [19] [20] [21]. Human-centered design (HCD) is a multi-disciplinary person-centered design approach. The core concept of HCD is to design "with" rather than "for" the involved individuals. In HCD, the human perspective drives the need for a space and its role, how it would be designed and how the function between users, space and technology would be allocated. [22].

Workplaces have evolved over time to respond to the quest of performance efficiency. The impacts of Covid19 pandemic along with the several precautionary incentives applied on users, in an effort to contain the spread of the virus and decrease the number of affected cases, enabled the realization that work can be done independently from the known collocated work spaces. Some of the said incentives that triggered this conclusion are: cities lockdown [23], imposing quarantine [6], restricting mobility [2] [24], suspending economical activities [23] [24], adopting Working From Home (WFH) strategies [25] [26], and practicing social distancing [2] [5].

In order to understand how the workplace had been affected by the pandemic, it is important to start by defining the "workplace" along with its purpose and what are its spatial attributes. A workplace is referred to as space where an organization is held and people work in during specific times, in order to achieve and realize objectives and goals [27]. Vischer argued that, with the 21st century bringing along advances in computing and telecommunication, both space usage and how people conduct their work in the workplace have been impacted. In which, reducing occupancy costs is a key driver of design decision-making, and companies are applying quality as well as cost criteria to workspace design. Furthermore, people no longer need to be fixed in space and time to work together, and the barrier between work and personal life has been broken [28]. Hence, workplace spatial attributes, should be flexible and technologically advanced while also being safe, healthy, comfortable, durable, aesthetically-pleasing, environmentally friendly and accessible [29].

With research indicating that spaces in the workplace have already gone through many changes driven by the social [29] [30], and technological development [28], it initiated focus on people productivity [27], health and well-being [30], as well as indoor environmental concerns in this regards [6]. However, what seems like an actual "good place to be in" has been challenged with the COVID19 virus global pandemic, where people had to stay home as well as refrain from socializing in order to stay safe and stop the virus from spreading [6] [7]. The question, though, is how did this crisis challenge the perceived good workplace structure?

The answer to this question can be found by acknowledging that the implementation of remote working as well as working from home strategies and the increased dependency on Information

Communication Technology (ICT), turned physical work spaces into virtual ones [16]. Hence, ICT has been the main driver to challenge the workplace spatial attributes during the coronavirus pandemic [16] [31]. While working remotely is not a new strategy being discussed in literature, in fact it has been thought of as the utopian framework of workplaces [28], it was not until the global eruption of coronavirus that it was applied worldwide [32]. Recent reports note that, 88% of organizations worldwide enforced and encouraged working from home ever since the start of the coronavirus pandemic [33]. As a result, it has been realized that work could be done differently using ICT, through its availability and accessibility, without majorly affecting employee's productivity and efficiency [34] [35].

The urgent shift and change in attitudes towards workplaces were driven by the uncertainty and breadth of the COVID-19 shock as well as the need to adapt to new ways of performing work tasks during and post the pandemic [7] [36]. This change has created a global and current debate on all levels and fields of research. Hence triggering the need to reshape the workplace [16] [25], with a highlight centered on human behavior and how this could affect the user-experience [6].

Therefore, it is important to study the status of the workplace under the current pandemic situation, as well as what are the changes that are happening in design and planning for the space layout. There is also a need to understand how these changes are affecting the employee's satisfaction, comfort, productivity and performance levels. Furthermore, analyzing the user's experience and needs in a workspace, and how should it look like for a post pandemic world, is needed at this point. This can be seen as a challenge and opportunity to reshape the workplace, its role and space.

In this context, this research aims to explore how work models have been disrupted by the pandemic, while looking into the challenges, the opportunities and the future role of the workplace. This paper will focus on cooperative workplace, which is an office typology of a public or a private business entity rather than one that is attached to an educational institute or a healthcare facility. The main preliminary research question for this paper is; *what are the current debates on the shift happening in workplace?*

2. Methodological Approach

COVID-19 has driven the need for timely evidence from existing knowledge to inform actionable decision-making on how can we ensure that the built environment is adequately prepared to contain or adapt any further challenges and be able to move forward [37]. Since a significant number of scientific publications are being released daily on the matter of shifting needs in the workplaces, identifying the relevant evidence in due time presents a great challenge and requires that the methods used in traditional literature reviews be adapted [38] [39] [40]. Hence, a rapid qualitative review is the approach adopted in this study.

Rapid Qualitative Reviews (RQRS) are ''*a form of knowledge synthesis that accelerates the process of conducting a traditional systematic review through streamlining or omitting specific methods to produce evidence for stakeholders in a resource-efficient manner" (pages 80-81)* [41]. There is no consensus on the ideal time to complete a rapid review. However, the usual time is considered to be between 8 weeks to 12 weeks [42]. Streamlining the method in a rapid literature review is done through narrowing the scope of the topic, conducting screening and data abstraction simultaneously as well as using review shortcuts such as: depending on limited number of papers to review and provide related summary reviews rather than extensive detailed ones [42] [43] [44].

The primary research question of "what are the current debates on the shift happening in workplace" generated several secondary questions, as shown in Table 1, which will map out the rest of the paper from results and discussion, ending in with suggested future research in the conclusion.

Table 1. Secondary research questions guiding the paper structure.

Results	Discussion
Challenges	Opportunities
1. How the workplace has been affected by the pandemic? 2. How and what is the technology role in directing this change? 3. How these changes have affected the users and why? 4. What are the changes that have been done to the space?	1. Do we need to go back to how work used to be conducted? 2. What would be the role of a work physical space post pandemic? 3. What are the suggested solutions on how to implement the change on the space and answer the raised challenges?

The first run of search was done through Google Scholar database, using the terms explained in Table 2 generated from the Boolean Operators, for research papers in English language published from 1st December 2019 (which was the date of the first recorded evidence of the coronavirus), until 18th March 2021 (which was the date when this research was summed up). The initial search generated 77 full text open access articles. These articles were filtered according to their type, in which websites agendas, newsletters and journal editorials and commentaries were excluded. The remaining 50 papers were screened through analyzing their titles, keywords, abstracts and conclusions for keywords listed in Table 2.

Table 2. Secondary research questions guiding the paper structure.

In the Title and Keywords	Abstract and Conclusion
(Workplace OR Offices OR Work Environments OR Work) OR (COVID19 OR COVID-19 OR Coronavirus OR SARS-CoV-2V OR Pandemic OR Epidemic) AND	(Effects OR Challenges OR Opportunities) OR (Spatial OR Space OR Design) AND (Change) OR (Technology OR ICT OR Digitization) AND (Effects) OR (User OR Employee OR Workers) AND (Perception OR Preferences) OR (Needs) OR (WFH OR work from home) OR (Remote Working OR Virtual Working) OR (Paradigm Shift) OR (User-centered Design) Or (Human-centered Design) OR (Healthy Space) OR

The final selected 29 papers were chosen for a full paper review, in which 19 were excluded following the inclusion and exclusion criteria set in Table 3. At the end, only 10 papers were selected to be included in this rapid review to identify the findings about the timely current debates happening around workplaces. The selected research explains the effects of technology on the transition and changes in work models as well as the employee's preferences, experience and behaviors, along with any mentioned or highlighted related spatial roles and if any changes are needed.

Table 3. Inclusion and exclusion criteria resulting, along with the papers included for this study.

Inclusion criteria	Exclusion criteria	Reference of papers included
• Explained the effects of technology on the transition of where and how work is being done [25] [45] [46] [47] [48] • Explain users experience and preferences [35] [49] [50] • Related spatial design changes and role [7] [51]	• Did not provide any input related to users perception and experience and focused on: ○ environmental consequences ○ building engineering ○ economical and management related issues	1. [7] 2. [25] 3. [35] 4. [51] 5. [45] 6. [46] 7. [47] 8. [49] 9. [50] 10. [48]

3. Results

3.1. ICT dependence, virtual working and working from home

With the pandemic invading the world in full-force, many organizations found themselves, introducing remote work practices with very little time to plan, or even consider alternative options [45] [48]. With social distancing in mind, the role of online applications has been increased in importance, to become critical for the continuity of personal and business services [45].

While working at home received relatively little attention before the crisis, it has become a key policy instrument used by governments across the world as a means of minimizing the spread of the pandemic [46] [48], and a necessity for the organizational survival of many businesses [51]. On the other hand, A term given in United Kingdom for working from home is 'telecommuting' and it implies the ability to work from or at home with association of high use of information and communication technologies and therefore varies substantially across sectors [35].

In what has been dubbed the world's 'largest work-from-home experiment', many practitioners, and researchers speculated whether large-scale working from home would become the 'new normal' post-pandemic [47] [48]. New normal era means that people live as normal as usual like as before COVID-19 outbreak but using health protocols and safety precautions as a way to deal with this virus and to improve the economic conditions [45] [47]. This transition has had its controversies with several identified advantages and disadvantages.

Researchers documented cost savings in transitioning non-essential personnel to virtual work and a reduction in the costs of office space, utilities, and other expenses [51]. With millions of workers shifting to WFH and/or to virtual office, many found out that it is both viable and manageable to fully opt for such methods to conduct business [47] [35]. With meetings are held online and the flexibility of working hours increases, employees can enjoy more personal time while being "at work. This allowed working parents to find a new work-life balance that seemed unrealistic in the past [45]. Employees have also been sensitized to the time they often spend commuting to and from their work and how this time is wasted from their day [46].

Financial, professional, and technical services are more likely to be performed at or from home, since communication with co-workers and customers can be done electronically [46]. In contrast, low-skilled, high service, and labor-intensive work are less likely to be done from home [46]. Surveys carried out during the COVID-19 crisis suggested that working at home continues to be skewed towards the group of better educated and higher paid personnel rather than the remaining working categories [46], hence, becoming the subject of debates on inequality within the workplace [7]. Furthermore, with the rise of WFH and telecommuting, it has been observed that many face challenges due to fundamental issues such as: not having adequate space at home to properly perform work duties [7] [46].

Nevertheless, ICT is playing "a central role" in many if not all aspects of the COVID- 19 pandemic, including "behavioral, temporal, societal, and organizational" and in particular, how organizations adjusted to 'the new normal' [35] [45]. Hence, triggering dependence on remote work trends and studies where remote practices were considered as an effective method which could indeed continue to the "new normal" and post pandemic [7] [51] [45].

3.2. Employee's health and well-being

3.2.1. Working virtually and Working from Home (WFH)

Many workers who were forced to work from home (WFH) have suffered from loneliness and depression due to the lack of social interaction with their colleagues [7] [25] [50]. This new phenomenon has strong negative relationship on employee's affective commitment, affiliative behaviors, and performance [7]. It has also been found that COVID-19 contributes to greater risk of employees encountering job burnout, which is a chronic stress syndrome, including permanent feelings of exhaustion and a distant attitude toward work [7] [25].

Contrastingly, it has been documented that, the initial high stress and low morale associated with making the sudden and difficult transition to working from home, has ironically been replaced with lower stress and higher morale as employees recognize the benefits of this work format [51]. It actually allows some employees greater flexibility, without compromising individual performance and productivity [25] [51] [48].

3.2.2. Returning to offices during the crisis

In some countries, companies intended for their employees to return to their regular place of work with availability and accessibility to a vaccine [47]. The returning workers experienced lifestyle changes from prolonged state of not working or working remotely to going to their collocated offices again. As a result, a particular attention was given to employees health and safety considerations, especially since infected rates have increased when that happened and people were quarantined again after returning to work [47] [49].

On the other hand, for some employees, returning to work and minimizing the spread of COVID-19 will improve employees self-esteem, financial status and rebuild social interaction while improving productivity, leading to better quality of life, less depression or stress, and improved general immunity and sleep quality [49] [50].

3.3. Paradigm Shift

One can assume that the noticeable shift in the workplace is already happening [51]. The effects of this virus abruptly forced people all over the world to work from home [49]. Without doubt, there is a great benefit to working from home, but it allows employees to remain within their comfort-zone, which could also lead to laziness and distractions [48]. While researching the consequences of the work from home and virtual "telecommuting" work situation it is shown that, COVID-19 pandemic also brought new perspectives towards the future of work [35] [51]. Especially with the obligated global, organizational and personal adjustment to the situation [51]. The rise in the number of infected employees' number which suggested that returning to work as usual may also increase the risk of COVID-19 infections [49].

Whereas workers are anticipating a post-pandemic return to "business as usual," many organizations find themselves asking some difficult questions in regard to their employee's safety and needs [51], especially with the controversial opinions evident on the advantages and disadvantages of such paradigm.

A paradigmatic shift is a fundamental change in the underlying assumptions of a phenomenon. In research, these are rare but impactful shifts that radically change our understanding of phenomena, by altering the foundational assumptions from which our understanding is derived [51]. The spectrum of shifts ranges from personal to professional, individual to organizational, and across most industries [51]. The world is at its most interdependent economically and has never faced this level of comprehensive interruption, which was recognized by many, and resulted in the need for a workplace paradigm shift caused by a pandemic with long-term effects [51] [48].

Many are adjusting to novel organizational demands of the pandemic while hoping for a swift "return to normal." In time, the implications of these demands may not only shift but also have a lasting effect on the way organizations and employees function, resulting in a "better new normal and post pandemic." [51]. Organizations should invest in their people and in creating strong employee-focused cultures, as well as avoid "back to normal" work activities as they were conducted prior to the pandemic. Instead, they should [51] [47] [49] [50]:

- Recognize and support their employees that are going through difficult times;
- Help employees feel safe and secure while also building loyalty to the organization, resulting in more dedicated and committed employees;
- Provide adequate support for employees to complete their work tasks at home and how to help them cope with the physical and psychological difficulties;
- Re-evaluate existing office space and shifting them to healthier ones;

- Provide a workplace where work and living environment coexist in one building and can adapt to transformation over time;
- Establish a new model of the economy based on psychoneuroimmunology preventive measures, whereby the focus will be on protecting the immunity and health of workers against COVID-19, through analyzing the interaction between psychological processes, the nervous and immune systems of the human body without sacrificing employee's productivity at the same time; and
- Safeguard employee's mental health by developing personal hygiene measures (e.g. hand hygiene, wearing masks) and organizational measures (e.g. social distancing, good ventilation, etc).

4. Discussion

The review allowed outlining three main questions on the current debate around the workspaces during the pandemic situation and the changes that are happening in design and planning, as well as what would be the role of the office after the disruption, and what changes should be introduced to increase work efficiency and safety.

4.1. Do we need to go back to how work used to be conducted?

As organizations evacuated workspaces to ensure social distancing, remote working seemed to be the natural solution, but not all industries and roles were able to adapt. Hence, remote working has had a mixed impact. Within a few days into adapting the remote working strategies, the often-ignored inequality in domestic work has arisen. Employees are exhausted by the extensive use of technologies and are under stress. As a result, quality of work decreased.

Some employees miss the socializing that happens in work spaces, and are eager to return to them. Also, it has been evident that culture of trusting employees to actually work from their homes, is still not yet fully established, which led to low employee morale and fatigue. While technology is needed to design innovative solutions for new hybrid modes of working, these modes need to be adapted to human behavior. The consensus is that going back past work habits will not happen and that the new normal is still evolving. However, workspaces will not diminish and most researchers agree on the advantages to both working in an office and working from home.

4.2. What would be the role of a work physical space post pandemic?

After many office workers were sent home due to the COVID-19 pandemic, for over a year now, researchers, designers, work managers and decision makers face big questions about safely reopening workspaces as well as on the type and what kind of space is truly needed for post-pandemic offices.

The longer we work from home and away from our colleagues, the more being together matters and the more we realize the extension of how impactful the places and spaces where we gather have become. We want more purposeful trips to the offices in order to meet face-to-face, socialize, brainstorm, and connect with each other again. Hence, workspaces are usually an integrated structure of various spaces for offices, meeting rooms, amenities and other multiple usages such as cafeterias, health and sports, rather than being a simple place for work only. Workplaces are expected to provide a whole host of benefits including a reassuring atmosphere, protection of workers from stress, unification of the organization, expression of organizational values, motivation and mobilization of staff, promotion of sociability and cooperation, and reflection of a company's desired image [30].

Workplaces are becoming an end in themselves as in they have an inclusive role in the surrounding community and everyone is aspiring to get something more out of them as well as being viewed as a benefit that will attract more talented, committed and productive workers in the next years. Hence, the role of work spaces is shifting to be a destination of vibrant hubs and collaborative spaces to foster intimate human connections, strengthened relationships, teach others, and build community, culture, and purpose. Such spaces will act as integrated spaces, entertainment ecosystems and socially responsible buildings that allow activities, which cannot be accomplished virtually, occur and provide a place to eat, collaborate, retain and train an incoming workforce.

4.3. What are the suggested solutions on how to implement the post-pandemic needs?

With the vaccine now available in major parts around the world, businesses are slowly, but surely, starting to bring back people to offices. However, many precautionary measures are being implemented such as: bringing back not more than 50-60% of employees to work, socially distanciated floor plans and increase spacing, body temperature and PCR tests checks and enable reservation systems.

While workers have some new needs and expectations, driven by COVID-19 pandemic, most of the suggested solutions are essential drivers in workplaces that will contribute to the user experience. User experience is at the heart of the human – centered design. It is defined as a design within the architectural discipline, which employs a combination of art and science while using the many rules that have been developed through holistic approach to gain a more in-depth understanding of users complex and multidimensional needs and experiences [52]. The user experience includes all the emotions, preferences, perceptions, physical and psychological responses, behaviors, and accomplishments [30]. Its interface is concerned with combination of elements, including spatial layout, enclosures, light, air, furniture, visual design, tools, systems, sound, and interaction [30]. Planning a positive user experience within the work environment can transform existing spaces into safe and comfortable environments in the new COVID-19 era [19] [30]. This could be through strategies and methods that already exists such as health and wellness, sustainability, choice, autonomy and social responsibility. However, the crisis heightened the need for such strategies to be actually implemented.

4.3.1. Office footprints:

Governments and private companies alike are increasingly reimagining the office to minimize and emphasize more efficiently the use of space in order to cut costs, while still promote collaborative work, merge teams, and accommodate increased remote working.

4.3.2. Flexibility and hybrid environments:

Creating a flexible environment is an opportunity to fix workplace pre-pandemic issues and provide a post-pandemic office that rapidly adjusts to new ways of working, enables office-to-home connectivity, dynamically allocate spaces with flexible spaces and furniture and allow better management to work spaces and anticipate evolving tenant needs.

The use of technology can enable employees who are not physically present in their offices have a similar experience along to those who are working from their offices; through fully integrating Physical and virtual experiences. This could promote equity among workers, maximize performance and allow companies to have better opportunities at engaging and supporting a larger range of talents.

4.3.3. Resilient and sustainable spaces:

Researchers and decision makers had taken the lead on analyzing, designing and planning resilient facilities. Resilient, in these cases, could be defined as: an approach for buildings and spaces abilities to anticipate, resist and adapt to vulnerabilities and changes for the purpose of recovering, bouncing back to its original state or evolving to a new balance and situation [3] [4].

Energy is an essential facilitator of economic growth and cultural development, influencing the future of buildings and spaces. To address the urgency of climate change, curb emissions and respond to environmental pressures, sustainable design is shifting toward increase indoor efficiency, de-carbonization and carbon neutrality.

Buildings that apply universal design with local cultural approaches and materials as well as obtains certificates in sustainable, health and wellbeing rating systems such as LEED or WELL Building Rating Systems will be perceived as safer spaces to be in.

4.3.4. Employees' health and well-being:

Along with sustainability and resilient considerations, work spaces in post-pandemic are highly focused on users health and wellness. Buildings that have connections with the outdoors, environmental control, mixed-use environments, Indoor Air Quality (IAQ) monitoring, and HVAC upgrades will appear more attractive and safer for tenants. As well as an office building's performance that is based on health- related measures through spatial analytics, behavioral data, and intelligent place-making can help inform a healthy and efficient workplaces.

Access to fresh air, water, sun, and shade has always been important with their benefits on employee's productivity and cognitive functioning; these benefits are more evident during and post pandemic. Tenants feel safer and healthier outdoors, they want their workplaces to offer easy connections to outdoor space.

In some cooperation offices, an outdoor program has been launched for its office building users, in which employees tenants can book spaces outdoors with Wi-Fi for meetings and calls. Furthermore, well positioned terraces and balconies along with interconnecting outdoor stairs will offer cohesive new social experiences. Other options could be implemented through open façades and retrofitted rooftops to provide additional workspaces that are connected to the outdoors. Rather than open-plan floors, the future office will provide multilevel settings with easier accessibility to views, movements, and inspirations.

5. Conclusions

A paradigm shift in the role, design and perception of a building is nothing new; in fact, Library spaces have been challenged drastically throughout the centuries and had experienced several paradigm shifts. It allowed such spaces to be resilient to crisis such as that of COVID-19 pandemic. The work spaces is witnessing a similar shift in design and spatial needs. This research explored the status and current debates of the workplace under the current pandemic situation as well as the changes and shift that are happening in design and planning. The results indicated the debate on whether we still need collocated work spaces as we came to know them, is still intact, however it is evident that there is a paradigm shift in the way work spaces will be designed for the new normal and post-pandemic world. This change is focused around the need for sustainable healthy and resilient spaces that are also flexible to accommodate user's behavior and enhance their productivity while contributing to their safety and well-being.

Simultaneously, in order for workspaces to evolve, attract talent and make investments go further they need to shift from being office environments focused on individual desks and more about creating shared experiences between users. Researchers and designers need to analyze the available knowledge in many crisis affected fields such as urban planning, architecture and spatial design. As we gain better knowledge and understanding about the current situation, we can realize the unique challenge it poses and for which we were unprepared-for. Success, resilience and overcoming such crisis is driven by the people's desire to reconnect and the lessons we learn from humanity and technology rather than the economic structure that we have been relying on. Therefore, acknowledging and prioritizing the spatial design paradigm shift to focus on user experience through human centered design is essential for any building and design strategy to be effective, especially in our ever-evolving contemporary world and with the uncertainties of the current pandemic.

This paper provided a rapid literature review from limited papers and researchers insights on what are the current debates on the shift happening in workplace caused by the COVID-19 pandemic. Limitations of such study is presented in the fact that the crisis is still happening; therefore, new research papers are being published every day, thus limiting this discussion to this paper deadline that needs to be revisited as the situation evolves, which is not something possible to include in this study. In addition, countries around the world have been affected differently by the crisis. Therefore, challenges and opportunities may differ among cities, cultures, social status and gender, another aspect that this study have not addressed.

Now more than ever, we have the opportunity to reimagine the future of cities in general and office spaces in particular. In this regard, future studies are needed in the fields of addressing users experience post pandemic and the importance of human-centered design. The social and knowledge grounds that an office space offers for the employees. How the user's post-pandemic needs from an office space can be met, through sustainable, resilient and healthy design. In addition to the knowledge, tools and strategies need to build new or improve existing spaces. Further experimental research studies also need to be conducted on the suggested design strategies in the discussion, since most of these are only acknowledged in electronic newsletters and conferences. Furthermore, a comparison on how such strategies may or may not differ between pre and post-pandemic needs to be elaborated.

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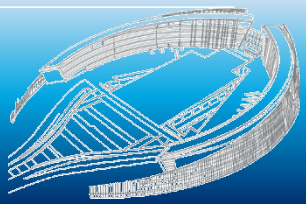
Session 4:

Sustainable Construction



Performance Analysis of Combined Bifacial Solar PV, Building Integrated Photovoltaics, and Solar Tracking System for Energy Efficient House

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Abstract: This paper presents results on the design and performance analysis of a bifacial solar PV system with and without a tracking system for an energy efficient house designed for the Solar Decathlon Middle East (SDME) 2021 in Dubai, United Arab Emirates. The main objective of this project is to design and test the performance of an integrated bifacial solar PV system and cool roof technology to enhance the solar energy production and reduce the building energy consumption. The goal is to develop clean, efficient, and sustainable energy systems (supply) to meet the electrical load of the building (balance the energy supply and demand towards net zero energy building). Design, modeling and simulation performance analysis, and optimization of the bifacial solar PV were performed in this study. The electrical loads (HVAC, lighting, and appliances) of the house were determined first. The solar PV simulations were performed using different configurations for the rooftop (28 panels) and façade building integrated PV (8 panels): (a) 28 panels fixed (towards south); (b) 8 vertical panels fixed (towards south); (c) 28 panel with azimuth tracking (d); 8 panels with azimuth tracking; (e) 28 bifacial panels fixed (towards south) with an albedo of 70%, height of 0.5m and pitch of 2.1m. The improvement in energy production by integrating different technologies is as 19.88% for rooftop tracking, 9.93% for bifaciality, and 10.14% for the tracking of the façade. The self-consumption of the tracking mechanism is 4.66%. An overall improvement of 35.29% has been achieved as compared to conventional mono-facial fixed installation. The results include the energy balance report, daily, monthly, and yearly energy production from the bifacial solar PV, and daily energy production during the SDME contest period. The simulation results showed an annual energy system production of 25625.9 kWh. The bifacial solar PV system production for November is 1965.4 kWh. The contest period is from 11th to 20th November 2021. Thereby the daily energy production will be averagely 63.3 kWh, and the total contest period production is estimated equal to 633.36 kWh.

Keywords: Solar House; Bi-facial Solar PV; Building Integrated PV; Solar Tracking System; Energy Efficiency; Cool Roof Technology; Building Energy; Performance Analysis.

1. Introduction

The United Arab Emirates is one of the leading ten countries with the highest electricity consumption per capita [1]. The residential sector is dominant in electricity consumption and solely responsible for 33.08% of total electricity consumption in the UAE [1, 2]. Thus, focusing on sustainable, energy efficient, net zero or near to net zero energy buildings is indispensable. The dependability on the state grid can be reduced by adding clean and renewable energy sources to each building. Solar PV systems are the direct source of electricity and can be easily implemented on existing and new residential buildings. UAE is among the countries blessed with huge potential of

PV energy production. The advancement in PV technologies, improvement in efficiencies, and competitiveness with fossil fuels are the convincing factors to adopt solar PV as a preferred green energy solution [3-5]. Bifacial PV (bPV), building integrated PV (BIPV) and tracking strategies are gaining attention and being adopted at large-scale PV power plants.

In contrast to the mono-facial PV (mPV), the bifacial PV (bPV) can produce electricity from the front as well as the rear side of the panel. The bPV cells have an anti-reflection coating and back contacts on the rear side [6]. The additional energy produced from the rear side increases the efficiency and lowers the levelized cost of energy (LCOE). It is anticipated that bPV technology will take 70% of the market share in 2030 [7]. The energy production from the rear side of bPV primarily depends on albedo and bifaciality. Albedo is defined as the measurement of reflected irradiance from the ground surface. High albedo means high reflectance on the rear side and consequently high-energy production by bPV [8]. The bifaciality is the ratio of power production by the rear side to that of the front side at maximum power point under standard testing conditions (STC) [9]. The high reflecting cool coating applied on the outer surface of the roof limits the transmission of sunlight and reduces the internal temperature of the building thus limiting the AC cooling load. In addition, the characteristics of high reflection enhance the albedo of the surface. It is reported that bifacial gain can be in the order of 10%-30% [10].

BIPV panels are adopted in a wide range of applications from exterior envelopes to the widow's glass [11]. BIPV façade system for typical office building can lead up to 27.7% energy saving in the emirate of Sharjah as reported in [11]. BIPV not only contributes to reducing the cooling load but also generates renewable electricity.

To track the sun's position and maintain the optimal orientation, solar tracking systems are introduced in PV applications. It helps the PV panels to receive the maximum amount of solar irradiance and consequently produce higher energy. A sophisticated system is implemented to control the tracking mechanism. Broadly, tracking systems are classified into single axis and dual axis tracking. The selection of optimal tracking strategy is subject to application, cost, and space constraints. Azimuth tracking is promising and reportedly increases energy production by 17.28% under UAE conditions [12].

In this study, a state-of-the-art solar PV system is proposed with the integration of technologies such as bifacial solar PV, BIPV, tracking system, battery backup, and reflecting coating on the roof surface. The improvement in energy production by employing each technology is studied with the help of PVsyst simulation. The daily system performance is analyzed primarily for Solar Decathlon Middle East (SDME) 2021 contest period and broadly on annual basis. The originality of this study is in the integration of several energy efficiency measures to maximize clean energy production (supply) and minimize energy consumption (demand). This study will serve as a reference to integrate different technologies in order to improve the energy production from PV and move towards net zero energy residential buildings.

2. Solar House and Solar PV System

2.1. Energy Efficient Solar House

The energy efficient solar house is designed to address the sustainability, innovation, and energy efficiency goals complying with SDME rules. With 84 m^2 occupied floor area, the gross volume of the designed house is 330.2 m^2 as shown in Figure 1. The primary objective is to reduce the energy consumption of the building and produce clean energy to meet the electrical loads. The goal of limited energy consumption is achieved in four steps: innovative building design, integration of cooling strategies in a unique way to reduce the HVAC consumption, selection of highly energy efficient home appliances, and intelligent home automation. The building is designed in innovative way to reduce the conditioned volume. The bio-sustainable cork sandwich between fibre cement panels is used to construct the envelope of conditioned volume. The bio-sustainable cork is selected to effectively insulate the inner envelope from the outer environment. Besides, the highly reflective white cool coating is applied on the outer envelope to limit direct solar heating. The design and orientation of the solar house also support the passive cooling by harvesting desert breeze in order to enhance the cross ventilation. All these measures assist the HVAC system to reduced energy consumption while maintaining comfort conditions. The selection of energy star-certified home appliances helps to further reduce the electricity demand of the house. Finally, intelligent home automation is implemented to manage and optimize energy consumption by mutual communication of occupants with devices.

The novel solar PV system is designed to meet the electricity demand of the solar house. Several technologies, i.e. bifacial PV panel, azimuth tracking, BIPV façade panel, and energy storage, are integrated in a unique way to maximize the energy production by the solar system.

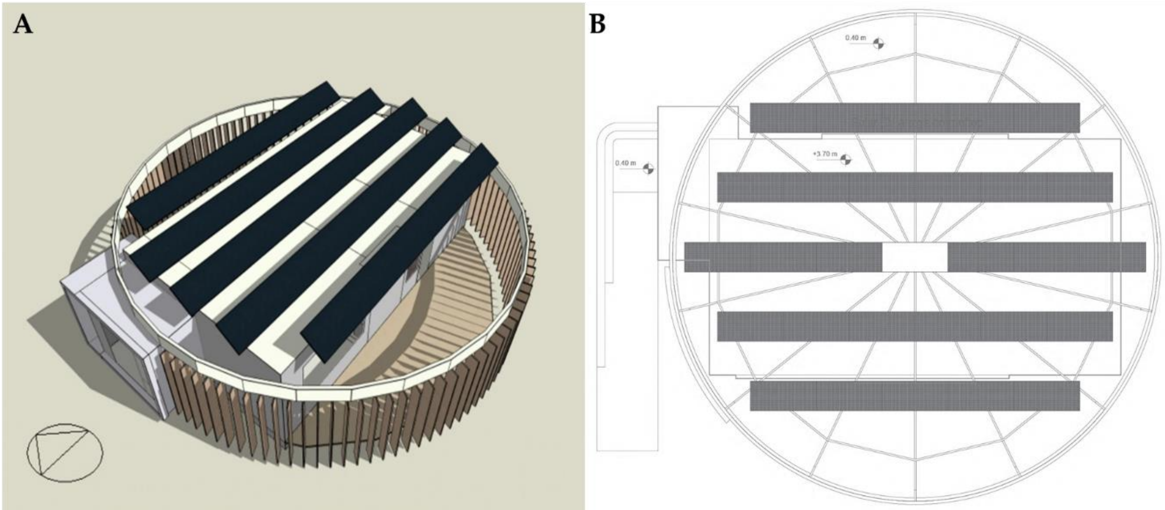

Figure 1. Energy Efficient Solar House: (A) Illustration, (B) Top view

2.2 Electrical Load and Energy Consumption

The SDME 2021 contest period will be from 11th to 20th November 2021. Energy consumption is calculated for both annual and contest periods as shown in Table 1. The electrical load is categorized into three main classes: lighting, HVAC, and appliances. During the contest period (November 11-20, 2021), lighting load, HVAC, and appliances consumptions are 22.13 kWh, 145.8 kWh and 420.4 kWh respectively. The annual energy consumptions are 1373.31 kWh for lighting, 9994.1 kWh for HVAC, and 23917 kWh for appliances. Overall energy consumption is 588.3 kWh during the contest period and 35284.41 kWh on annual basis.

Table 1. Energy Consumption of Energy Efficient Solar House.

Description	Energy Consumption During Contest Period (kWh)	Annual Energy Consumption (kWh)
Lighting Load	22.13	1373.31
HVAC	145.8	9994.1
Appliances	420.4	23917
Total consumption	588.33	35284.41

2.3 Solar PV system

The solar PV system is designed with the aim to meet the load demand of the energy efficient solar house during the contest period. 28 bPV (from Jinko Solar) are adopted and installed on the roof. The roof surface is coated with highly reflective paint to improve the albedo and consequently the energy production by the bPV. The azimuth tracking is incorporated to further improve the energy generation by bPV. A slew drive of rated 24V, 8A is used for tracking. 8 monocrystalline BIPV panels (from Invent Solar) are installed vertically on the façade, hanging from the tracking system. The Invent BIPV is selected due to its appealing aesthetic look. Two grid-connected inverters (from

SMA), battery storage inverter and energy storage (from LG) are integrated with the solar system. The total capacity of PV system is 13.6 kWp with AC capacity of 8.0 kWac. The limitation of 8KWac is due to SDME rules. The specifications of major components are presented in Table 2.

Table 2. Specifications of the solar PV system.

PV System Component	Description	
Bifacial PV Panels	Installation	Rooftop
	Model	Swan JKM400M72H-BDVP
	Manufacturer	Jinko Solar
	Type	Monocrystalline
	Technology	Bifacial
	Peak Power	400 W
	Dimension	2031 x 1008 x 30 mm
	Weight	26.6 kg
	Quantity	28
	Total Power	11200 Wp
Facade PV Panel	Installation	Vertical Façade
	Model	Q Panel
	Type	Monocrystalline
	Manufacturer	Invent Solar
	Peak Power	300 W
	Dimension	1663 x 997 x 35 mm
	Quantity	8
	Total Power	2400 Wp
Grid Connected Inverter	Type	2 x SMA Sunny Boy 4.0
	Power	4000 W
	Nominal AC voltage	230 V
	Quantity	2
	Total AC Power	8000 W
Battery Inverter	Battery inverter	Sunny Island 6.0H
	Power	4600 W
	Nominal AC voltage	230 V
	Quantity	1
Energy Storage	Battery bank	LG Chem RESU 10
	Nominal capacity	9800 Wh / 189 Ah
	Nominal voltage	51.8 V
	Quantity	1

2.4 Input Conditions - Weather Conditions

The energy generation by PV system depends on weather conditions. For the simulation analysis, the weather data is obtained from meteonorm 7.2 server by adding the location coordinates (latitude: 24.7602°, longitude: 55.3633°). Monthly average values of irradiance (global horizontal irradiance (GHI) and diffuse horizontal irradiance (DHI)), ambient temperature, wind velocity, and relative humidity are presented in Table 3.

Table **3.** Weather Conditions.

Site	SDME-UOS Site		**Country**	United Arab Emirates	
Region	Asia		**Source**	Meteonorm 7.2	
Latitude	24.7602°		**Longitude**	55.3633°	
Values	**GHI**	**DHI**	**Ambient Temperature**	**Wind Velocity**	**Relative Humidity**
Month	kWh/m²	kWh/m²	°C	m/s	%
January	119.2	48.2	18.7	3	61.9
February	125.2	55	20.5	3.3	57.1
March	168.9	68.2	24	3.5	48.3
April	186.9	74.4	28	3.5	40.3
May	219.2	83.2	33	3.5	35.5
June	207.6	91.9	34.1	3.3	42.4
July	188.4	95.6	35.8	3.4	43.7
August	192.2	91.5	35.7	3.4	43.2
September	170.4	75	32.6	3.11	51.1
October	155.9	58	29.7	2.8	49.9
November	126.2	49.1	24.7	2.8	57.6
December	108.8	47.4	20.7	2.8	63.9
Year	**1968.9**	**837.5**	**28.1**	**3.2**	**49.6**

3. Results and Discussion

PVsyst is a commercially available, specialized tool for designing, simulating, and performing analysis of solar PV systems. It is widely used in the PV industry for accurate estimation of energy production by the PV system. Several studies [12–14] are available in the literature for the validation of the accuracy and reliability of PVsyst simulations in the case of both mono-facial and bifacial PV panels.

In this study, 5-different configurations are simulated through PVsyst for rooftop (28-bifacial PV panels) and façade BIPV (8-PV panels) in order to analyze the improvement in the performance of the system by the inclusion of different technologies: (a) 28 panels fixed (towards south); (b) 8 vertical panels fixed (towards south); (c) 28 panel with azimuth tracking; (d) 8 panels with azimuth tracking; and (e) 28 bifacial panels fixed (towards south) with Albedo of 70% and height of 0.5 m. The height of 0.5 m is considered due to the limitation of the maximum height of the house by SDME. The 28-monofacial panels fixed towards the south at a tilt angle of 30° are considered as the base case. To simulate realistic conditions, typical losses associated with a solar PV system are considered during simulation. Free mounted module with air circulation is considered. Wiring loss: 1%; light induced degradation loss factor: 2.5%; module mismatch loss at MPP: 1%; string mismatch loss: 0.1%; and yearly soiling loss: 1%. In the case of bifacial PV panels, 2% rear shading loss and 2% rear mismatch loss are additionally considered. The results are analyzed for both the contest period and annual performance.

3.1. 28 Panels Fixed (towards south) for rooftop

The PVsyst is configured for 28-mono-facial PV panels fixed towards the south at 30 degree tilt. The tilt angle of 30 degree is selected to maximize the energy production in November with space constraint. The energy production is estimated to be 17384 kWh per year with a performance ratio of 73.75%.

3.2. 8 Vertical Panels Fixed (towards south) for the house façade

In case-2, the PVsyst is configured for vertically installed 8-façade BIPV panels fixed towards the south. The energy production is predicted as 2109.1 kWh per year with a performance ratio of 75.58%.

3.3. 28 Panel with Azimuth Tracking (rooftop)

In 3rd case, the PVsyst is configured for 28-monofacial panels with azimuth tracking. The energy production is expected to be 20839 kWh annually with a performance ratio of 72.69%. The improvement is 19.87% as compared to fixed orientation (case-1).

3.4. 8 Panels with Azimuth Tracking (façade)

In case-4, the simulation is performed for 8-vertical façade panels with azimuth tracking. The energy production is estimated as 3871.5 kWh annually which is 83.56% improvement as compared to fixed oriented (case-2). The performance ratio is predicted as 80.01%.

3.5. 28 Bifacial Panels Fixed (towards south) with Albedo of 70% and Height of 0.5 m

In this case, bifacial solar PV is selected at a fixed tilt angle of 30 degrees, albedo of 70%, height of 0.5 m from the roof surface, and pitch of 2.1 m is considered. Pitch is defined as the distance between two rows of PV installation. The bifacial PV panels produce 19110 kWh per year with a performance ratio of 81.08%. The improvement due to bifaciality is 9.93% as compared to monofacial PV panel (case-1).

3.6. Overall annual system production

The overall estimation of energy production is obtained by adding the % of improvement by each technology as presented in Table 4. It is estimated that the proposed system will produce 26437.5 kWh annually with a performance ratio of 78.9%. Figure 2 illustrates the monthly energy production and performance ratio of the proposed solar PV system.

The tracking mechanism consists of a slew drive rated 24V, 8A. The average electricity consumption of tracking mechanism is 2.22 kWh/day with annual consumption of 810.62 kWh. Thus, the net energy production by the PV system is 25625.9 kWh. The solar system can cover 72.6% of the annual energy consumption of the solar house.

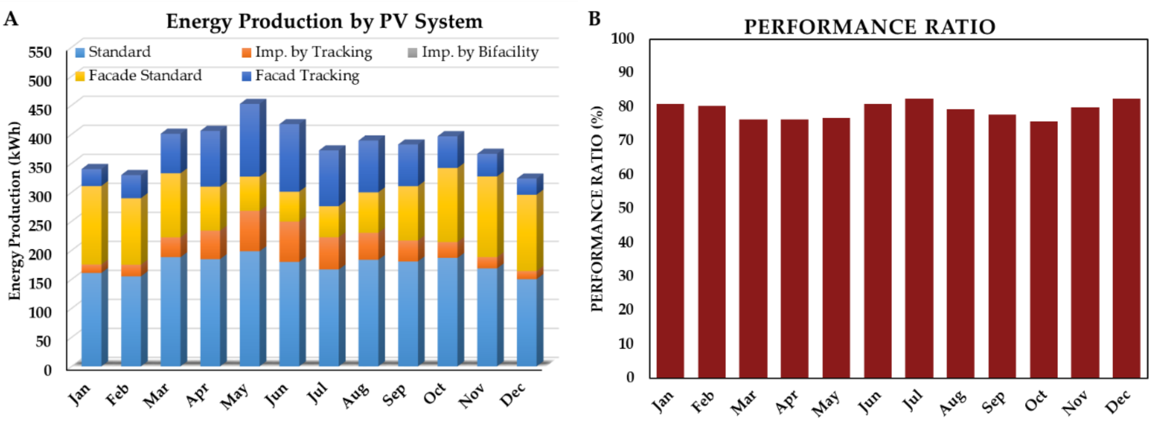

Figure 2. (A) Energy production by solar PV system (B) Performance ratio

Table 4. Solar PV system: Energy production and improvement by each technology.

Description	Standard	Imp. by Tracking	Imp. By bifacial PV	Facade Standard	Façade Tracking	Overall Production	Performance Ratio
Unit	kWh	kWh	kWh	kWh	kWh	kWh	%
January	1381.9	113.3	79.1	267.4	65.3	1906.9	80.8
February	1304.7	165.1	93.2	220.2	88.2	1871.3	80.2
March	1518.8	243.3	116.1	200.4	148.5	2227.1	76.3
April	1493.3	339.4	155.2	125.5	201.4	2314.8	76.4
May	1613.1	484.0	198.4	91.4	250.5	2637.4	76.6
June	1506.5	533.4	239.0	84.6	224.5	2588.0	80.9
July	1389.2	447.6	240.5	85.5	187.5	2350.2	82.5
August	1502.9	361.0	190.8	110.0	181.4	2346.1	79.3
September	1465.5	275.3	139.3	160.5	151.4	2192.1	77.6
October	1494.0	195.4	108.1	234.6	117.2	2149.3	75.8
November	1419.1	166.9	82.9	268.9	85.2	2023.0	79.8
December	1294.7	131.1	83.9	260.2	61.4	1831.4	82.5

3.7. During contest Period

The daily energy generation data is extracted from PVsyst in order to analyze the energy production during the contest period (11th November - 20th November) as shown in Figure 3. The solar system will produce 652.56 kWh with self-consumption 19.2 kWh for solar tracking. Thus, net energy production is 633.36 kWh. The total consumption of electricity during the contest period is estimated to be 588.33 kWh in order to accomplish the task given by SDME. Hence, the solar PV system fully covers energy consumption and extra energy is fed to the utility grid.

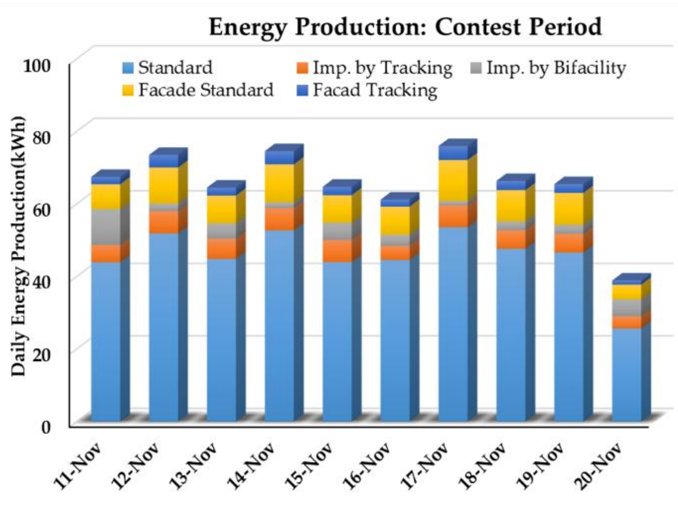

Figure **3.** Solar PV Production during the Contest Period

4. Conclusions

The solar PV system can be an appropriate solution to meet the electrical load of the building and step forward towards achieving net zero energy buildings. The energy consumption of the building can be reduced by introducing energy efficiency measures such as innovative building design, integration of cool strategies i.e. cool roof coating, passive and night cooling, selection of energy efficient home appliances, and smart energy management and home automation system. State of the art PV technologies such as bifacial PV, BIPV, solar tracking, and battery backup provide the opportunity to achieve clean, efficient, and sustainable energy solutions to meet the energy demands of the building. In this study, a solar PV system, that integrates the bPV, BIPV and azimuth tracking is proposed for clean, sustainable, and renewable electricity generation for the energy efficient house. The simulation of the designed PV system is performed through PVsyst software in order to estimate the energy production by the PV system and improvement achieved through incorporation of bPV, BIPV, and azimuth tracking as compared to the conventional fixed oriented PV system. The simulation results have shown that improvement in energy production is as follows: azimuth tracking: 19.87%; bifacial PV (bPV): 9.93%; and tracking of vertical BIPV improves 10.1%. The annual self-consumption of tracking mechanism is 810.62 kWh that is 4.66%. An overall improvement of 35.29% has been achieved as compared to conventional fixed mono-facial installation. The net system energy production is estimated as 25625.9 kWh/year. The net solar PV system production for November is 1965.4 kWh with 633.36 kWh during the contest period (11^{th} - 20^{th} November 2021). The proposed system fully covered the energy demand of the house (588.33 kWh) during the contest period.

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Optimizing Natural Ventilation Using Horizontal Wind Catchers in Residential Building in Hot Climate Regions

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Abstract: It is vital to reduce electrical consumption and obtain a comfortable indoor environment by providing airflow. This can be accomplished through passive ventilation, which is a well-known passive design technique. Natural ventilation involves changing the air between indoor spaces and the outdoor environment using natural resources. Despite its low efficiency, single-sided ventilation is more applicable than cross ventilation. However, designers often neglect this technique because it is difficult to assess its ability to maintain comfortable conditions. The current research aims to improve ventilation and temperature performance by using horizontal wind catcher ducts in residential buildings located in Irbid, Jordan, with single-sided ventilation. The research used building simulations using an advanced CFD program. Ansys FLUENT was used to find the best results for the natural ventilation of a building. The findings presented guidelines for implementing a new room design with single-sided ventilation to save energy and achieve a healthy environment to occupants by improving air circulation and reducing air temperatures during summer. The outcome of this study promotes further research in this area and serves as a reference for current and future building designs. This study is significant, as it is the first study to combine horizontal wind catchers with single-sided opening spaces in Jordan to enhance cross ventilation. Therefore, this paper contributes to improving building design in health and energy sectors to enhance indoor environments using passive techniques.

Keywords: Passive Design, Natural Ventilation, Single-sided Ventilation, Cross Ventilation, Wind Catcher, ANSYS FLUENT, CFD

1. Introduction.

People spend 80–90% of their time indoors (ASHRAE), and most residents of modern dwellings rely on mechanical or artificial ventilation to achieve thermal comfort. This has contributed to an increase in fossil fuel use, which leads to atmospheric pollution and global warming.

In hot arid regions, climatic conditions sometimes cause problems regarding thermal and ventilation comfort. Adaptations that take advantage of local environmental conditions solutions related to architectural design (passive design) can help to improve living conditions and reduce energy requirements in the world [1]. Many measures need to be taken to achieve sustainable energy, one of which involves ventilating the space using natural resources.

The current paper suggests new design options for single-sided ventilated rooms in residential buildings by introducing horizontal wind catcher duct systems to activate cross ventilation by utilising a variation of the pressure. Retrofitting buildings to be ventilated using passive techniques offers excellent opportunities for improving indoor conditions. Until now, little research has been conducted on this new design, especially in Jordan. Therefore, this study will investigate the variables that influence duct systems' operation and how to obtain the best results from large variations in pressure in the area surrounding the building.

2. Ventilation

2.1 Natural ventilation

Natural ventilation is one of the most effective passive cooling techniques promoting energy-efficient buildings and providing an acceptable balance between thermal performance and air quality. Naturally ventilated buildings consume 40% less energy than air-conditioned buildings [2]. There are three main kinds of natural ventilation: single-sided ventilation, cross ventilation, and stack ventilation [3]. The present study focuses on single-sided ventilation, by which one or more openings exist only on one wall of a room. Conversely, cross ventilation involves openings on two or more sides of a room.

According to previous studies on applying natural ventilation, single-sided ventilation has received less attention than other ventilation types in construction and design research, such as cross ventilation [4]. Although cross ventilation works efficiently, single-sided ventilation is still of great importance in building design [5].

Single-sided ventilation is a common solution for ventilating apartments because of various factors, such as site constraints and the fact that only one side of most apartments face outside (as this increases the number of units within a building) [6].

Single-sided ventilated buildings are assumed to be more inefficient than cross ventilated buildings in terms of their use of natural ventilation. However, studies show that single ventilation efficiency can be increased by implementing appropriate strategies, like utilising balconies, windows, and wing walls. Furthermore, many climatic devices have been introduced to improve building design, such as courtyards, wind towers, thermal massing, shading devices, and chimneys [7].

2.2 Introducing airflow with wind catchers

Wind catchers are an essential architectural element in various climates, especially tropical and hot climates. The wind catcher is one of the oldest passive structures in the history of human structures. It captures air from high areas and pushes it down toward indoor spaces. The basic concept underlying this device is that the air temperature can be changed within the tower by changing its density [7].

Currently, the only available research to investigate the relationship between duct and indoor airflow for single-sided ventilated buildings is that carried out by Allocca (2001), which used a horizontal duct system in an individual student to achieve cross ventilation throughout the apartment. However, the duct size was 0.25 m x 0.61 m, and the duct was built in the centre of the room. The results indicate that the ventilation rate is twice as high using this method than using single-sided ventilation. [8].

2.3 Residential buildings in Jordan

Today, most of the new residential buildings in Jordan are multi-storied apartments [9]. The vast majority of urban dwellers live in these apartments because of their high population growth and the cost of land [10]. In Jordan, dwellings are mainly classified into three categories: villas, houses, and apartments. The percentages of the 12 governorates groups for Jordan are 40.5% apartments, 54.1 % houses, and 4.8% villas [11].

Many problems arise when applying natural ventilation to apartments. Apartments ventilated via the single-sided method were mainly chosen for this case study because rooms that have single-sided ventilation tend to be located on the eastern side where there is less ventilation compare to the western side.

3. Methodology

The current research adopted the quantitative research method based on an advanced CFD program. ANSYS Fluent 19 software was used to provide high precision and reduce the probability of design errors and comprehensive outputs. This research uses analysis for the airflow and temperature performance within spaces that have a window on only one side. Several prototypes of horizontal wind catcher ducts have been suggested for a residential room by specifying the variables (window height, duct depth and position). Various prototypes were compared with the original case and cases combined with new devices to decide which would be the most appropriate for enhancing wind speed in living spaces.

3.1 Computational Fluid Dynamics (CFD)

The modelled and meshed geometry was exported to Ansys FLUENT for setting up and solving the fluid flow problem. General settings in Ansys FLUENT were chosen to obtain accurate results. In this validation case research, the standard k-epsilon turbulence model is selected to close the RANS equations. Pressure and velocity were coupled by the SIMPLE algorithm, and the second-order upwind differencing scheme was used in consideration of the computational time required. Convergence criteria for the relative differences in all predicted airflow and temperature values for 10,000 iterations did not exceed 0.5-1%. This change was < 0.1% in all cases.

3.2 Validation study

This section includes validation research for the fluent CFD model, especially regarding its ability to predict ventilation levels for structures (buoyancy force). By using Ansys FLUENT CFD, the case cavity with a C-shape was close to the experimental case. [12]. The viscous model with a sub-model as RNG has been set to k-epsilon ($\boldsymbol{k}-\boldsymbol{\varepsilon}$) for modelling predicted turbulent airflow. Moreover, enhanced wall treatment was set.

The cavity had a horizontal inlet and outlet, and the height of each was the same as the cavity width. The boundary conditions used for the experimental research were the same as those used by [13], and cases were divided into three groups based on cavity width (0.075 m, 0.125 m and 0.170 m). There were five multiple cases for each width, and each exhibited multiple heat flux. The source of heat was the wall at both openings.

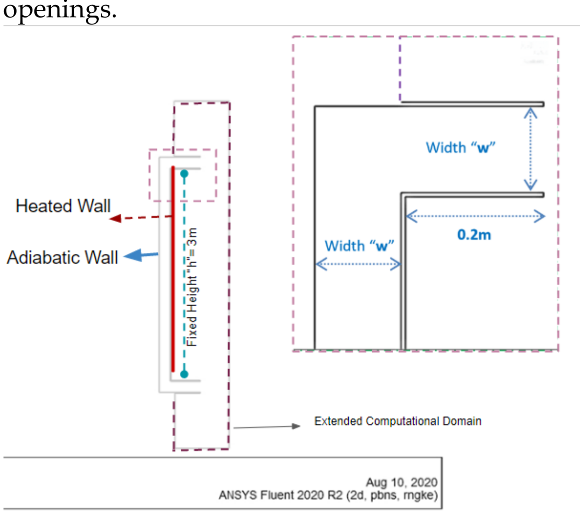


Figure 1: The C-shape cavity studied by La Pica et al. (1993) and tested by the author (width = 0.07 m, 0.125 m, or 0.170 m)

Figure 2 shows that the CFD model's expected outcomes were in good agreement with the experimental results. The absolute difference was < 10%; the average differences for widths of 0.170 m, 0.125 m, and 0.075 m were 5.4%, 4.9%, and 1.3%. In addition, the total average difference for all widths was roughly 3.9%, which aligns with Gan's results showing that the change of air velocity was < 5%. Thus, it was concluded that the CFD model can reliably predict airflow levels in naturally ventilated cavities using the tested models.

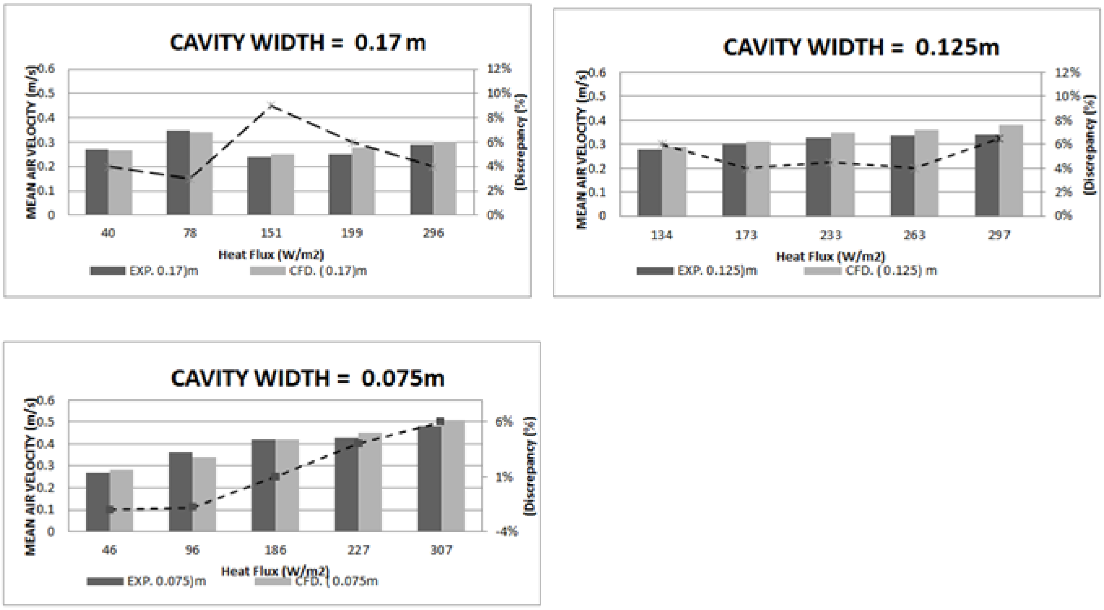


Figure 2: Comparative study between air velocity evaluated by La Pica et al. (1993) and air velocity determined using a fluent model.

3.3 Case Study Description: Case of Irbid, Jordan

A multi-story residential building representing typical buildings located in Irbid, Jordan, serves as the case study. The residential building consists of four floors. All floors are typical – specifically, the bedrooms assume an east-west orientation, the roof thickness of the building is 0.3 m, and its ceilings are 3.40 m high. The dimensions of the outer openings are 1.0 m * 2 m. These openings work as the inlet and outlet.

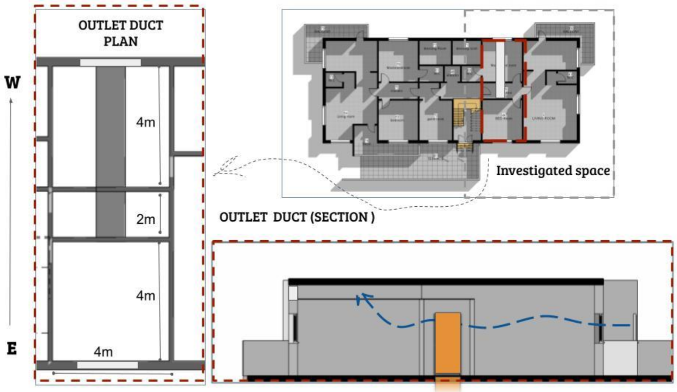


Figure 3: Investigated space (Reference case)

3.3.1 Horizontal wind catcher duct properties

Rectangular ducts were chosen, as they fit well in the building and are easy to install above ceilings and in walls. Also, one of the most efficient factors in the duct variables that affect airflow is a width-to-height ratio (aspect ratio) close to 1.

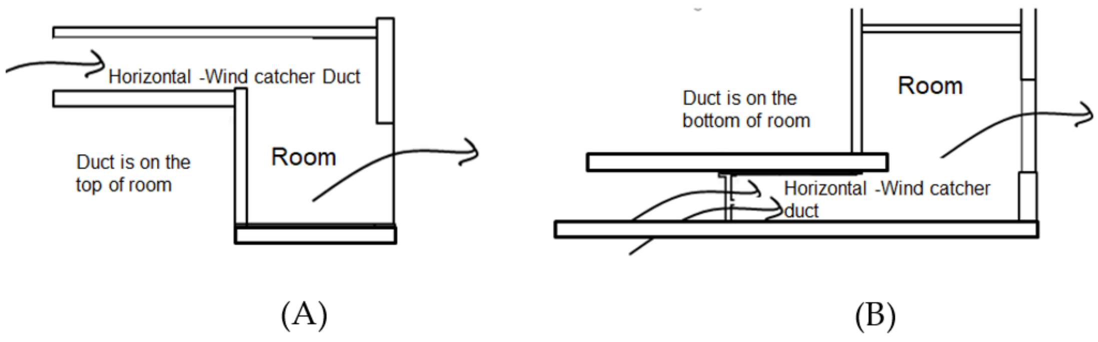


Figure 4: Horizontal wind catcher integrated into a room space (sections) a: high duct, b: low duct

3.4 Initial Studies: This section presents two initial studies carried out before the main work.

3.4.1 Mesh Size studies:

Six meshing cases with different features were examined. The domain of Mesh 6 is 0.2 m, and the edge is .002 m (Figure 5) and table 1. This mesh exhibited a change in air velocity and temperature performance of < 1%, whereas no other mesh produced a change. Therefore, this mesh was used for the present research.

Table 1. mesh sizes used in the study

	Mesh 1	Mesh 2	Mesh 3	Mesh 4	Mesh 5	Mesh 6
#cells						
Size	425810	210528	82536	425327	209094	81967
Domain	.1	.1	.1	.2	.2	.2
Edges	.001	.002	.005	.001	.002	.005

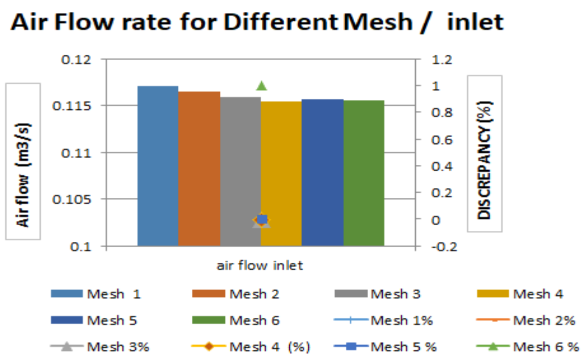


Figure 5: Different meshes for Preliminary Studies

3.4.2 Extension study for the computational domain:

Four scenarios were listed: 2x, 4x, 6x, and 8x, where x relates to the original height of the external vent's outlet for the window and the inlet for the duct.

It was discovered that changes in air velocity were <1 % for both the room and the duct when the size of the extension changed from 4x to 6x (Figure 6). This indicates the possibility of using 4x for smaller mesh sizes to reduce the computational time needed. On the other hand, similar increases in surface temperatures remained as high as 3%; however, between 6x and 8x, it fell to 1%. Therefore, 6x is the best extension. However, 4x was used for this research to save time. This means that a distance boundary of domain measures (4x) the inlet and outlet expansion.

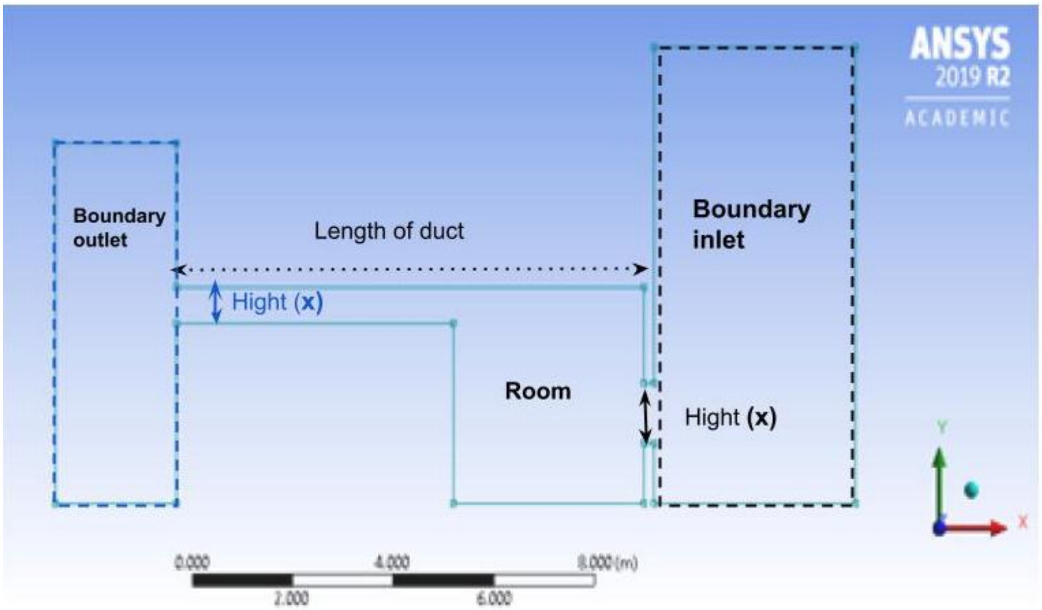


Figure 6: Extended Computational Domain

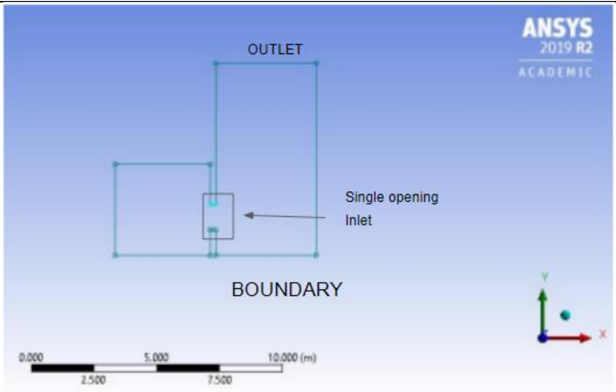
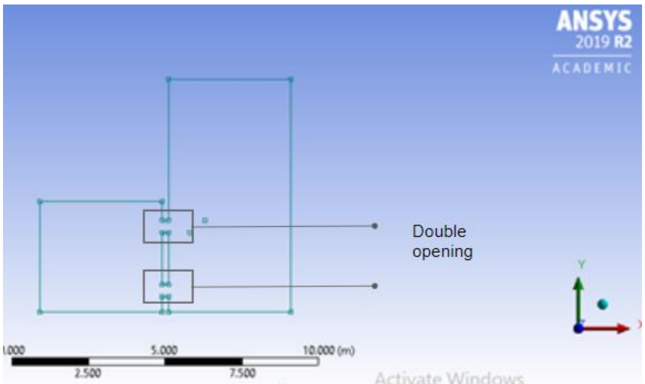
4. Simulation setup and model configurations

This section discusses the current case (a room typical of those found in buildings in Irbid, Jordan, utilising single-sided ventilation) and new cases (in which single-sided ventilation is integrated via a horizontal duct. The reference case has two configurations, and the new cases have two scenarios in which the typology of the horizontal wind catcher duct is classified according to the change in the height of inlet opening layouts due to changing the position and depth of the duct.

4.1 Reference case (Single-sided ventilation)

The reference case has two configurations: A and B. Configuration (A) has three scenarios divided according to the height of the window, while configuration (B) has four scenarios. The wall containing the window is divided into two openings of different heights as shown in Table 2.

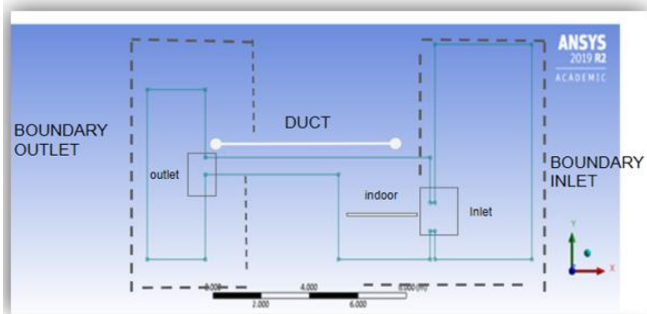
Table 2: Reference case (configurations A and B)

Reference case (single-sided ventilation)		
Case	**Specifications**	**Figure**
Configuration A		
1	Single opening, height is 1 m	
2	Single opening inlet, height is 1.5 m	
3	Single opening inlet, height is 2 m	
Configuration B		
1	Double openings inlet, height is 0.2 m for each opening	
2	Double openings inlet, height is 0.3 m for each opening	
3	Double openings inlet, height is 0.4 m for each opening	
4	Double openings inlet, height is 0.5 m for each opening	

4.2 Cases with a horizontal duct

Two scenarios are considered in this section according to the position of the duct in the space. In the first scenario, the duct is located in the upper level of the room; in the second case, it is located in the bottom of the room (table3 and table 4).

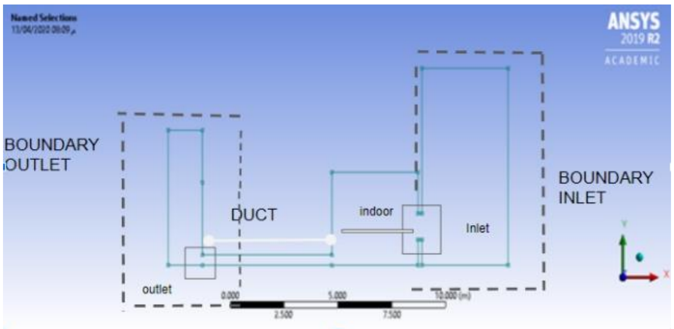
Table 3: Cases with a horizontal duct high position

Cases with horizontal duct (position of the duct is high)			
Scenario A	**Case**	**Specifications**	**Figure**
A-a	**1**	Opening of duct is (height 1 m* 0.2 m depth)	
A-a	**2**	Opening of duct is (height 1 m* 0.3 m depth)	
A-a	**3**	Opening of duct is (height 1 m* 0.4 m depth)	
A-a	**4**	Opening of duct is in the upper level of the room (height 1 m* 0.5 m depth)	
A-a	**5**	Opening of duct is (height 1 m* 0.6 m depth)	
A-b	**6**	Opening of duct is (height 1.5 m* 0.2 m depth)	

A-b	**7**	Opening of duct is (height 1.5 m* 0.3 m depth)	
A-b	**8**	Opening of duct is (height 1.5 m* 0.4 m depth)	
A-b	**9**	Opening of duct is (height 1.5 m* 0.5 m depth)	
A-b	**10**	Opening of duct is (height 1.5 m* 0.6 m depth)	
A-c	**11**	Opening of duct is (height 2 m* 0.2 m depth)	
A-c	**12**	Opening of duct is (height 2 m* 0.3 m depth)	
A-c	**13**	Opening of duct is (height 2 m* 0.4 m depth)	
A-c	**14**	Opening of duct is (height 2 m* 0.5 m depth)	
A-c	**15**	Opening of duct is (height 2 m* 0.6 m depth)	

Table 4: Cases with a horizontal duct low position

Cases with a horizontal duct (position of the duct is low)			
Scenario B	**Case**	**Specifications**	**Figure**
B-a	**1**	Opening of duct is (height 1 m* 0.4 m depth)	
B-a	**2**	Opening of duct is (height 1 m* 0.5 m depth)	
B-a	**3**	Opening of duct is (height 1 m* 0.6 m depth)	
B-b	**4**	Opening of duct is (height 1.5 m* 0.4 m depth)	
B-b	**5**	Opening of duct is (height 1.5 m* 0.5 m depth)	
B-b	**6**	Opening of duct is (height 1.5 m* 0.6 m depth)	
B-c	**7**	Opening of duct is (height 2 m* 0.4 m depth)	
B-c	**8**	Opening of duct is (height 2 m* 0.5 m depth)	
B-c	**9**	Opening of duct is (height 2 m* 0.6 m depth)	



5. Results and discussion

5.1 Reference case (single-sided ventilation) for reference configurations A and B

5.1.1 Airflow and Temperature Rate For Configuration A

The results show that single-sided ventilation generates a low ventilation rate because the airflow for the inlet and outlet are positive and negative. The difference between them reduces the airflow nearly to zero. As the height of the different windows increases, airflow also increases. On the other hand, the change is < 1%. In case 3, the airflow rate is increased (as shown in Figure 7). This means that 28% of the window-to-wall ratio provides improved ventilation. The 14% and 21% ratios with low airflow provided about the same rate of airflow.

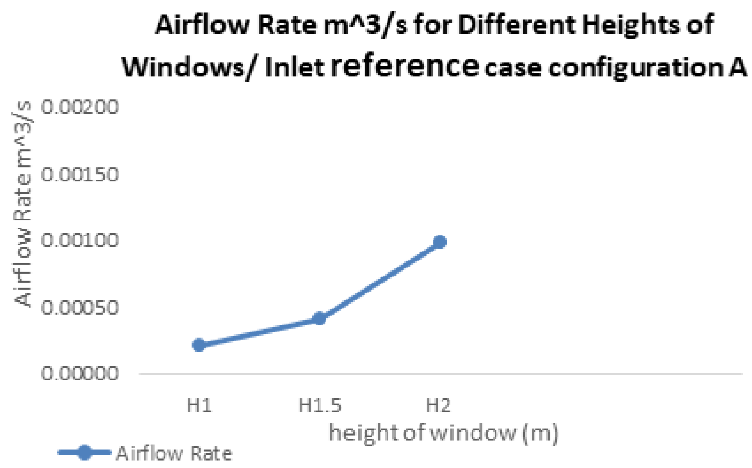


Figure 7: The airflow in the internal environment for configuration A

Figure 8 shows the temperature increase (ambient air temperature "30°C") associated with different window heights for the reference case (single-sided ventilation). Generally, the temperature increase for an inlet would decrease as the window height increased. This decrease was small for case 3, as the overall change was 10%. Meanwhile, changes in temperature in indoor space were < 7%. The lowest temperature was associated with case 1.

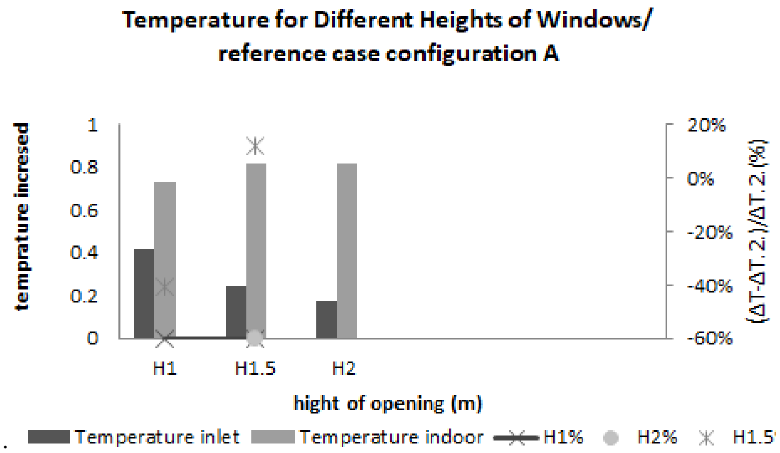


Figure 8: The internal environment temperature for configuration A

The CFD results clarify that in the room with single-sided ventilation, the cold and warm airflows come from the same opening. Due to wind pressure fluctuations and eddies, rotation flows were associated with single-sided ventilation (Figure 9).

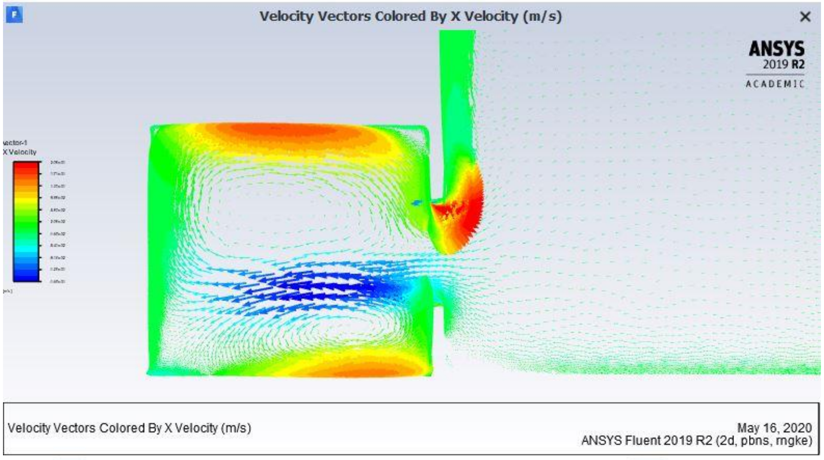


Figure 9: The path of the airflow in the internal environment for configuration A

5.1.2 Airflow and temperature rate for configuration (B) a double opening

The results show that the airflow rate in the inlet and outlet of the model is increased in the room when the height of double openings is increased. The change in airflow between the heights of 0.2 m to 0.5 m was 50%.

Figure 10 shows the increase in temperature (ambient air temperature "30°C") for different dimensions of double openings for the reference case (single-sided ventilation). Generally, the temperature in the inlet increases and the indoor temperature drops as the opening becomes taller. This drop for vent heights between 0.2 m and 0.5 m was approximately 30%. CFD modelling reveals that the change in temperature between the inlet and indoor is < 1%.

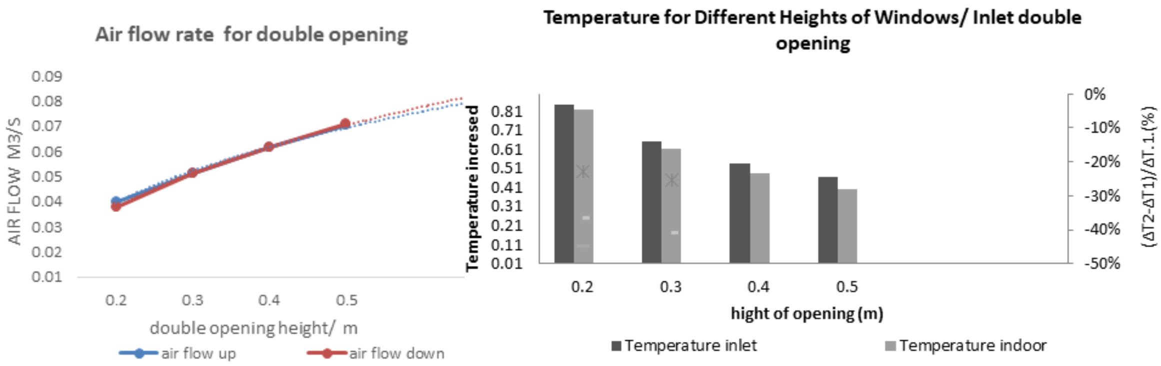


Figure 10: The airflow and temperature in the internal environment for configuration B

The CFD results depict two openings, one at the upper level of the wall and one at the lower level. Cool air flows into the low opening (Figure 11), and hot air flows out of the upper opening. This kind of ventilation stratifies the temperature inside the room. Spaces with upper and lower openings have a far greater impact on the interior temperature than spaces with only one opening.

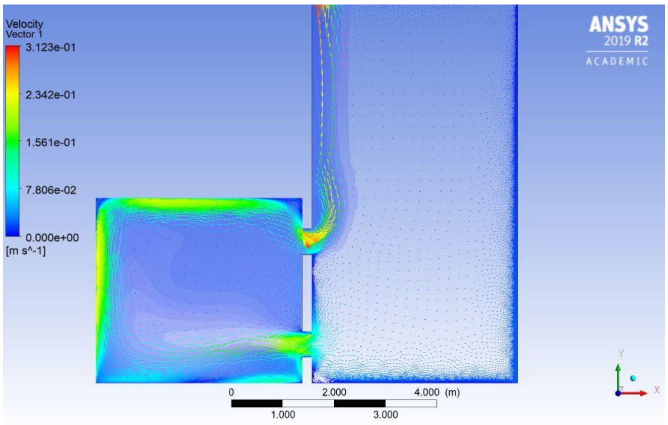


Figure 11: The path of air velocity for configuration B

Cases with a horizontal duct

5.1.3 Airflow and temperature rate when the duct is in the upper level of the room (scenario A)

The results show that when the inlet opening is larger than the outlet, the airflow within the space is reduced. The airflow described in section A-a (window height = 1 m) is slightly higher than in other cases by approximately 1-2%. For different depths of the horizontal duct (0.2-0.6 m), changes in airflow for the inlet and outlet in the room are approximately 50% when the window size is held constant. This means that the deeper a duct is, the higher the airflow rate. The airflow rate for case 6 was 0.07 m^3/s for a depth of 0.6 m. When the depth was 0.2 m (case 1), the airflow rate dropped to 0.04 m^3/s.

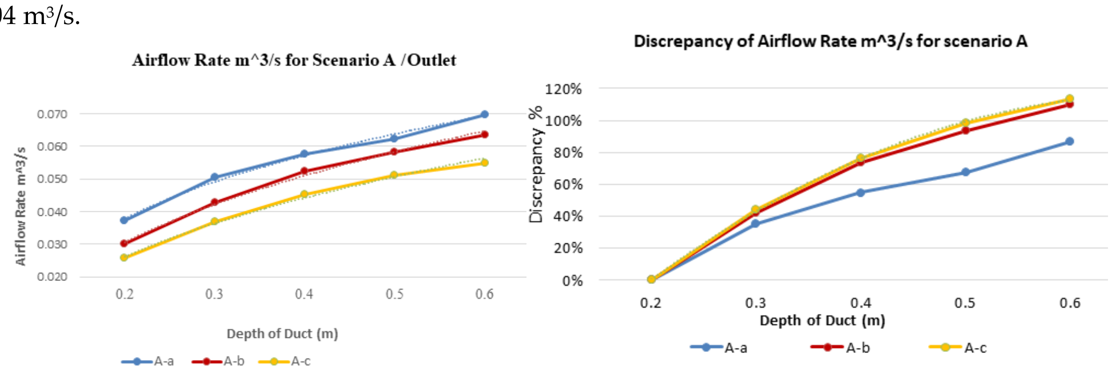


Figure 12: Graph analysis of airflow rates for outlet scenario A

Figure 13 shows the temperature increase (ambient air temperature "30°C") for the case with a horizontal duct. Generally, the temperature increase for the inlet and outlet decreased as the depth of the duct increased for three sections (A-a, A-b, and A-c). As seen in Figure 13A, the temperature increases for A-a and A-b of between 0.2 and 0.5 m decreased by approximately 10%. Meanwhile, the temperature increase associated with A-c dropped by 5%.

CFD modelling shows that the change in temperature between the different inlet heights for the same duct depth is slightly < 1%. Figure 13B shows that the temperature increases in the indoor space for A-a, A-b and A-c (0.2-0.6 m) decreased by 3%. C case 6 generated the best outcomes, with case 5 a close second – the difference between these two cases was only 2%.

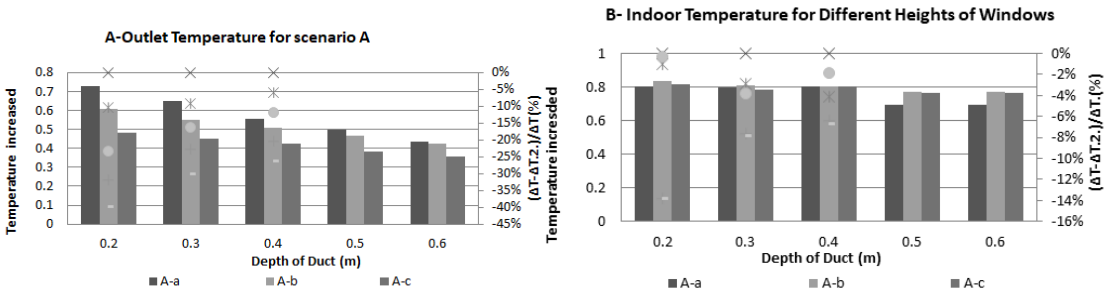


Figure 13: The airflow and temperatures in the internal environment for scenario A

CFD results show two openings with different entry and exit heights. The entry opening is located at the centre, and the exit is located on the upper part of the wall. Air flows into space from the entry opening and flows out from the top opening. In addition, the air velocity is increased in the narrow space based on the Venturi effect (Figure 14).

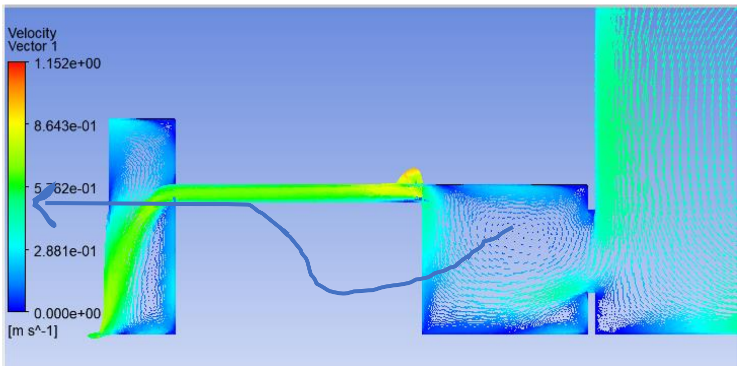


Figure 14: The velocity trajectory for scenario A

CFD presents contours of temperature, which show a temperature gradient, for scenario A. In this case, thermal fields would be cleared throughout the room. The results also indicate a slight change in temperature.

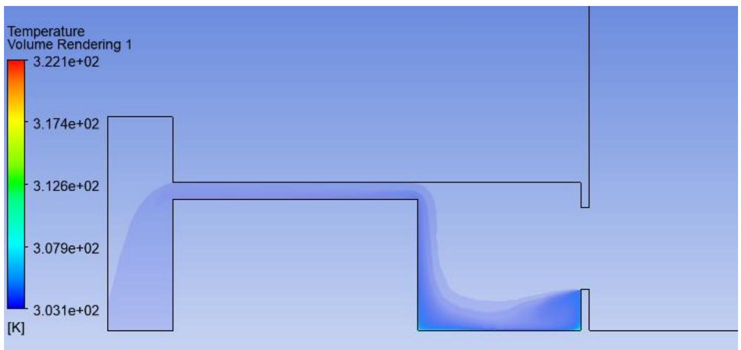


Figure 15: The temperature contour analysis for scenario A.

5.1.4 Airflow and temperature rate when the duct is placed at the bottom of the room (scenario B)

The results show that the airflow of section B-c (window height = 2 m) is slightly higher than that of other sections by approximately 4%. Changes in the depth of the horizontal duct (0.4-0.6 m) affected the airflow by approximately 12%, assuming that the window height did not change. However, the change for all sections is slightly lower (by 4%) for the duct depth of 0.6 m. As such, the deeper the duct, the higher the airflow rate. The airflow rate for case 9 was 0.06 m^3/s (duct depth = 0.6 m), whereas the airflow rate was 0.05 m^3/s when the depth was 0.4 m (case 7).

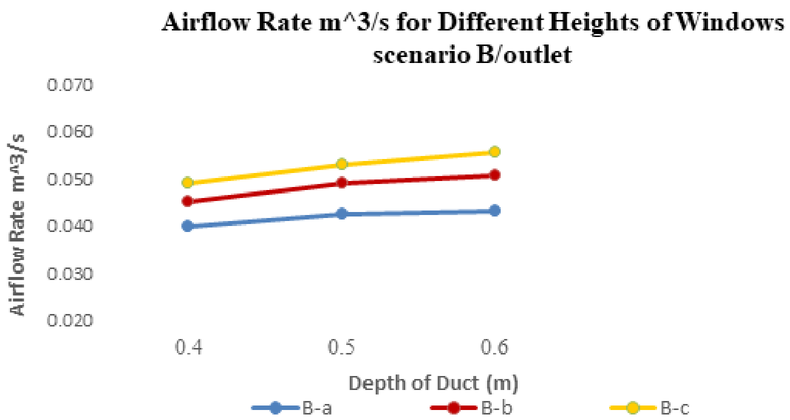


Figure 16: Graph analysis of airflow rate for scenario B

Figure 17 shows the increase in temperature (ambient air temperature "30°C") for scenario B. Generally, the inlet temperature increases for all sections were enhanced as the depth of the duct increased. In addition, when the height increases, the temperature dropped by more than 75% when the duct depth remained constant Figure A. However, as shown in Figure 17A, the temperature increased by approximately 10% for B-a (between 0.4 and 0.6 m), while it increased by 20% for B-c and B-b.

In Figure 17B, the temperature increase was hindered by an increase in depth from 0.4-0.6 m for B-a, decreasing by < 10%. This decrease was 15% for B-c and B-b. The CFD modelling results show that the change in indoor temperature when comparing the different inlet heights (when duct depth remained the same) was 20%. The graph shows that, in general, better agreement of inlet temperature was attained for case 7 (B-c) with a 0.4-m depth. Case 8 (depth = 0.5 m) is the closest alternative, with a discrepancy of 34%. Further, the indoor temperature of case 9 (B-c) (depth = 0.6 m) is only slightly (< 5%) different from that of case 8.

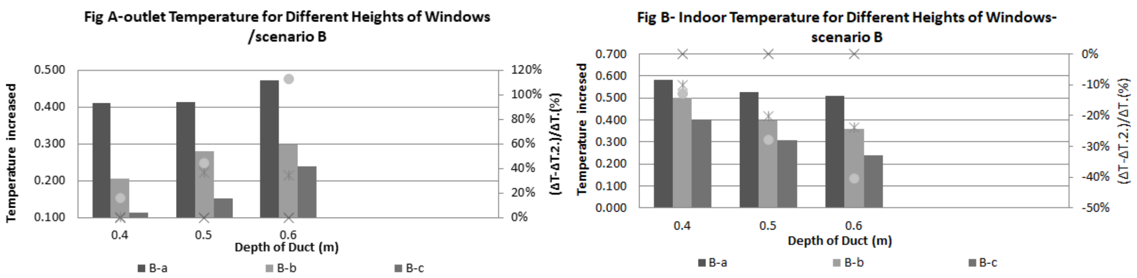


Figure 17: Graph analysis of air temperature rate in the internal environment for scenario B

The CFD results depict two openings of different heights for the inlet and outlet; the entry opening is at the centre of the space, and the exit is at the bottom. Air flows into space from the outlet and out from the window. This means that the airflow rate can be increased if the entry opening is shorter than the exit opening (Figure 18).

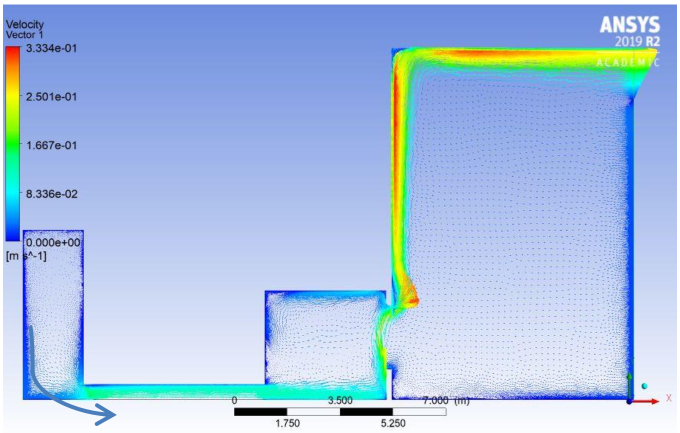


Figure 18: The trajectory of velocity for scenario B

The CFD results also present the temperature contours for scenario B, which indicate the presence of a temperature gradient. Thus, thermal fields are cleared throughout the room. The results also show that the temperature slightly changed.

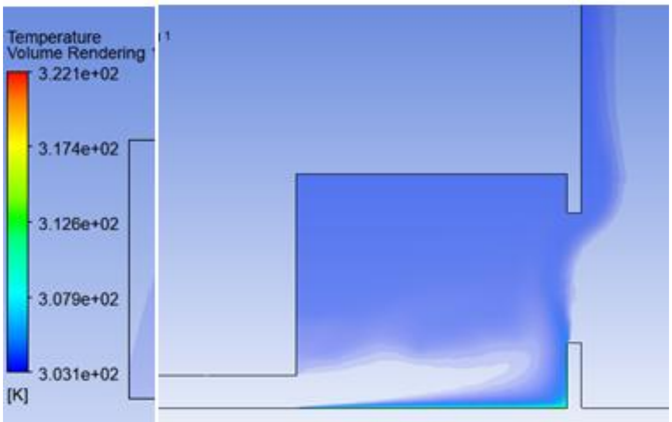


Figure 19: Contour analysis of temperature for scenario B.

6. Discussion

According to the applied optimisation methodology, both the height of the window and the depth of the duct affect the ventilation characteristics of an indoor space. Below, two elements are discussed regarding the effect on the ventilation of the space, namely airflow rate and air temperature rate.

Airflow rate:

The findings for the 31 selected samples are described as follows. The outcomes of the design assumptions are provided to understand their performance:

- Different opening height cases are integrated with the horizontal duct, which has one opening on the ceiling and another on the floor. In addition to variations in the depth of the duct from (0.2m to 0.6m) as shown in Figures was used. The airflow rate of section A-a (when inlet opening height is 1 m and the depth of the duct is 0.6 m) was 34% higher than when the duct was located at the bottom of the room (with the depth and height of the window remaining constant). The airflow rate decreased as the depth decreased. Figure 20 shows that, in general, the airflow rates for A-a (depth = 0.6 m) were the highest, though the rates for A-b are still the closest (change = 2%).

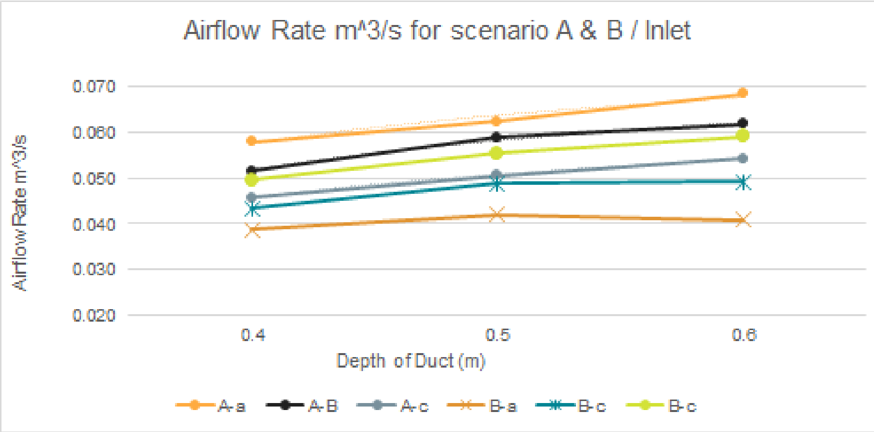


Figure 20: The airflow in the internal environment for scenarios A and B

Figure 21 depicts an unexpectedly large increase in airflow for the new mechanism of single-sided ventilation integrated with a 0.6-m-deep when compared to the reference case with window heights of 1 m,1.5 m, and 2 m.

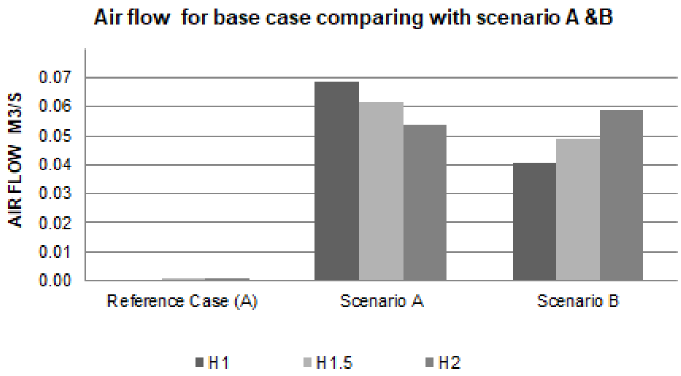


Figure 21: The airflow in the internal environment for configuration A and scenarios A and B

Figure 22 shows that the airflow of the reference case (configuration A) is low, while that of configuration B is relatively high and close to that of scenario A-a.

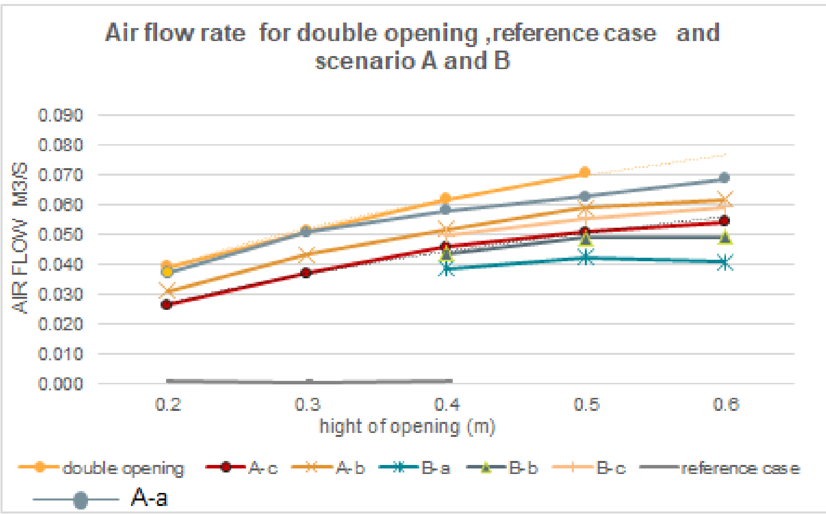


Figure 22: The airflow in the internal environment for configurations A and B and scenarios A and B

Figure 23 shows a comparison of the indoor temperature rates for both scenarios. The change in temperature increase dropped slightly (by 1-4%) when the depth was changed but the height remained the same. Specifically, the temperature increase was hindered as the duct depth increased. Of all cases, case B-c (window height = 2 m, duct depth = 0.6 m, duct located at the bottom of the floor) generated the lowest temperature.

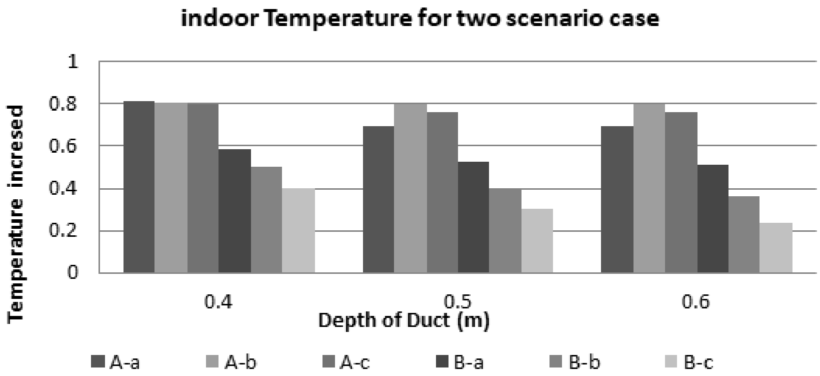


Figure 23: Indoor temperatures for scenarios A and B

Figure 24 shows that the temperature was lower in scenario B when the duct (depth = 0.6 m) was located at the bottom of the room. Moreover, relative changes in the temperature of the duct in scenario A were lower than in the reference case by 2%. Meanwhile, scenario B was lower for H1 by 35% and for H2 by 60%. The graph shows that, in general, the agreement was best for H2 with a 0.6-m depth.

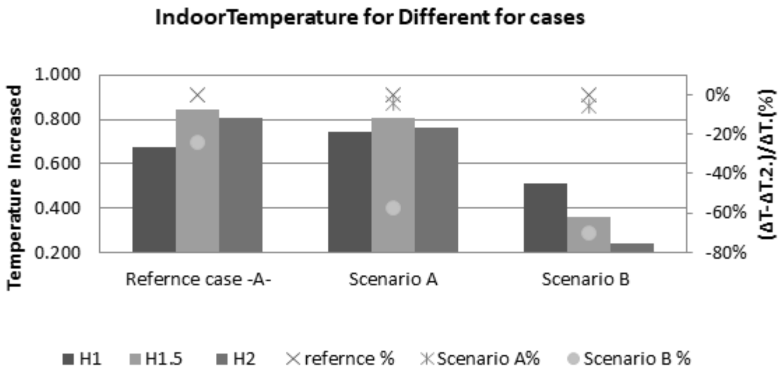


Figure 24: Indoor temperature for reference case A and two comparison scenarios (A and B)

The findings confirm that the natural ventilation factors are affected by the heights of windows, as well as the integrated duct with a single-sided opening, which, in turn, produces significant differences in the values of airflow rate and temperature rate.

- The best airflow rate was recorded when the duct is in the ceiling; the temperature rate decreases when the duct is at the bottom of the room.
- Sections A-a and B-c are close, with a discrepancy of < 1%. Section B-c allowed the air to flow from the duct from east to west. This section has achieved the goal of this research.

In both scenarios, airflow rate was maximised when the wind passed through this new mechanism as opposed to single-sided ventilation cases.

6. Conclusions

Natural ventilation is the leading passive method for cooling interior environments in hot climatic regions. Integrating a horizontal wind catcher duct in a single-sided ventilation system can yield efficient performance. This paper demonstrated the integration of horizontal wind catcher with single-sided ventilation in residential buildings in the Jordanian context through a computer simulation by testing different scenarios within a room.

The criteria for choosing the best scenario were based on the maximum ventilation rate demands and the best temperature rates for building occupants.

The simulation results showed that the case utilising a horizontal wind catcher duct increased the ventilation rate by 99% compared to the standard case. Furthermore, scenario B (section B-c) reduced the temperature of the room by 31.3% compared to section B-a and enhanced the temperature performance.

On the other hand, in scenario A, the duct did not allow air to flow to the other side of the room. In this scenario, section B-c is the inlet for air.

Regarding the distribution of airflow throughout the internal environment, scenario A-a produced the maximum ventilation and average air temperature. Compared to the basic model, these parameters were slightly increased. This is because the different pressures around the opening impacted the airflow within the building.

The results for the reference case show that the airflow of configuration A is lower than that of configuration B (which is close to the airflow of scenario A-a).

In addition, increasing the depth of the duct slightly increased the airflow (by 1%); thus, depths of 0.4 m and 0.5 m can be used and are recommended due to their low cost and flexible design.

In most cases, the optimal window width was 1-1.5 m. If the width exceeds 1.5 m, the cost will be higher. This supports the findings of the study Moore, which focused on the effect of the relative opening size and different outlet opening heights on indoor air velocity in wind-driven cross ventilation.

Another feature that distinguishes this paper is its practical method to enhance energy efficiency and thermal ventilation comfort. Finally, this paper serves society by providing a way to enhance indoor environments. Therefore, this work can be helpful in further research and can serve as a reference for current and future building designs.

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Exploration of Current Builders' Capacities to Deliver Zero Energy Buildings in China

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Abstract: To strengthen the global fight against climate change, China pledges to reach carbon neutrality by 2060. As one of the major energy consumption sectors in China, the building industry's role in CO_2 emission reductions is critical to the successful pursuit of the carbon neutrality goal. The concept of zero energy buildings (ZEBs) has gained increasing attention in China due to its effective efforts on energy saving and emission reduction. The objectives of this research are to investigate current builders' capacities for delivering ZEBs in China, to explore the differences in design and construction capacities of conventional and ZEB builders in China, and to assess the potentials of boosting Chinese builders' capacities for delivering ZEBs in the future. The research methods embrace several steps. Firstly, a checklist was developed based on the literature review to assess Chinese builders' capacities to deliver ZEBs. Secondly, relationships between different checklist questions were analyzed using association rule in software SPSS modeler. Thirdly, builders were clustered using TwoStep Cluster Analysis in software SPSS modeler. The findings of this research suggest that most Chinese builders, even ZEB builders have insufficient ZEB design and construction knowledge. ZEB demonstration projects are mainly developed in cooperation with foreign professional institutions. Moreover, conventional builders are less competitive than ZEB builders in passive design capacity, energy efficient building design capacity, renewable energy generation capacity and research capacity, which are the key skills that conventional builders are supposed to improve. Furthermore, one-third of conventional builders have NZEBs or ULEBs production experience. They have acquired related ZEB delivery capacities and they are the most likely ZEB builders in the future.

Keywords: Zero energy buildings; Builders' capacity; China

1. Introduction

To strengthen the global fight against climate change, in September 2020, the Chinese president announced that China pledges to reach carbon neutrality by 2060. As one of the three major energy consumption sectors in China, the construction industry accounts for 34.3% of the country's carbon dioxide (CO2) emissions [1]. With the economic growth and the rapid development of urbanization, it is estimated that the carbon emissions in the Chinese building sector will increase and the figure could be doubled by 2050 [2]. Accordingly, the building industry's role in CO2 emission reductions is critical to the successful pursuit of the carbon neutrality goal. The definition of zero energy building (ZEB) was originally proposed by Esbensen and Korsgaard in the 1970s, where a ZEB could be heated in winter by adopting solar energy as the main energy source [3]. The concept of ZEB has evolved constantly from its original description to a comprehensive concept for sustainable development, but there is currently no internationally agreed definition of ZEB [4]. Table 1 summarises the various definitions in different countries. Although these definitions are not the same, generally, a ZEB is a building with reduced energy demands via efficiency gains and its energy demand can be met through renewable energy sources [5]. They all share common goals of making full use of renewable energy and reducing carbon emissions.

Table 1. Definitions of ZEB in different countries

Time	Country	Definition	Content	Reference
1976	Denmark	Zero-Energy House	Buildings that use solar energy to satisfy the heating energy requirements in winter.	Esbensen and Korsgaard (1977)
1992	Germany	Energy Autonomous House	Connection to an external energy infrastructure is unnecessary, and the solar thermal/photovoltaic system can be integrated with the energy storage technology to satisfy the energy requirements at all times.	Voss et al. (1996)
2007	USA	Zero-energy Building	An energy-efficient building, for which the actual annual delivered source energy is less than or equal to the on-site renewable exported energy.	DOE (2015)
2007	UK	Zero-Carbon Home	Net CO2 emissions from all energy consumption in residential buildings are zero.	Department of Communities and Local Government (DCLG) (2007)
2010	EU	Nearly Zero-energy Buildings	Buildings with a very high energy efficiency, whose energy demand is close to zero or very low, and their energy supply is largely from renewable energy sources at or near the site	European Commission (2020)
2013	Canada	Net Zero-Energy Home	A home that only uses as much energy as it can produce from on-site renewable energy.	NetZero (2020)

China's efforts on building energy conservation have started since 1986, and the concept of ZEB has gained increasing attention since 2010 due to its effective efforts on energy saving and emission reduction [4]. In 2015, the Chinese Ministry of Housing and Urban-Rural Development (MOHURD) initiated the Building Energy-Efficiency Improvement Program (BEEIP), this is the first time that developing net (or nearly) ZEBs was formally presented in China (Wu et.al., 2015). As a multi-ethnic developing country with diverse climate zones, China has unique features in building type, living habits, indoor environment, and architectural characteristics, and there is no mature experience for reference, which has increased the difficulty of ZEB research and development.

Figure 1. Climate zones in China

As shown in Figure 1, China is mainly divided into five climate zones, including temperate zone, hot summer and warm winter, hot summer and cold winter, cold zone, and severe cold zone. The climate is related to the temperature, humidity and solar radiation of the region, which significantly impacts the building performance and the design strategies of ZEBs [6]. Adapting to local conditions and making reasonable use of ambient environment resources to create a comfortable indoor environment is necessary when design ZEBs. The complex and diverse climate has increased the difficulties to deliver ZEBs in China. Furthermore, ZEBs in developed countries are mostly low-rise buildings with up to three floors. However, the majority of buildings in Chinese urban areas are medium-to-high-rise buildings [7]. Li (2018) suggested that for residential buildings, the maximum number of floors is three when the rooftop PV system is the only energy source. Therefore, it is difficult to achieve ZEBs in Chinese cities [8].

Currently, it is difficult for China to directly move from the current building standard to the ZEB level [9]. Therefore, a roadmap for 2016-2030 building codes upgrading was developed to achieve ZEB [7]. China has completed the "30%-50%-65%" three-step energy-saving plan after 30 years of continuous efforts since 1986 (Figure.2) [7]. And a new three-step approach to setting national standards between 2016-2030 was put forward, including Low Energy Building Standard, Ultra Low Energy Building Standard, Nearly Zero Energy Building Standard. The definitions of ultra low energy building (ULEB), nearly zero energy building (NZEB) and zero energy building (ZEB) are summarised in Table 2 [10]. The Chinese standard for building energy efficiency in effect in 2015 is that residential buildings are more than 65% energy saving, and public buildings are more than 50% energy saving than 1980's baseline performance.

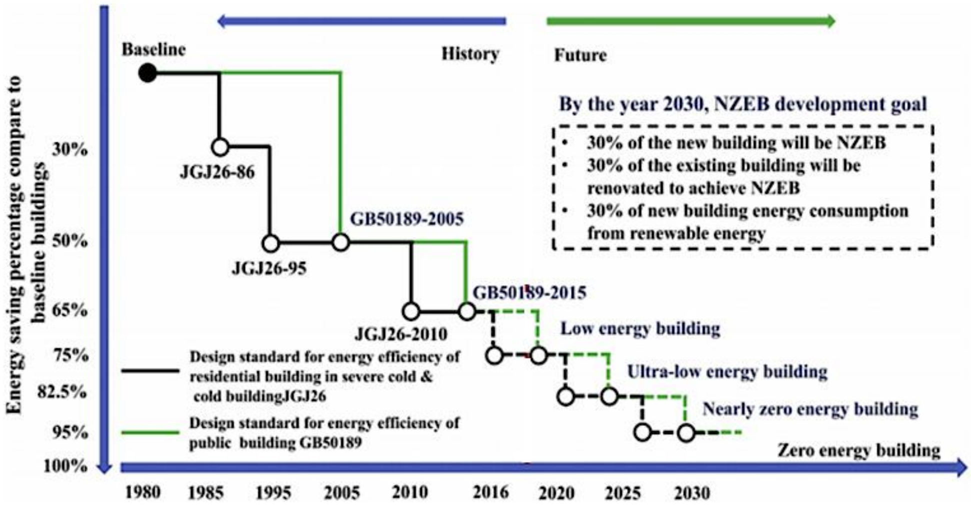

Figure 2. Roadmap of ZEB standard in China (Xu, 2017)

Table 2. The definition of ULEB, NZEB, and ZEB (MOHURD, 2019).

Definitions	Energy Reduction rate compared to 1980's baseline (Fig 2)	Energy reduction rate compared to standards in effect in 2015
Ultra-low energy building (ULEB)	82.50%	50%
Nearly zero energy building (NZEB)	95%	65%–70%
Zero-energy building (ZEB)	100%	100%

Driven by the national policies launched by the central government, some provinces and cities have also actively initiated related standards and guidelines to promote the development of ZEB based on local conditions, such as Beijing, Hebei, Shandong, and Shanghai [11]. Among the five climatic regions in China, the related policies in cold climate are dominated. Table 3 summarizes standards related to ZEBs in some provincial-level regions in China. In response to government policies, a number of ULEB or NZEB demonstration projects has been built in different climate zones to play a leading role in improving building energy performance.

Table 3. A summary of standards related to ZEB in China

Provincial-level region	Title and number	Enforcement date	Note
China	Passive Ultra Low Energy Green Building Technical Guide (Residential building)	2015.11.10	For design, construction, operation
	National Standard Chart Passive Low Energy Buildings - Residential Buildings in Cold and Cold Areas(16J908-8)	2016.09.01	For design, construction
	Nearly Zero Energy Buildings Technology Standard	2019.09.01	For design, construction, operation, evaluation
	Detection and Evaluation Standard for Nearly Zero Energy Building	2019	Detection and Evaluation Standard
	Technical Standard for Ultra-Low Energy Buildings in Public Institutions T/CECS 713-2020	2020.12.01	For design, construction, operation, evaluation
Beijing	Design Standard for Ultra-low Energy Residential Buildings	2020.04.01	For design
	Application Guide for Beijing Ultra-low Energy Consumption Demonstration Construction Project	2018.04.19	For farm house
	Guidelines for the Design and Construction Acceptance of Ultra-low Energy Residential Buildings in Beijing	Under development	For design, construction, evaluation
	Technical Regulations for Construction of Ultra-low Energy Residential Buildings in Beijing	Under development	For construction
Hebei	Design Standard for Energy Efficiency of Passive Ultra-Low Energy Residential Buildings DB13(J)T 177-2015	2015.05.01	For design
	Passive Low-Energy Residential Building Energy-Saving Structure DBJT02-109-2016	2016.06.01	For design
	Passive Low Energy Building Construction and Evaluation Procedures DB13(J)/T 238-2017	2017.09.01	For construction, evaluation
	Design Standard for Energy Efficiency of Passive Ultra-Low Energy Public buildings DB13(J)/T 263-2018	2018.09.01	For design, construction
Shandong	Passive Ultra-Low Energy Residential Building Energy-Saving Design Standards DB37/T5074-2016	2016.12.01	For design
	Key Points for Special Acceptance of Passive Ultra-low Energy Green Building Demonstration Project in Shandong Province	2017.07.05	For evaluation
	Technical Guidelines for Construction of Ultra-low Energy Buildings in Shandong JD 14-041-2018	2018.10.01	For construction
Shanghai	Technical Standard for Ultra-Low Energy Buildings in Shanghai	2019.03	For design, construction, operation, evaluation
	Green building evaluation standard in Shanghai DGTJ08-2090	2020.07.01	For evaluation

With the development of building design technologies in China, more ZEBs have emerged, such as Nanjing Green Lighthouse and the 0+ house in Tianjin. ZEB design strategies in China include three steps. First, adopting passive design strategies to reduce the energy demand of the building. Passive building design strategies refer to approaches that maximize the use of free energy from the surrounding environment to reduce energy demand for space heating or cooling [12, 13]. Major approaches include buildings' orientation and location, high-performance building envelopes, natural ventilation and daylighting [14, 15]. The second step is improving the efficiency of the building energy system through active measures. Active measures refer to using energy efficient technologies to reduce the energy consumption of heating, ventilation and air conditioning (HVAC), lighting, and domestic hot water (DHW). Typical measures include high-efficient lighting, lighting dimming controls, combined heating and power and solar water heaters [16-19]. The last step is applying renewable energy as the energy source and achieving "zero energy consumption" in the annual operation cycle [4]. In China, the majority of ZEBs or NZEBs or ULEBs use a solar photovoltaic (PV) system to generate renewable energy.

The development of ZEBs has made some progress over the past decade. Researchers have investigated the feasibility of achieving ZEBs in different climate zones in China using model simulation software eQUEST for energy performance evaluation, the result indicates that it is possible to achieve ZEBs in model simulation when the building is well designed with passive strategies, active strategies and a PV system [20, 21]. But the number of ZEBs in China is minimal. And the majority of existing studies related to ZEBs focus only on theories and model simulations. There is a lack of existing studies that have explored builders' capacities to deliver ZEBs in China. ZEB development in China is still facing a lot of challenges. To provide a clear perspective or guidance for China's ZEB development, the exploration of current builders' capacities to deliver ZEBs in China is needed.

2. Materials and Methods

2.1 Checklist development

Firstly, to investigate current builders' capacities to deliver ZEBs in China, a checklist was developed based on the literature review. To facilitate data analysis, all questions are designed as 'yes' or 'no' questions. Q1 is to explore builders' ZEB production experience, so ZEB builders and conventional builders can be separated and the difference between them can be explored. Q2 to Q8 are designed to understand builders' ZEB related capacities. Moreover, Q9 and Q10 are to investigate whether willingness or responsibility can be a drive for the builder to deliver ZEBs. Then, 50 builders were selected for the checklist assessment, including 10 existing ZEB builders, and 40 conventional builders. Conventional builders were selected from the top 50 of '2020 China Real Estate Companies Comprehensive Strength Ranking' [22]. Top companies are selected because they better represent the capabilities of Chinese builders and their data are more publicly available, which can be easily obtained for analysis. The checklist questions were answered for all the companies using secondary data sources, such as related government databases, the company website and annual reports. And Microsoft Excel was used to generate tables and figures for a simple descriptive evaluation of the capacities of builders.

Table 4. Checklist questions and explanations

No.	Objectives	Questions	Explanations
1	ZEB production experience	Q1. Has the company ever produced zero energy buildings (ZEBs) in China?	This question is to separate ZEB builders and conventional builders to explore the difference between them.
2	NZEB or ULEB production experience	Q2. Has the company ever produced nearly zero energy buildings (NZEBs) or ultra low energy buildings (ULEBs) in China?	Some builders do not have ZEB production experience, but they have delivered NZEB or ULEB projects, which is an important experience for them to explore ZEBs in the future.
3	Design and construction knowledge	Q3. Can the company produce ZEB projects without the help of other organizations?	Some builders have ZEB production experience, but they sought the help of other organizations during the design process. This question is to explore builders' own design and construction knowledge.
4	Passive design capacity	Q4. Does the company apply passive design strategies to its buildings?	Applying passive design strategies energy is an essential step to achieve ZEBs in China. This question is to explore builders' passive design capacity.
5	Energy efficient building design capacity	Q5. Does the company apply energy efficient measures to most of its buildings in 2020?	Applying energy efficient measures is an essential step to achieve ZEBs in China. This question is to explore the builder's energy efficient building design capacity.
6	Renewable energy generation awareness and implementation capacity	Q6. Does the company install a solar photovoltaic (PV) system in its buildings?	Solar energy resources are abundant in 2/3 of the area in China. Solar energy is mainly used as renewable energy resource to achieve ZEBs in China. This question is to explore builders' renewable energy generation awareness and implementation capacity.

7	Construction innovation	Q7. Does the company deliver modular buildings?	Delivering modular buildings is an important construction innovation for builders to reduce the cost of ZEBs. This question is to explore builders' construction innovation capacity.
8	Research capacity	Q8. Does the company attend ZEB related seminars or conferences	Companies that have attended ZEB related seminars or conferences have ZEB research capacity. This question is to explore builders' research capacity.
9	Willingness	Q9. Does the company emphasize ZEBs as a market strategy ?	Companies that emphasize green buildings as a market strategy are willing to deliver ZEBs. This question is to explore builders' willingness to deliver ZEBs.
10	Responsibility	Q10. Is the company committed to building a sustainable future?	Companies who committed to building a sustainable future might feel responsible to deliver ZEBs. This question is to explore builders' responsibilities to deliver ZEBs.

2.2 Applied machine learning techniques

Two machine learning techniques were applied in this research, including the association rule (Apriori) algorithm and the TwoStep Cluster Analysis.

2.2.1 Association rule (Apriori) algorithm

A rule-based machine learning technique, the association rule (Apriori) algorithm was used to explore the differences in design and construction capacities of conventional and ZEB builders. Associations between different checklist questions were analyzed using the association rule in software SPSS modeler. As a well-recognized data mining approach, the association rule intends to discover interesting associations between variables in large databases [23, 24]. One advantage of the association rule algorithm is that associations and rules can be found between any of the variables, and each of them may have a different conclusion [25]. In this research, the Apriori algorithm, a well-known association rule approach, has been employed to find rules and associations that exist between the checklist questions. It can efficiently search association rules using straightforward and easy to understand computations [26].

An association rule can be defined as X ⇒ Y, where X and Y are subsets of an itemset. X and Y usually refer to the antecedent and the consequent of the rule respectively. The support, confidence and lift are essential perimeters in association rules. The support indicates how frequent a combination of antecedent and consequent of a rule appears together in the database. The confidence shows the strength or the credibility of the association by measuring the share of cases in which the consequent occurs given that the antecedent has occurred [27]. The lift determines the increase in the probability of the occurrence of a rule relative to the probability of the antecedent and consequent being independent [28]. If the lift is 1, it means that the antecedent and the consequent are independent and hence the rule is not useful in predicting future occurrences. But a lift above 1 implies that the antecedent and the consequent are positively correlated, which makes the rule possibly helpful. The larger the lift, the more significant the association rule. The support, confidence and lift can be estimated using the following equations:

$$Support(X \Rightarrow Y) = \frac{Transactions\ containing\ both\ X\ and\ Y}{Total\ number\ of\ transactions} \quad (1)$$

$$\text{Confidence}(\text{X} \Rightarrow \text{Y}) = \frac{\text{Transactions containing both X and Y}}{\text{Transactions containing both X}} \quad (2)$$

$$\text{Lift}(X \Rightarrow Y) = \frac{\text{Transactions containing both X and Y}}{\text{Transactions containing X} \times \text{Transactions containing Y}} \quad (3)$$

In this research, the SPSS modeler was applied to generate the association rules. In the SPSS modeler, the checklist result was imported in Excel format, and then the minimum support and confidence need to be predefined to filter associations. A minimum support value of 0.2 and a minimum confidence value of 0.8 were adopted in this data analysis. Then the association rule satisfied predefined minimum thresholds can be generated by the software.

2.2.2 TwoStep Cluster analysis

To assess the potentials of boosting Chinese builders' capacities for delivering ZEBs in the future, builders were clustered using another machine learning technique, TwoStep Cluster analysis in software IBM SPSS modeler. The TwoStep Cluster analysis is an exploratory tool designed to find natural clusters in a dataset that is otherwise not apparent [29]. Different from traditional hierarchical clustering techniques, the TwoStep Cluster analysis employs a likelihood-based approach to model distances between categorical variables, which is suitable for clustering binary valued data [30]. The minimum number of clusters is set as 5 in this research. By comparing the values of a model selection criterion across different clustering solutions, the optimal number of clusters can be automatically determined. In this research, a discussion is provided by ranking different company categories from the most likely ZEB builders of tomorrow to the least likely ZEB builders in the future.

3. Results

3.1 Current builders' capacities to deliver ZEBs in China

A checklist was employed to investigate current builders' capacities to deliver ZEBs in China. The results of checklist questions for all 50 companies are shown in Table 5 below. Figure 3 illustrates the results of each checklist question. Fifty companies are involved in the analysis, and the majority of them are conventional builders who have no ZEB production experience, accounting for 80%. Generally, ZEB builders perform better than conventional builders under all question contexts. But the result of Q3 shows that only four out of ten ZEB builders have the ability to produce ZEB without the help of others. Most builders do not acquire enough ZEB design and construction knowledge to deliver ZEB projects on their own, and they need the help of other organizations. Besides, 32.5% of conventional builders have produced ULEB or NZEB, which can be an important experience for them to explore ZEBs in the future. The results of Q4, Q5, Q6 and Q8 show that some conventional builders have passive design capacity, energy efficient building design capacity, renewable energy generation awareness and implementation capacity or research capacities, but they have no ZEB production experiences due to some barriers. Moreover, the result of Q7 shows that 60% of ZEB builders and 30% of conventional builders deliver modular buildings, which is considered as an important construction innovation to reduce the cost of ZEBs. Furthermore, the results of Q9 and Q10 show that 82.5% of conventional builders are committed to building a sustainable future, but they do not emphasize ZEBs as a market strategy.

Table 5. Results of checklist questions

No.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
2	Y	Y	N	Y	Y	Y	N	Y	Y	Y
3	Y	N	N	Y	Y	Y	N	Y	Y	Y
4	Y	N	N	Y	Y	Y	N	Y	Y	N
5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
9	Y	Y	N	Y	Y	Y	N	Y	Y	Y
10	Y	N	N	Y	Y	Y	N	Y	N	N
11	N	Y	N	Y	Y	Y	N	Y	N	Y
12	N	Y	N	Y	N	Y	Y	Y	N	Y
13	N	N	N	N	N	N	N	N	N	N
14	N	Y	N	Y	N	Y	N	Y	N	Y
15	N	Y	N	Y	N	Y	Y	N	N	N
16	N	N	N	N	N	N	Y	N	N	Y
17	N	Y	N	Y	Y	Y	N	Y	N	Y
18	N	N	N	N	N	N	Y	N	N	Y
19	N	N	N	N	N	N	N	N	N	N
20	N	N	N	N	N	N	Y	Y	N	Y
21	N	Y	N	Y	Y	Y	Y	Y	N	Y
22	N	N	N	N	N	Y	Y	N	N	N
23	N	N	N	N	N	Y	Y	N	N	N
24	N	N	N	N	N	N	Y	N	N	Y
25	N	N	N	N	N	N	N	N	N	Y
26	N	Y	N	Y	N	Y	Y	Y	N	Y
27	N	Y	N	Y	Y	Y	N	Y	N	Y
28	N	N	N	N	N	N	Y	N	N	Y
29	N	N	N	Y	N	N	N	N	N	Y
30	N	Y	N	Y	N	N	N	N	N	Y
31	N	N	N	N	N	N	N	N	N	Y
32	N	Y	N	Y	N	Y	N	Y	N	Y
33	N	N	N	N	N	N	N	N	N	Y
34	N	N	N	N	N	N	N	N	N	Y
35	N	N	N	N	N	N	N	N	N	Y
36	N	N	N	N	N	N	N	N	N	Y
37	N	Y	N	N	N	Y	N	Y	N	Y
38	N	N	N	N	N	N	N	N	N	Y
39	N	Y	N	Y	Y	Y	N	Y	N	Y
40	N	N	N	N	N	N	N	N	N	N
41	N	N	N	N	N	N	N	N	N	Y
42	N	N	N	N	N	N	N	N	N	N
43	N	N	N	N	N	N	N	N	N	Y
44	N	Y	N	Y	Y	Y	N	Y	N	Y
45	N	N	N	N	N	N	Y	N	N	Y
46	N	N	N	N	N	N	N	N	N	Y
47	N	N	N	N	N	N	N	N	N	Y
48	N	N	N	N	N	N	N	N	N	Y
49	N	N	N	Y	Y	N	N	Y	N	Y
50	N	N	N	N	N	N	N	Y	N	Y

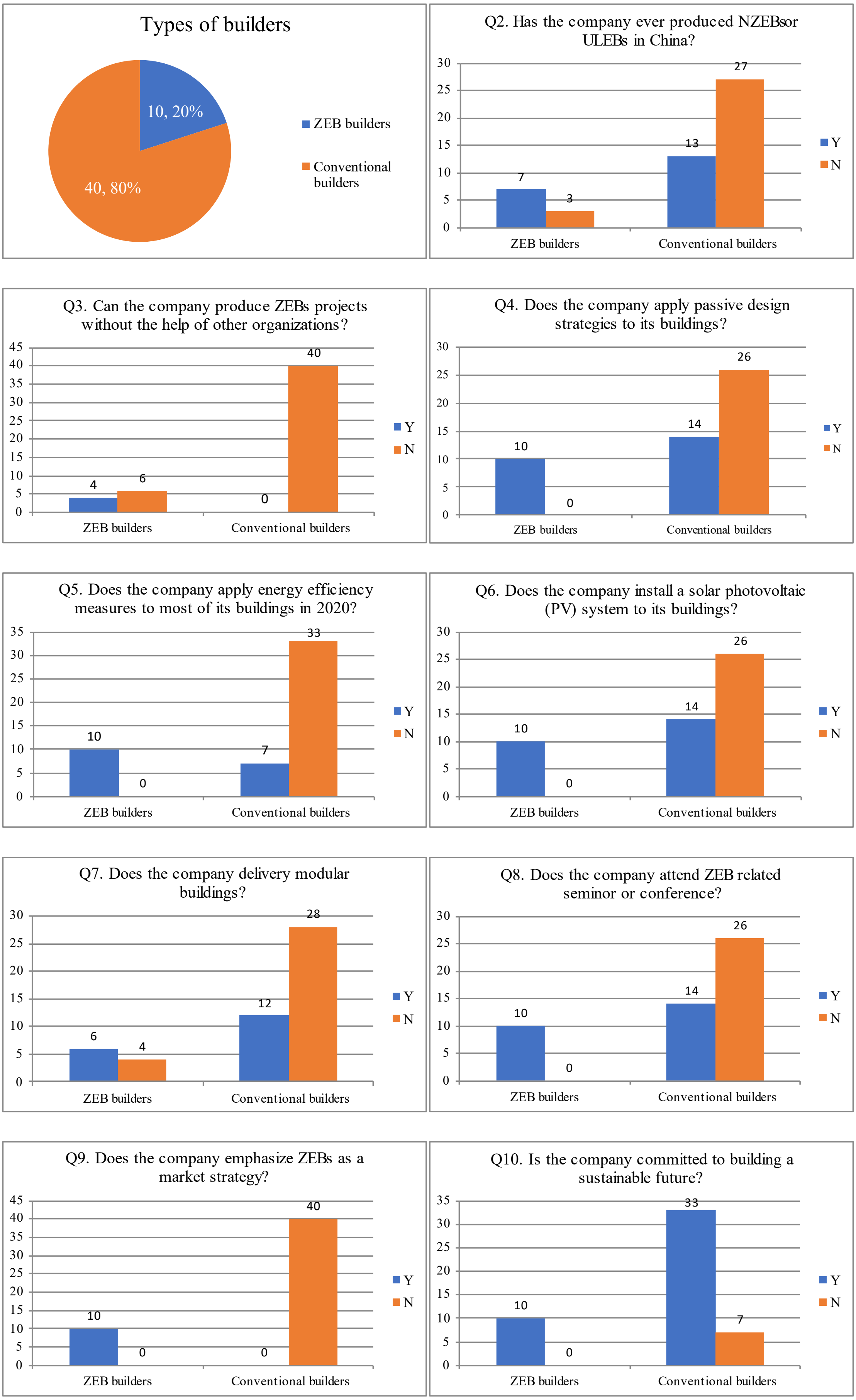

Figure 3. Results of checklist questions

3.2 Differences between conventional builders and ZEB builders

The association rule analysis employing the Apriori algorithm was adopted to explore the differences in design and construction capacities of conventional and ZEB builders. The minimum support and minimum confidence were set as 0.2 and 0.8 respectively in the association rule analysis. Table 6 shows the associations identified with Q1 set as the antecedent. Five association rules that meet minimum criteria were generated. The lift values of all associations are above 1. The results indicate that ZEB builders have passive design capacities, energy efficient building design capacities, renewable energy generation capacities, ZEB research capacities and ZEB production willingness. Table 7 shows association rules generated with Q2 set as the antecedent. The results indicate that builders' NZEB or ULEB production experiences are associated with passive design capacities, research capacities, renewable energy generation awareness and implementation capacities and responsibilities. There is no rule generated with Q3 set as antecedent when the minimum support is set as 0.2. As shown in Table 8, the support and confidence of all associations are 0.08 and 1 respectively when Q3 is set as antecedent. This means that builders' design and construction knowledge is, to some extent, related to all other questions, but not explicitly related to a particular factor. Table 9 shows association rules generated with Q4 set as the antecedent. The results indicate that builders' passive design capacities are associated with their renewable energy generation capacities, research capacities and responsibilities. Table 10 shows association rules generated with Q5 set as the antecedent. The results indicate that builders' energy efficient building design capacities are associated with their passive design capacities, renewable energy generation awareness and implementation capacities, research capacities and responsibilities.

Table 11 shows association rules generated with Q6 set as the antecedent. The results indicate that builders' renewable energy generation awareness and implementation capacities are associated with their passive design capacities and research capacities. Table 12 shows association rules generated with Q7 set as the antecedent. The results indicate that builders' construction innovation capacities are associated with their renewable energy generation awareness and implementation capacities and responsibilities. Table 13 shows association rules generated with Q8 set as the antecedent. The results indicate that builders' research capacities are associated with their passive design capacities, renewable energy generation awareness and implementation capacities and responsibilities. Table 14 shows association rules generated with Q9 set as the antecedent. The results indicate that builders' ZEB production willingness is associated with various factors, including ZEB production experience, passive design capacities, energy efficient building design capacities, renewable energy generation awareness and implementation capacities and responsibilities, research capacities and responsibilities. Table 15 shows that there is no rule generated with Q10 set as antecedent when the minimum confidence is set as 0.8. Three associations are generated when the minimum confidence is set as 0.4, which means that builders' responsibilities are associated with their NZEB or ULEB production experience, passive design capacities and research capacities. Moreover, Q9 and Q10 are designed to investigate whether willingness (Q9) or responsibility (Q10) can be the driving force for the company to deliver ZEBs. The lift value of the association between Q1 and Q10 is below 1, which means that there is no positive correlation between Q1 and Q10. So, the result indicates that ZEB builders produce ZEBs more out of willingness rather than out of responsibility.

Table 6. Associations with Q1 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q5	Q1	20	100	2.94
Q8	Q1	20	100	2.17
Q6	Q1	20	100	2.08
Q4	Q1	20	100	2.08
Q9	Q1	20	90	5

Table 7. Associations with Q2 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q6	Q2	40	95	1.98
Q4	Q2	40	95	1.98
Q10	Q2	40	95	1.16
Q8	Q2	40	90	1.96

Table 8. Associations with Q3 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q9	Q3	8	100	5.56
Q1	Q3	8	100	5
Q7	Q3	8	100	2.94
Q5	Q3	8	100	2.94
Q2	Q3	8	100	2.5
Q8	Q3	8	100	2.17
Q6	Q3	8	100	2.08
Q4	Q3	8	100	2.08
Q10	Q3	8	100	1.22

Table 9. Associations with Q4 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q8	Q4	48	87.5	1.9
Q6	Q4	48	87.5	1.82
Q10	Q4	48	87.5	1.07

Table 10. Associations with Q5 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q8	Q5	34	100	2.17
Q4	Q5	34	100	2.08
Q6	Q5	34	94	1.96
Q10	Q5	34	88	1.08

Table 11. Associations with Q6 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q8	Q6	48	88	1.90
Q4	Q6	48	88	1.82

Table 12. Associations with Q7 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q10	Q7	34	82	1.00
Q6	Q7	34	65	1.35

Table 13. Associations with Q8 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q6	Q8	46	91	1.90
Q4	Q8	46	91	1.90
Q10	Q8	46	91	1.11

Table 14. Associations with Q9 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q1	Q9	18	100	5.00
Q5	Q9	18	100	2.94
Q8	Q9	18	100	2.17
Q6	Q9	18	100	2.08
Q4	Q9	18	100	2.08
Q10	Q9	18	89	1.08

Table 15. Associations with Q10 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q8	Q10	82	51	1.11
Q4	Q10	82	51	1.07
Q2	Q10	82	46	1.16

Table 16. Associations regarding Q9 and Q10

Consequent	Antecedent	Support %	Confidence %	Lift
Q9	Q1	20	90	5
Q10	Q1	20	80	0.98

3.3 Categories of builders in China

To assess the potentials of boosting Chinese builders' capacities to deliver ZEBs in the future, the TwoStep Cluster analysis was employed to cluster builders. Five clusters were generated through the TwoStep Cluster analysis (Figure 4). Figure 5 demonstrates the clusters inputs. Cluster 1 is ZEB builders who have acquired ZEB design and construction capacities. Cluster 2 represents conventional builders who have NZEBs or ULEBs production experience. They have acquired some level of ZEB delivery capacities, such as passive design capacity, energy efficient building design capacity, renewable energy generation capacity, and research capacities, but their ZEB design and construction knowledge is insufficient to deliver ZEB projects. Cluster 3 refers to conventional builders who deliver modular buildings and are committed to building a sustainable future, but they do not acquire any ZEB delivery capacities. Cluster 4 is conventional builders who are committed to building a sustainable future, but they also do not acquire any ZEB delivery capacities. Cluster 4 is the largest cluster among all the clusters, accounting for 32% of builders. Cluster 5 refers to conventional builders delivering modular buildings without any ZEB delivery capacities. Cluster 5 is the smallest cluster, with only 6% of builders in Cluster 5.

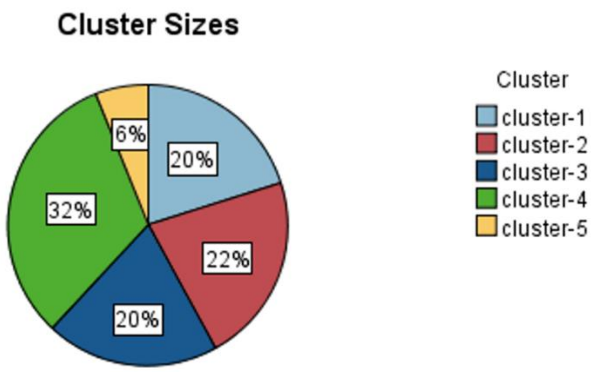

Figure 4. Clusters generated through TwoStep Cluster analysis

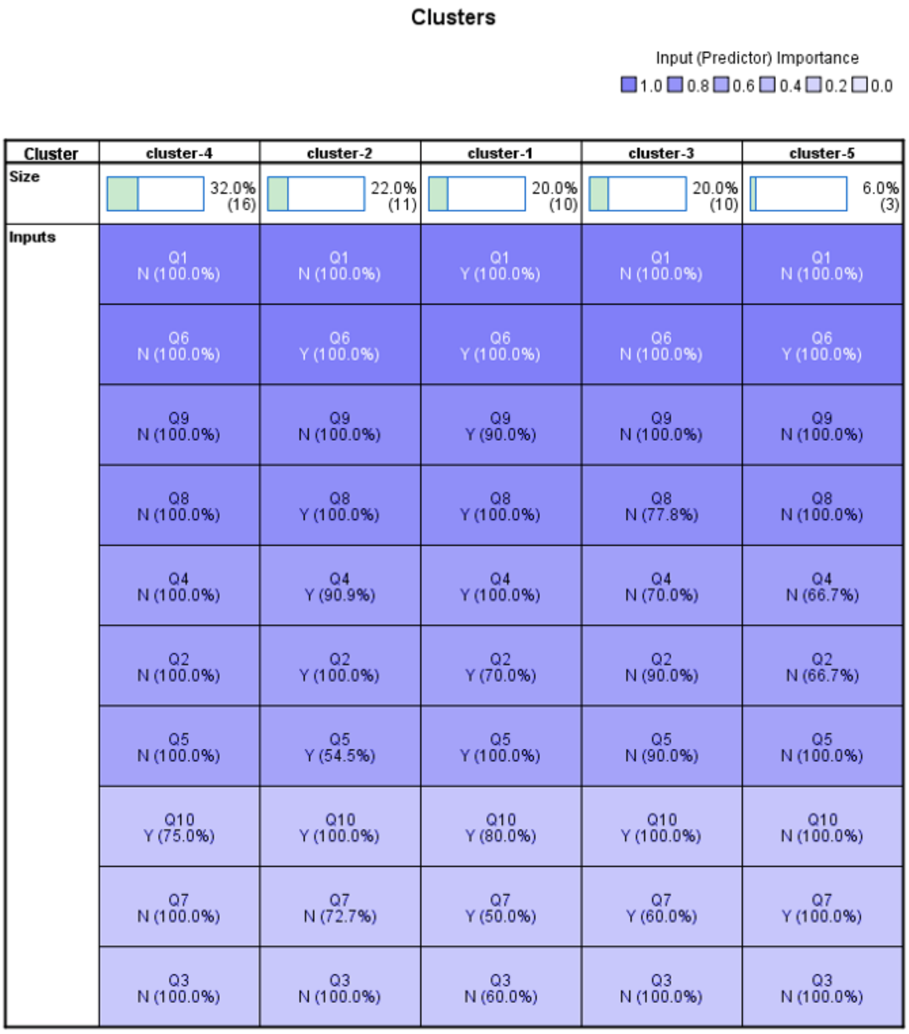

Figure 51. Clusters inputs

4. Discussion

4.1 Current builders' capacities to deliver ZEBs in China

The findings of this research show that only a small number of builders have delivered ZEBs in China. Most ZEB builders only have one ZEB production experience, their knowledge is insufficient for them to produce ZEBs on their own. So ZEB demonstration projects are usually developed in cooperation with foreign professional institutions. Due to the lack of relevant experience and knowledge, the development of ZEBs in China mainly refers to the experience of developed countries [31]. But China has diverse climate zones and unique features in building type and living habits. Completely referring to foreign standards cannot support a large-scale promotion of ZEBs. Therefore, research capacities and technological innovation capabilities are important for Chinese builders. The findings support the arguments of Tang, S. [32], who suggested that enhancing enterprises' independent research capacity and technological innovation capability is critical in the development of ZEBs in China.

The results also show that all ZEB builders and 35% of conventional builders have attended ZEB related seminars or conferences, which can be an important way for them to strengthen their research capacities and technological innovation capabilities. But related research activities seem to be inadequate now. 82.5% of conventional builders are committed to building a sustainable future, but they do not emphasize ZEBs as a market strategy. This might be due to the inadequate education and promotion of ZEBs and immature ZEB related technologies in China. It is reported that most builders and consumers have an inadequate understanding of ZEBs and they are not aware of the values of

ZEBs [31]. Besides, there is a lack of enough policies and standards support for ZEB projects [9]. So, it is recommended that the Chinese government should take actions to strengthen the education and promotion of ZEBs in China, and the builders in China should actively participate in related activities.

Moreover, the findings of this research show that 32.5% of conventional builders have ULEB or NZEB production experience, they have acquired some level of ZEB delivery capacities, such as passive design capacity, energy efficient building design capacity, renewable energy generation awareness and implementation capacity. But they have not delivered ZEBs. The design and construction methods of ULEB and NZEB are similar to that of ZEB, but has lower requirements in energy consumption (MOHURD, 2019). Due to the complex context of China, the ZEB design and construction technologies in China is immature [31]. It is difficult for China to directly move from the current building standard to the ZEB level [9]. But the exploration of ULEB and NZEB can be an important experience for builders to become ZEB suppliers in the future.

4.2 Differences between conventional builders and ZEB builders

The results of the association rule analysis indicate that builders' ZEB production experience is associated with passive design capacities, energy efficient building design capacities, renewable energy generation awareness and implementation capacities, research capacities and ZEB production willingness. Besides, builders' NZEB or ULEB experience is associated with passive design capacities, renewable energy generation awareness and implementation capacities and responsibilities. Compared with ZEB builders, NZEB or ULEB builders lack research capacities and ZEB production willingness. This can also be explained by the lack of ZEB standards and guidelines. China has published NZEB and ULEB standards in some climate zones, but there is no published ZEB standard currently. Immature technology can be one of the main barriers to develop ZEBs in China.

Compared with other conventional builders, ZEB/NZEB/ULEB builders have acquired passive design capacities, renewable energy generation awareness and implementation capacities, and research capacities, which are identified to be the key skills for builders to deliver ZEB projects. Conventional builders should learn from ZEB builders and improve related capacity. Additionally, the financial conditions of a company might impact its capacity to deliver ZEBs. The construction costs of ZEBs are usually much high than conventional buildings [33]. In addition, current ZEB projects are mainly delivered in cooperation with foreign institutions, where additional consulting fees are required. Therefore, ZEB projects are mainly delivered by companies that have sufficient financial strength.

The results also indicate that ZEB production willingness, rather than responsibility is the main driver for builders to deliver ZEBs, which is also a major difference between ZEB builders and conventional builders. So, the government can introduce more policies to provide a supportive environment for builders to deliver ZEBs. Incentive policies and economic measures are important drivers for the development of building energy efficiency [34]. Developed countries, such as United States, Japan, and Germany have introduced a series of incentives to encourage building energy efficiency improvement, including financial subsidies, tax deductions and exemptions, and loan concessions [35-37]. However, most government policies in China are mandatory and there is a lack of incentives and economic measures to encourage the development of ZEBs [4]. The high initial costs and insufficient incentives have led to the loss of competitiveness and market of ZEBs in China [38]. Therefore, more incentive policies and economic measures can be introduced to encourage conventional builders to deliver ZEBs.

4.3 Potentials of boosting builders' capacities to deliver ZEBs

Through the TwoStep Cluster analysis, the builders are divided into five categories. Table 17 shows the summary of the cluster analysis. Cluster 1 is ZEB builders who have acquired ZEB design and construction capacities. Cluster 2 represents conventional builders who have NZEBs or ULEBs production experience. Cluster 2 accounts for 20% of the builders, they are the most likely ZEB builders in the future. Among all the conventional builders, only builders in Cluster 2 acquire related ZEB delivery capacities, such as passive design capacity, energy efficient building design capacity, renewable energy generation awareness and implementation capacity, and research capacities, but their ZEB design and construction knowledge might be insufficient for them to deliver ZEB projects. In addition, compared with ZEB builders, they lack the willingness to build ZEBs and they did not seek the help of other foreign organizations as most ZEB builders do.

The second likely ZEB builders in the future are builders in Cluster 3. They are conventional builders who deliver modular buildings and are committed to building a sustainable future, but they do not acquire any ZEB delivery capacities. Researchers have suggested that adopting modular design strategies can enable large quantities of prefabrication in the factory and assembly on site, which can greatly reduce production costs of ZEBs, and make them more competitive in the market [39]. Compared with other builders, modular building suppliers have construction innovation capabilities, as well as better cost control abilities. Additionally, they are committed to building a sustainable future. They are very promising to become future ZEB builders as long as they are willing to learn relevant ZEB design and construction skills. Strengthening the education and promotion of ZEBs can help turn them into ZEB suppliers in the future.

Cluster 4 has the third-highest possibility of becoming ZEB builders in the future. They are conventional builders who are committed to building a sustainable future, but they do not acquire any ZEB delivery capacities. Cluster 4 contains the largest number of builders, accounting for 32%. Similar to builders in cluster 3, they have an inadequate understanding of ZEBs and are not aware of the values of ZEBs. Education and promotion of ZEBs are important to encourage them to become ZEB builders in the future. Cluster 5 refers to conventional builders who deliver modular buildings. Cluster 5 is the smallest cluster, with only 6% of builders in Cluster 5. They have construction innovation capacities. However, different from builders in other clusters, they are not committed to building a sustainable future. The chance for them to become ZEB builders in the future is the lowest. Education on the importance of sustainable development is a prerequisite for persuading them to build ZEBs.

Table 17. Cluster analysis and ranks

	Rank of possibility of becoming futuer ZEB builders	NZEBs or ULEBs production experience	Sufficient Design and construction knowledge	ZEB related capacities (Passive design, energy efficiency design, renewable energy generation, research capacity)	Construction innovation (Modular building)	Willingness (Emphasize ZEB as a market strategy)	Responsibility (Build a sustainable future)
Cluster 1 (ZEB builders) (20%)		Y	-	Y	Y	Y	Y
Cluster 2 (Conventional builders) (22%)	1	Y	-	Y	-	-	Y
Cluster 3 (Conventional builders) (20%)	2	-	-	-	Y	-	Y
Cluster 4 (Conventional builders) (32%)	3	-	-	-	-	-	Y
Cluster 5 (Conventional builders) (6%)	4	-	-	-	Y	-	-

5. Conclusions

5.1 Main conclusions

The building sector is one of the major energy consumption sectors in China, reducing its CO2 emission is critical to the successful pursuit of the country's carbon neutrality goal. Developing ZEBs is an important measure for China to reduce its carbon emission. Although ZEB has witnessed some progress in the past decade and there are some existing ZEB projects in China, ZEB development in China is still facing a lot of challenges. Currently, there is only a small number of builders who have delivered ZEBs, and most builders, even ZEB builders lack enough ZEB design and construction knowledge to deliver ZEB projects on their own. So, most ZEB demonstration projects are developed in cooperation with foreign professional institutions. China has diverse climate zones and unique national contexts, which means ZEB development in China cannot completely referring to foreign standards. Therefore, enhancing enterprises' independent research capacity and technological innovation capability is critical to generalise the country's ZEB movement.

Most conventional builders in China are committed to building a sustainable future, but they do not emphasize ZEBs as a market strategy. Furthermore, one-third of conventional builders have NZEBs or ULEBs production experience. They are the most likely ZEB builders in the future since the design and construction strategies of ULEB/NZEB are very similar to that of ZEB. They have acquired related ZEB delivery capacities, such as passive design capacity, energy efficient building design capacity, renewable energy generation capacity, and research capacities, but they lack adequate design and construction knowledge to deliver ZEB projects. Compared with ZEB builders, they also lack the willingness to build ZEBs and they did not seek the help of other foreign organizations as most ZEB builders do.

The barriers for conventional builders to deliver ZEBs could be immature domestic technology, inadequate understanding of ZEBs, economical deficiency and lack of incentives. The results also indicate that ZEB builders produce ZEBs more out of willingness rather than out of responsibility. Improving technology and enhancing education and promotion of ZEBs are essential to turn conventional builders into ZEB suppliers in the future. Additionally, the government can introduce more policies to provide a supportive environment for builders to deliver ZEBs. Moreover, conventional builders are less competitive than ZEB builders in passive design capacity, energy efficient building design capacity, renewable energy generation capacity and research capacity, which are identified to be the key skills that conventional builders need to learn.

5.2 Recommendations

In order to facilitate a wide delivery of ZEBs in China, the following recommendations are provided.

1) Conventional builders should learn from ZEB builders and improve their passive design capacities, energy efficient building design capacities, renewable energy generation awareness and implementation capacities, and research capacities.
2) All builders in China should actively participate in ZEB related training and research activities, and improve their independent research capacity and technological innovation capability.
3) The Chinese government should strengthen the education and promotion of ZEBs, as well as education on the importance and benefits of sustainable development.
4) The Chinese government needs to introduce more incentive policies and economic measures to promote the delivery of ZEBs.

5.3 Importance, limitations and further research

This research improves the existing understanding of builders' capacities to deliver ZEBs in China today. Differences in design and construction capacities of conventional and ZEB builders are discussed. The potentials of boosting Chinese builders' capacities for delivering ZEBs in the future are also assessed. In addition, possible solutions have been provided to help transfer current conventional builders into future ZEB suppliers. This research can provide implications for Chinese builders and policymakers to develop the most effective and appropriate approaches to generalise the country's ZEB movement in response to the country's urgent need for CO2 mitigation.

However, it should be noticed that this research has some limitations. One of the limitations is that only secondary data are used for analysis. The local builders or staff were not contacted directly due to the absence of ethics approval as well as COVID-19 disturbance in business operation. Therefore, future research can be conducted based on a combination of secondary data and primary data, which can achieve a higher level of data reliability. Moreover, only top companies are analysed in this research. Further research can build on this research and include small companies for a more in-depth and comprehensive analysis. Additionally, based on the findings of this research, future explorations can focus on how to improve builders' understanding of ZEBs and increase their willingness to deliver ZEBs.

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Evaluating the Factors That Cause Cost and Time Overrun in the Residential Construction Projects in the UAE: Project Manager Perspective

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Abstract: The construction industry is considered an essential element to stabilize countries economically. In the UAE, this sector has received a lot of attention and development since the discovery of oil. This has enhanced the continuous expansion in construction activities. Recently, the construction projects in the UAE and KSA together reached around 70% of the whole projects in the Middle East region, and the majority of it was in Dubai, which in 2018 enhanced its Gross Domestic Product (GDP) to reach 14.5%. Therefore, the decision-makers apply multiple methods at different projects in order to achieve the prime factors for project success which are: cost, time, quality, and safety. However, the construction industry exposed to different variables and unpredictable causes, such as availability of the main resources, different environmental conditions, financial issues, and poor productivity. Meanwhile, there is a great interest in delivering residential construction projects to cover the demand of shelter on time and within the estimated cost limits, and most importantly with the required quality, considering all variables. The aim of this research is to define and rank the factors that contribute to the cost and time overrun on the construction projects. The authors defined the most frequent factors that were affecting the project's cost and time from literature review, then applied the Relative Importance Index (RII) technique on 7-point Likert-scale results that were conducted by the participants. They were thirty construction project managers in the UAE, whose experience range between 5 and 20 years. The most significant factor that contribute to cost overrun is "delay in material delivery." On the other hand, the most significant factors that contribute to time overrun are "the inadequate experience of contractor" and "delay in material delivery" as well.

Keywords: UAE, construction industry, Construction management constraints, mismatching, Contractor, Estimated cost and time, Actual cost and time.

1. Introduction

The construction industry is considered as a major player in the UAE economy, which contributes to achieve wealth and generate employment [1]. This sector services the demand of new facilities, infrastructure and buildings [2]. The UAE accounts for almost 29% of the total construction projects in the GCC , which is the second highest number of projects, after the KSA (43%) [3] as shown in Figure1. As is evident from our current reality, the construction industry is diversified and interrelated with the various sectors of the economy [2]. To summarize, it can be said that and according to The Arab World Competitiveness Report (2007), the UAE is the most competitive economy in the Arab world among the Middle East and particularly the Gulf States countries. That has huge mega-projects announced to reflect a robust and consistent growth.

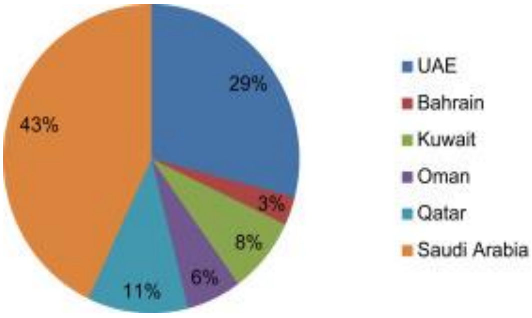

Figure 1: Percentage of construction projects in the GCC [4]

1.1. Causes Factors of Cost and Time Overrun

Construction processes considered complex procedures, there are some factors that contributed to the main problems which related to the project's cost, duration, and quality. Understanding these factors may help the construction stakeholders to mitigate the negative impacts on the construction processes. Some of these factors are common across different countries, however, some are vary based on the culture and practices of the countries [5]. The cause's factors of time and cost overrun in the construction projects attract the attention of scholars worldwide in order to improve the performance of the construction processes. Number of scholars categorized these factors in different groups [5,6]. The author combined the factors from the previous studies based on its relevance into financial group, construction stakeholders' group, construction documents group, and external group, summarized as follow:

Financial factors: this contain sub-categories such as late payment, poor management of cash flow, insufficient financial resource, and financial market instability. So for the late payment the factors that cause cost and time overrun are: client's poor financial and business management and insufficient documentation and information for valuation [7]. Besides that, the delay in progress payment by the owner and delay to supplier and sub-contractors are the main causing factors to delays in the UAE's construction projects thus increasing the cost [8,9]. While for the sub-categories causes of the poor cash flow include: (1) too many projects are handled by the contractor at the same time; (2) instable financial background of the contractor; and (3) lack of regular cash flow forecasting [10]. Moving to the insufficient financial resources, the main issue here is the lack of fund which will affect the project's cash flow [11,12]. The major underlying sub-categories of causing delays and cost overrun factors are difficulties in obtaining loan from financiers and allocation of government budget not in place [10]. End up with the financial market instability which contain inflation of material prices, labor wages and transportation costs, increment of interest rate in repayment of loan and increment of foreign exchange rate for imported materials and plants [10]. There are strong and direct relationships between the financial factors (late payment, poor cash flow management, insufficient financial resources and financial market instability) as Figure 2 illustrates. So, for example, extra commitments can be a result of the instability of the market. Which will lead to shortfalls in the cash flow thus consequently lead to project delay [10].

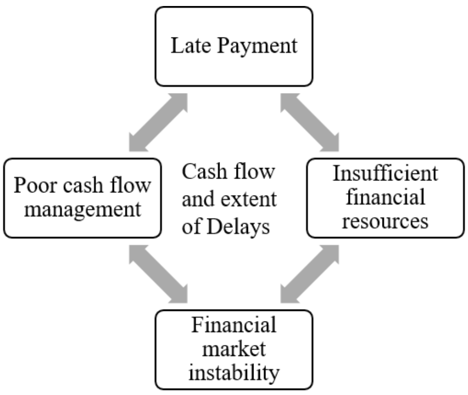

Figure 2: Illustrate the relationships between the financial factors, [10]

Construction stakeholders' factors: each one of these stakeholders may has some actions that could lead to delay and cost overrun during the construction processes. For instance the client may have ambiguous requirement and needs and instability decisions from the clients which may affect the delivery and the cost of the projects [6,13–16]. Also any delays in progressing the payments will lead to delay in delivering the project and thus to increase the cost [6]. While the factors that are related to the consultants (designer/engineers) are the poor documentation and design quality [9,17–21] and the defects to supervise the work and materials that should fulfill the requirements of the drawings and specifications [22]. Factors related to the contractors such as the lack of planning programs and the poorly prepared one and poor site management ranks among the top ten influencing factors causing delays in project delivery and cost growth [23–28].

Construction document factors: the causes factors associated with the contract and bidding documents such omission of certain general condition, typographical errors, spelling errors, arrangement of contract divisions [22]. Moreover, un-enough preparation time for the bidding documents may lead to an increase in the project cost and expansion for the project period as it happened in India due to the mistakes that could be occurring [26].

External factors: which contain two parts which are weather and social and culture consideration. Extreme climate condition either it is too hot or too cold is the most unfavorable for contractors to work with. So, the operations conducted during these climates are characterized by low productivity [17,27,29–31]. While the main causes factor of the social and cultural consideration are the political and institutional all these affect the management style and the speed of processes undertaken [6,22].

1.1.1. Summarization of Investigation Factors from Previous Studies

In order to have a general view about the main factors affecting cost and time of the construction projects, the authors reviewed around 40 different study, and found almost 40 different factors [1,4–7,9–11,13–24,29,31–33,33–58]. However, the authors analyzed the top ten most frequent factors from these previous studies. As shown in Table 1, there are twelve factors, as two additional factors where included because some factors ranked in the top ten frequent factors in the cost overrun but not in the top ten frequent factors in the time overrun, and vice versa. The authors took a further step and group these factors based on it source of cause. First, contractor factors' group includes three factors, which are "contractor's difficulties in project financing," "inadequate experience of contractor," and "poor definition of payment milestone/distribution of cash flow." Second, consultant factors' group includes two factors, which are "consultant's poor management of contractor's schedule" and "delay in conducting inspection and testing." Third, client factors' group includes two factors, which are "client's payment delays" and "conflicts among joint owners of the project." Fourth, external factors' group includes two factors, which are "unforeseen weather conditions" and "hot weather effects on construction activities." Fifth, material factors' group includes one factor, which is "Delay in materials delivery." Sixth, labor and equipment factors' group include one factor, which is "shortage of labor." Last, communication factors' group includes one factor, which is "lack of effective communication among project parties."

Table 1: comparing the top ten frequent factors of the cost and time overrun

Code	Factor	Ranking of Cost overrun	Ranking of Time overrun	References
F01	Contractor's Difficulties in project financing	1	2	[17,23,26,31,32,35,59]
F02	Inadequate experience of contractor	2	5	[2,5,9,10]
F03	Poor management of contractor's schedule	3	3	[1,8,10,14,17,19,25,31]

F04	Client's Payment delays	4	9	[30,32,33,39,42,46,48,53]
F05	Delays in materials delivery	5	1	[23,36,40,41,45,57,58,60,61]
F06	Conflicts among joint owners of the project	6	6	[17,20–22,25,25,26,32,33,48]
F07	Unforeseen weather conditions	7	7	[1,8,9,15,35,42,48,54]
F08	Poor definition of payment milestone/distribution of cash flow	8	14	[18,22,27,37,45–47,55,56]
F09	Lack of effective communication among project parties	9	4	[7,8,10,11]
F10	Hot weather effects on construction activities	10	11	[6,15,17,23,27]
F11	Delay in conducting inspection and testing	13	8	[4,17,46,51,52,58]
F12	Shortage of labor	26	10	[2,5,9,20,36,43]

As shown in Table 1 and Figure 3, the contractor's group has two of the most significant factors in the cost overrun. The "contractor's difficulties in project financing" is the first-ranking position in the cost overrun factors and the second-ranking position in time overrun factors. This indicates how important this factor is, so the contractors should have a good distribution of cash flow to finance the project and avoid falling into the risks. Moreover, the "inadequate experience of the contractor" is the second-ranking position in the cost overrun factors, and the fifth-ranking position in the time overrun factors. This high ranking in the cost overrun factors due to the major responsibilities of the contractors, so any defects on them will lead directly to increase the project's cost.

The "consultant's poor management of the contractor's schedule" is considered one of the factors that have very large effects on time and cost together because it is the third-ranking position in both, which indicates how risky this factor is. It is widely understood that any poor management of any stakeholders means the lack of experience that they have. Which will lead to failing the project in terms of cost and time. Although, "delays in material delivery" factor is the most frequent factor in the time overrun and causes delay in submitting the projects, but it is the fifth-ranking position in the cost overrun. While "conflicts among joint owners of the project", and "unforeseen weather conditions" have the same ranking in cost and time overrun. These have the sixth-ranking and seventh-ranking position respectively as clear shown in Figure 3, and Table 1. Which means they have the same effects on the time and cost of the projects. Another observation is, both factors "delays in conducting inspection and testing" and "shortage of labors" are not included in the top ten ranking of the cost overrun because it is affected on the productivity thus the project duration only. In adjacent to that, both factors "poor definition of payment milestone or distribution of cash flow" and "hot weather effect on construction activities" are not include in the top ten ranking of the time overrun.

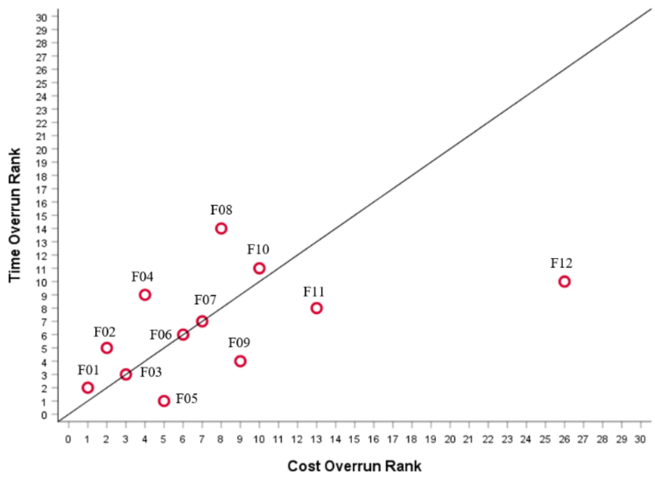

Figure 3: scatter plot showing the relationship between the top ten frequent factors of cost and time overrun

It is worth noting that Faridi and El Sayegh [22] studied the causes factors of time and cost overrun for the UAE's construction projects in general. They found that "poor initial planning", "delays in preparation and drawings", "poor site management and supervision", "delay in decision making from the clients", and "delays in achieving permits from the government" are the most significant factors causing the time and cost overrun. Not only that, there are a number of studies conducted in the UAE to address the factors that affect construction projects progress and performance [8,19,46]. Moreover, literature has shed the light on the importance of construction industry issues and focusing on the projects' time and cost issues. However, there is a dearth of comprehensive studies to determine the most significant causes factors for delays and cost overrun especially in the residential construction projects in the UAE. The reasons behind selecting the residential construction projects are: there is high attention nowadays for the residential projects in order to meet the demand through supply, and because the residential projects in the UAE exposed to cost and time overrun issues [38]. Therefore, this study is intended to fill the gap by the main objective which is summarized as the following; assess the most significant influence factors in terms of cost and time.

2. Materials and Methods

The authors asked the participants to rank the top ten frequent factors from the previous studies based on their experience. The main instrument of this study is the quantitate approach by using Likert-scale survey [65]. The seven point Likert-scale was selected, because it provides more varieties of options and alterative thus will achieve the reliability of the response from interviewees [65]. There were thirty project and executive managers included in the study. They are working in different company role such as client, contractor, and consultant companies. The data were analyzed by using the Relative Importance Index in order to determine the relative importance of the various causes factors of delays and cost overrun. The Seven-point scale ranged from '1': strongly disagree; '2': disagree; '3': somewhat disagree; '4': neither agree nor disagree; '5': somewhat agree; '6': agree; '7': strongly agree. The following formula was used to calculate the RII:

$$RII = \Sigma(w*x) / (A*N)$$

Where 'w' is referring to the weight that assigned by participants in this study (i.e. in this case between 1 and 7). Where 'x' is referring to the frequency of each weightage, 'A' is referring to the highest weight (i.e. 7 in this case), and 'N' is referring to the total number of participants. The RII values should be between 0 and 1, where higher value of RII means, that factor is more importance among the other factors. This analysis will be applied twice, the first time to determine the importance of factors associated with cost overrun, and the second time to assess the importance of the factors that associated with the time overrun.

3. Results

3.1 RII for Cost Overrun Factors

According to the value of the RII, the factors were ranked, where the higher RII value indicates the strong effect of this factor and vice versa. For the cost overrun factors, the highest value of RII is 0.909 for the "delay in materials delivery" factor and took the first-ranked. Therefore, it is the most significant factor that leads to an increase in the cost in the residential construction projects as Table 2 and Figure 4 show. Following with the "lack of experience of the contractor" factor and the RII value for this factor is 0.961 and has the second-ranked, so it is influence on the cost of the projects is less than the "delay in materials delivery."

The RII values of the "poor definition of payment milestone/distribution of cash flow" and "conflicts among joint owners of the projects" are similar and they have the third-ranked position and their RII value is 0.885. The similar value of RII means that these factors have the same influence on the cost overrun phenomena. The fourth-ranked position is for the "lack of effective communication among project parties" with RII value equal to 0.857. Following with the fifth-ranked position for the "client's delay payment" with RII value equal to 0.852. Followed by "client's payment delay", "contractor's difficulties in project financing", "poor management of contractor's schedule", and "unforeseen weather condition". They are sixth-ranked, seventh-ranked, eighth-ranked, and ninth-ranked position respectively. End-up with the last-rank position for the "hot weather" factor with RII value equal to 0.661 which is the lowest influence factor on the cost overrun in the residential construction projects, as shown in Table 2 and Figure 4.

3.2 RII for Time Overrun Factors

For the factors that are associated with the time overrun, the RII values and thus the rankings are different than the factors of the cost overrun. The highest RII value is 0.971 for the "inadequate experience of the contractor" and it is the first-ranked factor, as shown in Table 4 and Figure 6. Therefore, it is considered as the most significant factor that affected the time in the residential construction projects. Meanwhile, the "delays in materials delivery" factor has the same value of the "inadequate experience of contractor" factor and has the same ranking. This indicate that they have the same significant influence on the project's delay. Following with the "client's delay payment" that has the third-ranked position with RII value equal to 0.957; "shortage of labor" that has the fourth-ranked position with RII value equal to 0.952; and "consultant's delay in conducting inspections and testing" that has the fifth-ranked position with RII value equal to 0.938. Followed by "contractor's difficulties in project financing", "Lack of effective communication among project parties", and "Poor management of contractor's schedule" and end-up with "Unforeseen weather conditions" with the RII values equal to 0.923, 0.904, 0.857, and 0.819 respectively, as Table 2 and Figure 4 show.

3.3 Comparison of Cost and Time Overrun RII values

To compare the ranking of the cost and time overrun factors based on the RII value of each factor, it is observed that there are some similarities such as "delays in materials delivery" which has the first-ranked in both classifications, which indicate that this factor is the most affected one among the other factors of cost and time overrun in the residential construction projects in the UAE. Turning to the "inadequate experience of the contractor" which is the second most affected factor because it took the second-ranked in cost overrun and the first-ranked in the time overrun, so it will affect the project's duration more than the cost of the residential construction projects in the UAE. This is due to the damages and repetitions of some activities which required more time to accomplish the activities. The "poor definition of payment milestone or distribution of cash flow" is indicates as third-ranking in the cost overrun and indicates as "None" in the time overrun, as it was not included in the top ten frequent factors that are related to the time overrun. Because of that, the decision makers in the UAE should take actions that could eliminate the impacts of this factor in the project's cost. Furthermore, the "hot weather" factor has the lowest effects on the project's cost, also it is not one of the top ten affected factors on the project's time as Table 2 illustrates. Therefore, the planning engineers estimate the impacts of this factor and they take it into account from the beginning stages of the construction processes.

Table 2: The RII value and the ranking of each factors of cost and time overrun

Code	Factor	Cost overrun		Time overrun	
		RII value	**Ranking**	**RII value**	**Ranking**
F01	Delays in materials delivery	0.909	1	0.971	1
F02	Inadequate experience of contractor	0.961	2	0.971	1
F03	Poor definition of payment milestone/distribution of cash flow	0.885	3	None	None
F04	Conflicts among joint owners of the project	0.885	3	0.928	6
F05	Lack of effective communication among project parties	0.857	5	0.904	8
F06	Client's delay payment	0.852	6	0.957	3
F07	Contractor's Difficulties in project financing	0.842	7	0.923	7
F08	Poor management of contractor's schedule	0.819	8	0.857	9
F09	Unforeseen weather conditions	0.671	9	0.819	10
F10	Hot weather effects on construction activities	0.661	10	None	None
F11	Shortage of Labor	None	None	0.952	4
F12	Consultant's delay in conducting inspection and testing	None	None	0.938	5

Figure 4 presents and compare only the eight common factors between the cost and time. The factors that are not in the top ten factors of either cost or time overrun are excluded from Figure 4. These factors are "shortage of labor", "consultant's delay in conducting inspection and testing", "hot weather that effects on construction activities", and "poor definition of payment milestone/distribution of cash flow".

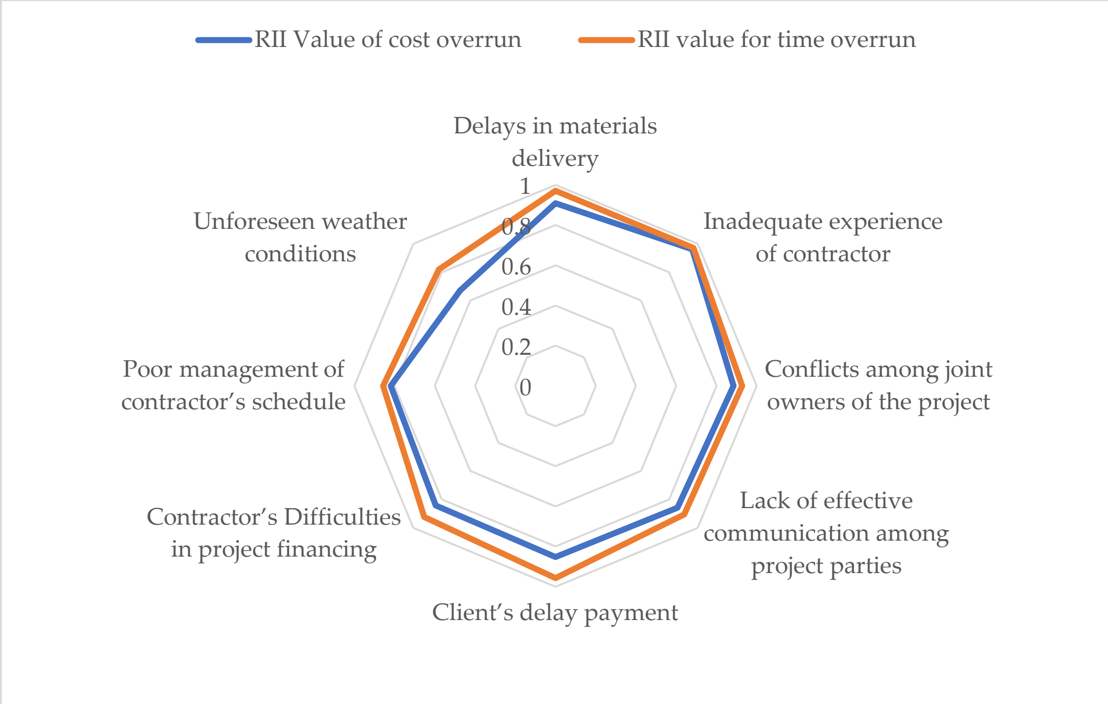

Figure 4: compare the ranking of the cost and time overrun factors based on the RII value

4. Discussion

4.1 Comparison between the RII value and previous studies for cost overrun factors

This technique revealed some similarities and differences with the findings from the literature review. The following Table 3 presents two classifications for each factor. The first ranking is based on the RII values, whilst, the second ranking is based on the frequency of each factor in the forty selected studies. The similarity between these two classifications is the ranking of the "inadequate experience of contractor" factor. This factor has second-ranked position in both classifications, which indicating how important it is in the UAE and other countries. Due to the main responsibilities of the contractor which all need enough experience to deal with different situations and managing the construction sites. Another similarity between the two classifications is the "hot weather" effects on the cost of the project, as this factor ranked last in both classifications. Which means there is a slight impact on the project cost.

The differences between these two rankings are for the remaining factors. For example, in the RII ranking, the "delays in material delivery" are the first-ranking position while in the previous studies it is the fifth-ranking position. So this factor is based on the context, and here in the UAE, the municipalities required high-quality specifications of the materials. So, the higher the quality, the higher the cost. This indicates the extent of the importance of this factor in the UAE, which is supposed to take immediate decisions to mitigate its impacts on the cost of the project. Another differences between these two ranking is clear on the "contractor's difficulties in project financing" factor. Based on the RII ranking this factor is sixth-ranking position, while for the previous studies this factor is the first-ranking position. So this factor does not have a strong impact on the cost of the project in the UAE unlike other countries, due to the ability of the clients to finance their projects.

Table 3: Comparison between the ranking of cost overrun factors based on the RII values and Based on the previous studies

Code	Factor	Cost overrun		Time Overrun	
		Ranking based on RII value	Ranking based on previous studies	Ranking based on RII value	Ranking based on previous studies
F01	Delays in materials delivery	1	5	5	5
F02	Inadequate experience of contractor	2	2	2	1
F03	Poor definition of payment milestone/distribution of cash flow	3	8	8	9
F04	Conflicts among joint owners of the project	3	6	6	10
F05	Lack of effective communication among project parties	5	9	9	8
F06	Client's delay payment	6	4	4	6
F07	Contractor's Difficulties in project financing	7	1	1	2
F08	Poor management of contractor's schedule	8	3	3	4
F09	Unforeseen weather conditions	9	7	7	3
F10	Hot weather effects on construction activities	10	10	10	7

4.2 Comparison between the RII value and previous studies for time overrun factors

For the time overrun factors, there are also some similarities and differences between the two classifications. There are two similarities between them, which are for the rate of the "delays in materials delivery" factor which has the first-ranking position in both as Table 3 presents. Therefore, it is clear that this factor has the most significant impact on the time overrun issue in the UAE and other countries. Sometimes, delivering the materials to the construction site by importing them from the other regions required more time. Therefore, the contractor should order them at a proper time in order to deliver them without any delays and clients should confirm their decision on material selection fast. The second similarity is the ranking of the "conflicts among joint owners of the project" and it is the sixth-ranking position in both classifications.

The "inadequate experience of contractor" factor may have a significant impact on the project's time in the UAE as it has a first-ranking and fifth-ranking position in the other studies. This is because the good experience of the contractor that avoid any repetitions for the construction activities thus no need for the time extensions. Therefore, the client should take their time to select a good contractor from the beginning. The second important factor for the time overrun is the "client's payment delay" factor which has the second-ranking position in the UAE. By logic, any payment delays will affect all the sequence activities in the construction processes such as ordering the materials, the availability of the labor and equipment, and so on. Table 3 shows also that the "shortage of labor" factor is very critical for the project's duration as it has the third-ranking position in the UAE. Because they are increasing the productivity of the construction processes which then reduces the project's time. The "unforeseen or unpredictable weather" factor has the lowest impact on the project's duration as it has the last-ranking position in the UAE. This is because the client's head office estimates the project's duration with considering this factor. "Contractor's difficulties in project financing" is seventh-ranking position in the UAE, while it is the second-ranking position in the other countries. Therefore, the impacts of this factor in the UAE is less than on the other countries. As well as the "poor management of the contractor's schedule" factor which is the ninth-ranking position in the UAE and in the other countries it is second-ranking position, so it has high impacts on them.

5. Conclusions

This study was conducted to knock the door of sustainability from the economic aspect and add more knowledge in the literature related to building construction management in the UAE. Specifically, the mismatch of the estimated cost with the actual cost since the beginning of the construction era to the present time, as well as the project's duration. This leads to cause issues against construction expansion and sustainability (economic aspect). Therefore, this study has been conducted to cover the evaluation of the top ten factors of the cost and time overrun from the literature review, to determine their influence on the cost and time issues in the residential construction projects in the UAE. The ranking of the factors in this study is based on the RII values while the factors of the literature review were depending on how often it was repeated in the forty selected studies. There are differences between the results, and this due to conducting different studies in different countries, which have different regulations and practices. Also, the effect of the COVID-19 has an influence on a number of mentioned factors. The authors asked thirty project and executive managers to rank these factors using the Likert-scale method. Then, a calculation was conducted by using Microsoft Excel for Office 365 based on the RII formula. Based on the RII values, following are the factors that increase the cost from high to low: "delays in materials delivery", "the inadequate experience of contractor", "poor definition of milestone or poor distribution of cash flow", "conflict among joint owners", lack of effective communication among project parties", "client's delay payment", "contractor's difficulties in project financing", "poor management of contractor' schedule", "unforeseen weather conditions", and "hot weather that affected the construction activities" respectively. Whilst, following are the factors that increase the project's duration from high to low: the "inadequate experience of contractor", "delays in materials delivery", "client's delay payment", "shortage of labor", "consultant's delay in conducting inspection and testing", "conflict among joint owners", "contractor's difficulties in project financing", "lack of effective communication among project parties", "poor management of contractor' schedule", and "unforeseen weather conditions" respectively.

This study contributes to enhancing more knowledge about economic sustainability and adding more information about building construction management constraints in the UAE. Also, it will contribute to expand the construction projects and increase the benefits for the construction stakeholders. Actually, the method of this study can be applied in different countries and in different industries other than the construction industry. In addition to that, it can be applied with different sample sizes, in different time periods. This research has opened the door for several future studies in order to explore some solutions that could eliminate the causes factors and their impact on the cost and time overrun in the construction residential projects. That's may increase the expansion of the construction industry and productivity to serve the stakeholders. In addition, it helps the industry leaders to suggest a system that assesses the efficiency of the project in terms of project duration and from the financial point of view based on the project data. Which may help to determine the possibility of the project to accomplish on the specified time and cost or not.

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Pavement Crack Detection by Convolutional AdaBoost Architecture

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Abstract: In pavement structures, the occurrence and propagation of cracks are critical elements that affect road performance, health, and pose a potential threat to the safety of vehicles. The pavement condition information usually collected by manual inspection is laborious, time-consuming, inspector dependent, and easily vulnerable to the perspicacity of the inspector. Therefore, this paper aims to present a computer vision-based crack detection system for pavement structures. In the proposed work, a Convolutional Neural Network (CNN) is used for feature extraction and an Ada-Boost classifier is used for classification. The combined architecture is named the Convolutional AdaBoost architecture. A comparative study was conducted and the performance of various classifiers, such as Random Forest (RF), Logistic Regression (LR), Multi-Layer Perceptron (MLP), Support Vector Machine (SVM), Decision Tree (DT), Ada-Boost, and Softmax, was evaluated using different evaluation metrics. The dataset was created based on various pavement structures in the United Arab Emirates and consists of 5600 crack and non-crack images. From the experimental results, it is concluded that the combined CNN features and Ada-Boost classifier yield the best performance with an accuracy of 98%. The performance of other classifiers with CNN features is also comparable with each other. Overall, the integrated Convolutional AdaBoost improves pavement crack detection performance and is more accurate than using CNN alone.

Keywords: Crack Detection; Computer Vision; Automatic inspection; Convolutional Neural Networks; sliding window.

1. Introduction

On roads, the occurrence and propagation of cracks are critical elements that affect road performance, health, and pose a potential threat to the safety of vehicles. By the end of 2019, 93 countries have their highways, the length of which is about 532576.5 km, which China has crossed some 142000 km. In the next few decades, the issue of road inspection and maintenance will become more prominent due to the increase in traffic load and environmental effects. It is a great challenge for the public road authorities to maintain an acceptable service standard for the entire road system and find effective maintenance. The pavement condition information can be gathered manually, i.e. by visually inspecting and assessing the road by subjective human experts, or automatically. Manual inspection techniques are laborious, costly, inspector dependent, and prone to human error. In addition to these, according to research [1] conducted by the Federal Highway Administration (FHWA), numerous factors affect the accuracy and reliability of manual inspection results.

Studies performed by [2] have shown the inadequacies of visual inspection, such as inherent variability and absence of consistency in results. Inadequate inspection and condition assessment can lead to a variety of accidents, such as the Minneapolis Interstate 35W Bridge Collapse in which 13 people died and 145 were injured [31]. Another example is the incident of a freight train in the Rebunhama Tunnel in Japan on November 28, 1999, which occurred as shear cracks in the structure were not detected properly [3]. To overcome all the problems associated with manual assessment, automatic inspection techniques provide an efficient solution that decreases subjectivity and can be used as an alternative to the human eye.

In the past decade, the latest developments in the computer science field have made it possible to make and utilize computer vision approaches for various pavement engineering applications [4][5]. Also, infrastructure and road maintenance authorities are becoming more involved in using automatic image-based pavement assessment systems. These systems use image processing and machine vision models to make the process simpler, cost-efficient, and automated [6-8]. The rate of designing and utilizing computer vision-based civil infrastructure inspection and monitoring systems has dramatically increased [4].

Developing an efficient vision-based automated pavement crack detection system has always been a challenging problem in the research environment and has attracted research interest recently. Crack detection in pavement images is relatively difficult compared to other civil infrastructure images because of the low contrast between the pavement surface and the crack, irregular size and random shape of the crack, intensity variation in the image, multi-texture, and shadowing in the images [9]. Researchers have done extensive research on the crack detection problem and proposed many image processing, local information-based, and machine learning (Traditional and deep learning) techniques that are widely used today. Image processing methods for crack detection include edge detection [10], thresholding and segmentation [11], region growing [12] and peculation-based techniques [13]. Local information-based models use various filters, such as morphological filters, statistical filters [14-16], median filters, and multi-scale line filters with the Hessian matrix [17] and so on.

The evolution of machine learning has resulted in pavement crack detection reaching an inevitable peak of advancement. Machine learning approaches can learn deep features and can be categorized into supervised learning or unsupervised learning. The major difference between the two approaches is that unsupervised learning does not require the labeling of data. Supervised learning is sub-categorized into traditional approaches and deep learning. Traditional machine learning approaches for pavement crack detection consist of two steps: feature extraction and classification. As shown in our previous work [30], various features are extracted from images and given to classifiers to determine the class of extracted features. However, if the extracted features do not represent the actual cracks, the classifier may not give accurate results.

The capability and robustness of traditional approaches have been greatly extended by deep learning techniques. These models are different from traditional machine learning approaches in that they can learn the representations of the data without introducing any hand-crafted rules or knowledge and have shown great performance in solving pavement crack detection problems [18-21]. Zhang et al. [19] and Ali et al. [32] proposed a customized CNN architecture for crack detection in the pavement structure. Wang et al. [33] proposed a CNN architecture having three convolutional and two fully connected layers for asphalt pavement crack recognition. Leo et al. [20] studied the effect of network depth on the accuracy of the CNN model. The accuracy of CNN architecture can be improved by using an integrated CNN architecture, which is evident from various previous works [23-29]. Chen et al. [23] proposed a video-based crack detection system for metallic surfaces. The system was based on the integration of CNN and Naive Bayes data fusion systems and can detect defects more accurately and rapidly using a lightweight network method. Kang et al. [28] proposed a novel and accurate CNN-SVM-based leakage detection system for water distribution systems. In [24], the authors combine CNN features with genetic programming for the image classification task. Niu & Suen et al. [25] proposed a CNN-SVM algorithm for handwriting recognition in which CNN features were used with an SVM classifier.

This research proposed an image-based automatic pavement crack detection algorithm using the convolutional Ada-Boost architecture. In the proposed architecture, features are extracted using CNN while the Ad-Boost classifier is used for the classification of crack and non-crack. The performance of the proposed architecture is also compared with CNN, CNN-SVM, CNN-RF, CNN-LR, CNN-MLP, CNN-SVM, and CNN-DT architectures. This research aims to create an automatic pavement crack detection system that can be used to inspect cracks in road structures. The contribution of the paper is the integration of CNN architecture with the Ada-Boost classifier to improve CNN performance. Additionally, the performance of the proposed architecture is compared with different ensembled CNN architectures. Finally, the proposed image-based crack detection system can be used as an effective tool for the long-term monitoring of infrastructure.

The rest of the paper is organized as follows: Section 2 represents the system overview. Experiments and results are explained in this section followed by the discussion in Section 4. Finally, in Section 5, the conclusion of the proposed work is presented.

2. System Overview

The overview of the proposed system is shown in Figure 1. The proposed system consists of three main modules.

(1) Database Creation.
(2) CNN-based Feature Extraction
(3) Classification.

The output of the system is the decision of whether a patch belongs to a crack class or a non-crack class.

2.1. Dataset Creation

In the proposed work, images with pixel resolutions of 4032×3024 are taken using a Samsung Note 8 smartphone from various roads in the United Arab Emirates. The collected images are converted into small patches of dimension 224×224. The acquired 5200 images were manually labeled by assigning Label 1 to crack patches and 0 to non-crack patches. In the crack patches, the crack region is visible as shown in Figure 2. The distribution of crack and non-crack patches in the dataset is equal. The data split ratio of 6:2:2 is taken, which shows that 60% of training data is used for training, 20% of data is used for validation and 20% is used for testing of the proposed system.

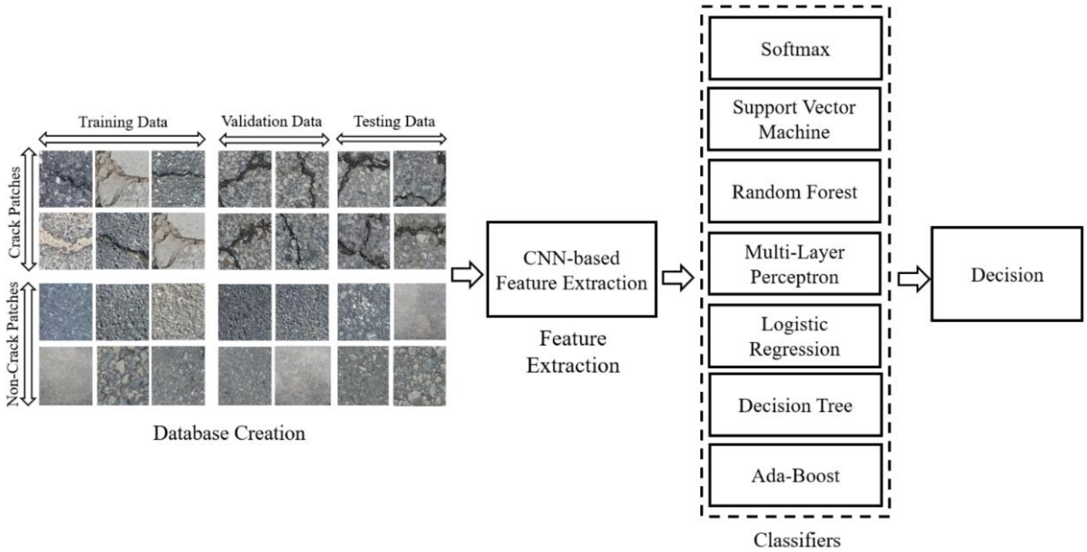

Figure 1. Overview of the proposed system

2.2. Feature Extraction using CNN

The CNN is a well-known deep learning architecture that has shown prevalent performance in the field of computer vision. CNN architecture comprises a feature extractor and a classifier. The features

Figure 2. Samples of cracked and non-cracked patches.

extractor consists of many layers which take the images as an input in the form of 2D arrays and extract relevant features from them. The main aim of using CNN as a feature extractor is that it automatically learns the useful features from the input data. The architecture of CNN used as a feature extractor is the proposed work. The architecture of CNN is modified by replacing the softmax classifiers with SVM, RF, LR, DT, MLP, and Ada-Boost classifiers.

2.2.1. Convolutional Neural Network Architecture

In the proposed work, the Keras sequential model of CNN is used for feature extraction. The architecture consists of three main layers.

- Convolutional Layer.
- Activation Layer.
- Max-Polling Layer.

The input image passes through various convolution and max-pooling layers to reduce its special size and the final feature vector is obtained at the fully connected layer.

2.2.1.1 Convolutional Layer

The main function of a convolutional layer is the learning of feature representation of the given inputs. The Convolutional Layer determines a local feature connection from the previous layer as shown in Equation 1.

$$Obtained\ features\ map = \sum(Input_{S\times S}.K_{S\times S}) + F\_bias \quad (1)$$

In the above equation, $Input_{S\times S}$ represents the local receptive field, $K_{S\times S}$ represents the filter weights, where S represent the window size of the kernel. The term F_bias represents the filter bias. In the convolution operation, element-wise multiplication of kernel $K_{S\times S}$ and input tensor $Input_{S\times S}$ takes place and the values are summed up to obtain the output value (feature maps) at the corresponding position of the output tensor.

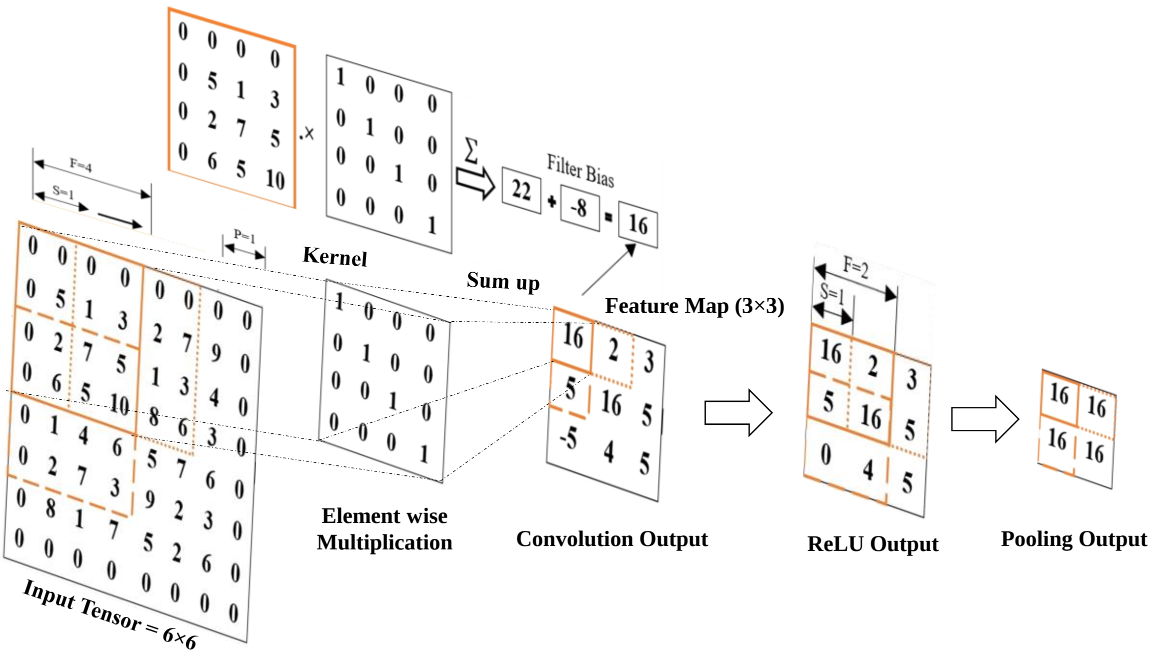

Figure 3. Representation of Convolutional, Activation, and Max-Pooling operations.

2.2.1.2 Activation Layer

The output of the convolutional layer is passed through the activation layer. The main purpose of activation layer ReLU (Rectified Linear Units) is to introduce non-linearity to the system (decision function and of the overall network) without affecting the receptive fields of the convolution layer, as shown in Figure 3. ReLU provides faster computation in comparison to other non-linear functions such as sigmoid, hyperbolic tangent, etc. The operation of the activation layer is depicted in Equation 2 below.

$$\sigma(v\_element) = \max(0, v\_element) \quad (2)$$

where $v\_element$ represents the elements of the input vectors.

2.2.1.3 Max-Pooling Layer

Max-Pooling performs a down sampling operation on the output of the activation layer, which helps in reducing the size of the feature vector and computational time. In the max-pooling operation, the image is divided into small non-overlapping blocks and the maximum value of each block is calculated as shown in Figure 3.

2.2.1.3 Fully Connected Layer

The feature maps obtained from convolutional and max-pooling layers are flattened and given to fully connected layers. The main task of a fully connected layer is logical inference. In the proposed work, the output of this layer is given as an input to other classifiers. The calculation of the output of the fully connected layer is described in Equation (3).

$$Final\_Vector_{i\times 1} = Weight_{i\times o}.Input_{o\times 1}.Bias_{i\times 1} \quad (3)$$

In the above equation, $Final\_Vector$ is the output of the fully connected layer, $Weight$ and $Bias$ are the weight and bias matrix, while i and o represent the size of the input and output vector.

2.3. Classifiers

In the proposed work, the features extracted from CNN are given to Ada-Boost and various other classifiers. Each classifier is discussed in detail below.

2.3.1. Ada-Boost Classifier

Ada-Boost is an iterative ensemble boosting classifier which combines various classifiers to enhance the accuracy of less accurate classifiers. In the Ada-Boost classifier, randomly a training subset is selected, and the model is trained iteratively. Based on the accurate prediction of the previous training, a new training subset data is selected. During the process, weights are assigned to both observation and classifiers. The observations wrongly classified are assigned higher weights so that these observations get a high probability of classification in the next iteration. The iteration continues until the complete training samples fit without any errors and the maximum number of estimators is reached. Once the process is completed, the new test sample is classified based on voting across all the learning algorithms.

2.3.2. Softmax classifier

The final layer in the CNN architecture is the softmax layer, which is used to calculate normalized class probabilities $P(y^{(i)} = n^{(i)}|x^{(i)}; W)$ for each class $n^{(i)}$ in n classes using Equation 4

$$P(y^{(i)} = n^{(i)}|x^{(i)}; W) = \begin{bmatrix} y^{(i)} = 1|x^{(i)}; W \\ y^{(i)} = 2|x^{(i)}; W \\ \vdots \\ y^{(i)} = n|x^{(i)}; W \end{bmatrix} = \frac{1}{\sum_{j=1}^{n} e^{W_j^T x^{(i)}}} \begin{bmatrix} e^{W_1^T x^{(i)}} \\ e^{W_2^T x^{(i)}} \\ \vdots \\ e^{W_n^T x^{(i)}} \end{bmatrix} \quad (4)$$

Here, m is the total number of data samples, where $i = 1\ldots m$. W represents the weights, and the input to the classifier is denoted $e^{W_n^T x^{(i)}}$. Equation (4) takes a vector with arbitrary real-valued scores as input and outputs a vector with values between 0 and 1.

2.3.3. Random Forest Classifier

Random Forest is a supervised machine learning classifier, which is a combination of multiple decision trees. Each decision tree produces a prediction of the sample, which is achieved by classifying a sample x recursively branching left or right until the last node of the decision tree is reached. The predictions from these multiple decision trees are combined and select the most voted prediction as the result. In the proposed work, the output of the fully connected layer is given as an input to the Random Forest Classifier (RFC). In the RFC, the main aim of using the validation dataset is to optimize various parameters such as Tree Maximum Depth (D), Estimators Numbers (E), and minimum sample split (M). In the proposed work, the parameters of RFC are varied during the training and validation phase to select suitable parameters that can achieve the best results.

2.3.4. Support Vector Machine

The support vector machine is generally used for classification and regression problems. The main attraction of SVM is its ability to handle categorical, multiple, and continuous variables. Additionally, it is also capable of learning in high-dimensional space with a limited amount of training data. In the SVM algorithm, a hyperplane is constructed in multidimensional space to separate the data classes. The hyperplane is constructed in an iterative way to minimize classification errors. Once a maximum marginal hyperplane is selected, it will efficiently divide the data into various classes. In the proposed work, various combinations of C and gamma parameters are applied to the validation data to achieve maximum accuracy.

2.3.5. Logistic Regression Classifier

Logistic regression refers to a classifier that classifies an observation into one of two classes. This algorithm can be used to classify both categorical and numerical variables. Multinomial logistic regression is used when classifying into more than two classes. The model is generally presented in the following format in Eq. 5, where βrefers to the parameters and x represents the explanatory variables.

$$\log(odds) = \beta_0 + \beta_1 * x1 + \cdots + \beta_n * x_n \quad (5)$$

2.3.6. Multilayer perceptron (MLP) Classifier

The multilayer perceptron is one of the classes of feed-forward Artificial Neural networks. The MLP Network consists of 3 layers; input, hidden, and output layer. The layers are fully connected by using a nonlinear activation function feeding forward. Logistic sigmoid or hyperbolic tangent are commonly used as activation functions. In MLP, the backpropagation technique is used. Backpropagation is a supervised learning technique that propagates the errors back through the network, starting at the output units, to adjust the weight of the network.

2.3.7. Decision Tree Classifier

A decision tree is a tree-like structure in which the internal nodes in the tree represent the features (or attributes), the branching in the tree represents the decision rules, and the leaf represents the outcome of the tree. The top node of the tree is known as the root node, which has the largest information gain among all the nodes. In the algorithm, the tree is built in a recursive manner known as recursive partitioning, which is an iterative process that splits the data into partitions and further into branches. The depth of the tree is usually specified to overcome the problem of overfitting. A decision is obtained at the end of the algorithm, which usually covers all the training samples.

3. Experiments and Results

The performance of the proposed convolutional Ada-boost architecture is evaluated and compared with six more CNN integrated architectures, i.e. CNN-SVM, CNN-RF, CNN-DT, CNN-MLP, CNN-LR, and CNN-Softmax. The evaluation of the architecture is performed on performance metrics such as accuracy, precision, recall, and F1 score. All the experiments are conducted using the created dataset, which consists of 5200 crack and non-crack patches having a resolution of 224×224. The implementation was performed using Python programming on an Alienware Arura R8 core i9-9900k CPU @3.60 GHz desktop system with 32 GB RAM and an NVIDIA GeForce RTX 2080 GPU. For the CNN feature extraction, the number of convolutional layers and the parameters and epochs are 5, 2.70 M, and 20, respectively.

In the first phase of experiments, the traditional CNN model (CNN-Softmax) was evaluated. The accuracy and loss graphs of the training and validation and the ROC curve of the CNN model are shown in Figures 4 and 5. From the accuracy and loss graph, it is evident that the accuracy and loss of the CNN model become stable after 20 epochs and there is a slight deviation between the training and validation graphs, which shows that the model is not subjected to overfitting. The training validation and testing accuracy of the CNN-Softmax model were recorded to be 0.972, 0.960, and 0.956, respectively. After evaluating the CNN-Softmax classifier, the features are obtained from the fully connected layer of the model and the Ada-Boost classifier is integrated to evaluate the accuracy of the proposed model. The best accuracy, precision, recall, and F1 score of the convolutional Ada-boost architecture are 0.9820, 0.9807, 0.9845, and 0.9826 respectively, as shown in Table 2. The maximum performance for the architecture is achieved by keeping the number of estimators between 50 and 100. This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

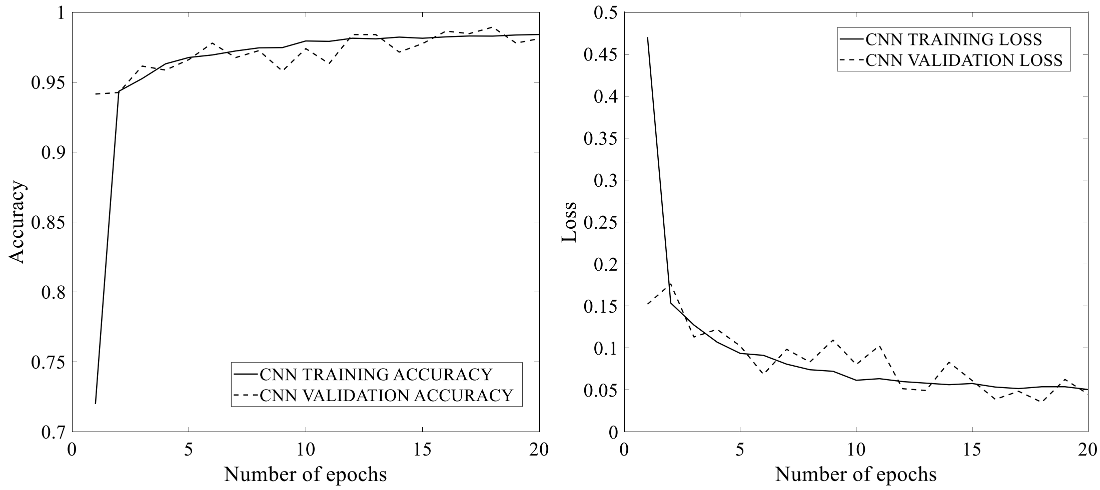

Figure 4. Accuracy and loss graphs of the training and validation CNN model

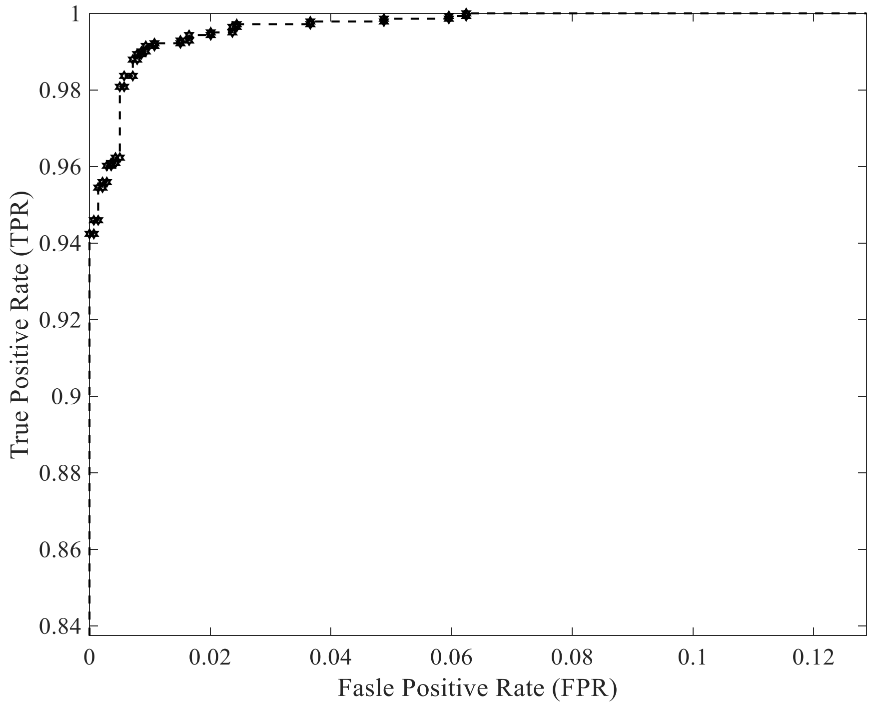

Figure 5. ROC curve (receiver operating characteristic curve) of the CNN model.

To compare the performance of the proposed architecture, the CNN-based features are given to RF, DT, SVM, LR, and MLP models. The best accuracy, precision-recall, and F1 score for CNN-DT are recorded to be 0.9690, 0.9672, 0.9729, and 0.9700, respectively. The decision tree performed well on the CNN by using the parameters $criterion = 'entropy'$, ', $splitter = 'random'$, $max\_depth = None$, $min\_samples\_split = 2$, $min\_samples\_leaf = 1$ as shown in Table 3. As shown in Table 4, the optimal parameters for RF are $n\_estimators = 100$ and $criterion = gini$. The best accuracy, recall, precision, and F1 score for the RF classifier is 0.9740, 0.9730, 0.9768, and 0.9749, respectively. Similarly, for the MLP classifier, the best performance is achieved by keeping the $hidden\_layer\_sizes = 50$, $activation =' relu'$, $solver = 'adam'$and $max\_iterations = 400$ as shown in Table 5. The accuracy, recall, precision, and F1 score of 0.9640, 0.9740, 0.9730, and 0.9768, respectively is recorded for the MLP classifier. The optimal parameters for SVM classifier on which the best accuracy, recall, precision, and recall of 0.9690, 0.9672, 0.9729 and 0.9700 is achieved are $C = 1$, $kernel = 'linear'$, $gamma = 'scale'$ and $cache_{size} = 200$ as shown in Table 7. Moreover, the best accuracy for a Logistic regression classifier is achieved on the parameter values $penalty = 'l1'$, $dual = False$, $tol =$

0.0001, $C = 1.0$, $fit\_intercept = True$ as depicted in Table 6 The accuracy, precision, recall, and F1 score of LR classifier is 0.9730, 0.9750, 0.9731 and 0.9740 respectively. The combined results and confusion matrices for all the architectures are summarized in Table 8, respectively. From the combined table it is evident that the proposed Convolutional Ada-Boost architecture outperformed all the other architectures in terms of classification accuracy, recall, precision, and F1 score.

Table 1. CNN-Softmax Results

No of Epochs	Training Accuracy	Validation Accuracy	Testing Accuracy	Precision	Recall	F1 score	AUC
20	0.972	0.960	0.956	0.960	0.960	0.960	0.960

Table 2. CNN-AdaBoost Results

No of Estimators	Random State	Accuracy	Precision	Recall	F1 score
50	0	0.9820	0.9807	0.9845	0.9826
100	0	0.9820	0.9807	0.9845	0.9826

Table 3. CNN-DT Results

Criterion	splitter	Max_Depth	Accuracy	Precision	Recall	F1 score
gini	best	None	0.9680	0.9784	0.9595	0.9689
entropy	best	None	0.9600	0.9669	0.9557	0.9612
entropy	random	None	0.9690	0.9672	0.9729	0.9700

Table 4. CNN-RF Results

Criterion	No of Estimators	Accuracy	Precision	Recall	F1 score
gini	50	0.9720	0.9767	0.9692	0.9729
gini	100	0.9740	0.9730	0.9768	0.9749
entropy	50	0.9730	0.9730	0.9749	0.9740
entropy	100	0.9730	0.9730	0.9749	0.9740

Table 5. CNN-MLP Results

Hidden Layers	Solver	Max_Iteration	Activation	Accuracy	Precision	Recall	F1 score
30	adam	400	relu	0.9640	0.9630	0.9668	0.9649
50	adam	400	relu	0.9640	0.9740	0.9730	0.9768

Table 6. CNN-LR Results

Penalty	Tolerance	C	Accuracy	Precision	Recall	F1 score
L1	0.0001	1.0	0.9730	0.9750	0.9731	0.9740
L2	0.0001	1.0	0.9720	0.9730	0.9730	0.9730

Table 7. CNN-SVM Results

C	Kernel	gamma	Cache_size	Accuracy	Precision	Recall	F1 score
1.0	rbf	scale	200	0.9680	0.9769	0.9620	0.9694
1.0	linear	scale	200	0.9690	0.9672	0.9729	0.9700
1.0	poly	scale	200	0.8860	0.8209	0.9981	0.9009

Table 8. Combine Results and Confusion Metrices of all the Models

Model	Performance Metrics						
	Dataset size 5200 (Crack= 2600; Non crack =2600)						
	Confusion Matrices			Accuracy	Precision	Recall	F1 score
CNN	Class	Crack (0)	Non-Crack (1)	0.9560	1.000	0.960	0.9563
	Crack (0)	482	0				
	Non-Crack (1)	44	474				
CNN-AdaBoost	Crack (0)	506	13	0.9820	0.9807	0.9845	0.9826
	Non-Crack (1)	11	470				
CNN-SVM	Crack (0)	502	17	0.9690	0.9672	0.9729	0.9700
	Non-Crack (1)	14	467				
CNN-RF	Crack (0)	503	16	0.9740	0.9730	0.9768	0.9749
	Non-Crack (1)	12	469				
CNN-DT	Crack (0)	502	7	0.9690	0.9672	0.9729	0.9700
	Non-Crack (1)	14	467				
CNN-LR	Crack (0)	506	13	0.9730	0.9750	0.9731	0.9740
	Non-Crack (1)	14	467				
CNN-MLP	Crack (0)	501	18	0.9740	0.9730	0.9768	0.9749
	Non-Crack (1)	13	468				

4. Discussion

The proposed research shows the effectiveness of CNN features in terms of different performance metrics. CNN can extract useful patterns from a large amount of training data. A promising level of accuracy can be achieved by giving the acquired features as an input to other classifiers. It is found that the proposed Convolutional Ada-Boost architecture achieves the best accuracy, precision, recall, and F score in comparison with the other integrated CNN architectures. The performance of CNN-softmax, CNN-RF, CNN-LR, CNN-DT, CNN-SVM, and CNN-MLP are comparable with each other.

The proposed system enables automatic crack detection, which is very useful when inspecting pavement structures. The proposed research also demonstrates the usefulness of various integrated CNN architecture models in inspecting road surfaces. These architectures ensure frequent and automatic inspection of concrete structures by providing condition information from the data they store. The system can be updated by providing more data from different structures to the models. The trained model can then be used to detect several types of other defects in pavement structures. We consider that these models can also be used as a prototype for real-time crack detection and localization.

5. Conclusions

In this paper, a new CNN architecture is proposed by integrating the CNN architecture with the Ada-Boost classifier. The proposed architecture is named Convolutional Ada-Boost Architecture. Also, in the proposed work, the performance of the proposed Convolutional Ada-Boost architecture is compared with six different CNN architectures in terms of various evaluation metrics. For the dataset creation, images were acquired by using a smartphone camera on various road surfaces in the United Arab Emirates. Experiments are conducted by giving the CNN features to other classifiers to investigate their performance. It can be concluded that for the crack detection problem, CNN should be used in the feature extraction phase and the Ada-Boost classifier should be used instead of the Softmax classifier. From the discussion, it can also be concluded that the proposed crack detection system in combination with camera technology can be used for inspection of damage to pavement structures, especially cracks, from road images.

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Earthen Stabilized Construction Methods and their Adaptation to the Modern Life Needs

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Abstract: This paper investigates the potential of earth as a construction material, a neglected source that embodies many opportunities for sustainable architecture and design's future. The need for creating alternative solutions to toxic materials is vital; as the world goes through financial inflation, energy scarcity, and global warming. The world's population increases around 83 million annually [1], alongside the instancy for adequate shelters in some communities that suffer from poverty, immigration, water scarcity, or natural disasters, which creates a higher demand for urban growth and housing to overcome this shortage. Introducing sustainable efficient solutions can re-establish the balance in the ecosystem by limiting energy consumption and fulfilling the eager need for urban development. Earth is a highly available material that has been a vital material in primitive and vernacular construction, it has been widely used due to its flexibility, strength, noise control, fire resistance, high thermal mass, and adaptation to various construction methods [2]. However, since the invention of steel and concrete, they have been a preference because of their outstanding stability, the wide range of possibilities in form and height, and the short construction time. Regardless of their high cost in fabrication and transportation, their extensive energy consumption, pollution, and contribution to global warming. The main objective is to introduce alternative solutions that overcome earth shortcomings and widen its use in construction. Which collectively reduce the chemical materials' usage in the built environment, carbon emissions rates during the production process, reduce deforestation, contribute to economic and energy efficiency, and increase human comfort.

Keywords: Earthen structures; Stabilized rammed earth; Compressed stabilized earthen block; 3D printing earth.

1. Introduction

"Earth turns to gold in the hands of the wise" Rumi [3]. Earth is a great source for construction materials that have been neglected for the past decades; as the industrial revolution invaded the market with polished materials such as concrete, steel, and plastic-based materials. Chemical manufactured materials have been contributing to the outrageous pollution rates and carbon emissions, due to their production, transportation, and construction [3]. Concrete is the second most used substance on Earth after water, it's one of the highest carbon dioxide emitters with up to 2.8bn metric ton, it also consumes 10th of the world's industrial water, which stops water supplies for irrigation and drinking [4]. ''It is time to move out of the "concrete age" and stop thinking primarily about how a building looks'', Anthony Thistleton [4].

Earth is a common material in vernacular structures for various reasons. Its availability at any site saves transportation cost and creates a complementary source of material, earth's flexibility allows its molding to various forms and shapes, the great range of construction methods it adapts to such as rammed earth, earthen blocks, hand coiling, plastering, and molding home accessorize, moreover earth's high thermal mass that allows stabilizing temperature's fluctuation in the interior spaces, its detoxifying effect for the indoor air through absorbing toxins and smells, earth's noise control and fire resistance features, and its moisture control through absorbing and releasing humidity that maintains a clean and comfortable living space [2]. However, the architectural experience, form, and market's perception changed exponentially; due to the development of materials and building methods, the use of earthen structures has diminished gradually, as it lacks adaptability and efficiency to the contemporary design in comparison to steel and concrete, and it gained a social aversion associated with poverty and uncivilization.

Earth is considered a highly sustainable material that has been used since tens of thousands of years in Middle Eastern and North African architecture and approximately 30% of the world's population uses it as a building material [5]. Therefore, developing the material to overcome its shortcomings will contribute to create greener architecture and reduce the carbon footprint of the urban development.

Technological advancement is utilized in developing earth as a construction material to create sustainable and cost-effective substitutes to contemporary methods. Moreover, applying proper interventions based on soil properties such as density, permeability, and plasticity to improve the material's performance and stability. Replacing the traditional construction methods with automated machines and robots to fasten the building process following the rapid growth rates of the urban areas, minimize the construction waste, and reduce human deficits [5]. This contributes to increase the accessibility and adaptation of cost-effective sustainable techniques when the world suffers from energy scarcity and inadequate living conditions.

This research focuses on resolving two main aspects of earth: its additive mediums for a higher efficiency mixture, and its incorporation with developed construction methods. The data is generated based on reviewing various literature, that has documented results from conducted experiments on earth as a construction material. Also, analyzing diverse successful case studies that have used earth and achieved high-performance results.

The objective of the research is achieved by highlighting the potential of earth and its adaptability to assorted contexts and the efficiency in achieving specific results when treated and implemented in the correct form, size, and suitable function. The summary highlights the results and lists guidelines that create a clear reference for designers and architects to ease the use of earth and encourage its integration in the design.

2. Materials and Methods

Over the years, earth has been combined with various mediums, to allow its moldability, strength and to avoid its corruption and deterioration with time. Also, various methods have been adopted to ease the process to increase its efficiency.

2.1 Literature Review

This research reviews the material, its physical features, and its performance once combined with stabilizing mediums. Also, highlights the relation between the types of mediums and their functionality for specific structural or architectural components.

2.1.1 Earthen Mixture

Earthen material is defined mainly by the type of soil used in its creation, which intervenes greatly in defining the success rate of that material. "The suitability of a soil for a particular application and its associated construction technique is determined by the combination of its: i) texture, mostly linked to particle size distribution; ii) hydration state, driven by the amount and the type of reaction to water at the molecular level; and iii) its stabilization, which determines its resistance to erosion, compression, flexural stress, and other chemical and mechanical properties." J. Paul Getty Trust [6].

Water is a vital component of the earthen mixture as it adds plasticity and moldability features to earth. The amount of water added distinguishes the quality of the mixtures, the percentage varies between 8%, 12%, and 18% which results in creating wet, plastic, humid, or compressed moldings based on the soil dryness. Excessive use of water results in cracks when the earth dries, due to the high shrinkage rate. In addition to water, cement is introduced to inherit concrete blocks strength while conserving the eco-friendly features embedded in using soil as a natural material, Figure1 [6,7].

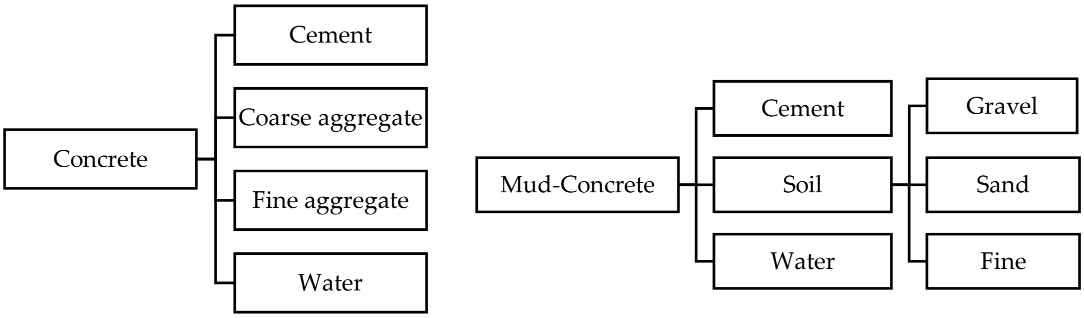


Figure 1. The difference between concrete and mud concrete mixtures [7].

Studies have also shown the possibility of using lime or lime cement content as stabilizers with reduced silt and clay. Lime is a more sustainable material derived from limestone; therefore, it requires less energy to be produced and can be burned at a lower temperature than cement. Furthermore, lime can be produced locally and on a small scale, which eliminates transportation costs, lime can be used as a stabilizer for single-story build with a percentage of 10%, which is relatively higher than cement which requires 5% for the same level of strength. On the contrary, lime can accommodate variation due to structural settlement and temperature changes without resulting in cracks [7].

2.1.2 Earth Waterproofing

Earth deteriorates in a humid and moist environment, air humidity affects walls mainly, ground moisture softens the foundation, and rainfalls affect roofs. Once a single element is affected, it consequently weakens the full structure and may cause its collapse.

Waterproofing is essential for foundations and roofs to protect the building from deterioration, new water repellent additives waterproof earth and protect it from moisture but these solutions prevent earth from breathing [8]. Resinmix is a company specialized in advanced materials for the building industry, it offers two solutions for waterproofing one for the outdoor using resi-star which is an epoxy resin with bitumen, and another for the indoor using resi-seal which is a cement coating [9].

Auroville Earth Institute is a nonprofit organization that is specialized in researching earth-based technologies for over 30 years and it's the UNESCO chair ''Earthen Architecture''. It developed earthen waterproofing instead of cement, which is a plastering made of water, lime, tannin, and alum. The mixture is applied using several coats, each coat has different proportions of the mixture ingredient. The last coat is a 5mm thick layer composed of lime paste, soil, and sand. Based on the institute's experiments, the waterproofing is effective for up to 5 years only and needs further performance improvements, Table 1 [10].

Table 1. The Waterproofing percentage after rainfalls [10].

True Content	Immediately after 402 mm rainfall in 5 days		2 weeks after the rainfall, under full sun	
	Outside	Inside	Outside	Inside
Vaults apex	100 %	31. 6 %	19. 4%	22 %
Windowsill	59. 8 %	27. 8 %	20 %	21. 8%

2.2 Case-studies

The research analyzes divergent case studies with various parameters and time periods. The first is vernacular (Shibam's vernacular earthen skyscrapers in Shibam, Yemen), the second is vernacular approach by an architect (New Gourna by Hasan Fathy in Gourna, Egypt), and the third is a modern life reinterpretation (''Earthship'' pioneered by Michael Reynolds in New Mexico, USA). These projects reflect some leading examples of successful earthen structures, that embody many lessons of creativity, adaptation, and sustainability.

2.2.1 Shibam's Earthen Skyscrapers

Shibam is a walled city in Yemen with over 7000 habitats, it was created during the 16th century, and it is described as Manhattan of the desert [11]. Its earthen skyscrapers are multiple-story houses that are mostly 5 stories high and sometimes reach up to 8 or 9 levels, Figure 2. The foundations are made of stone to create a water-resistant stable base, while the walls are made of earthen sun-dried blocks. The ground floor usually has no windows and has the thickest walls. The wall thickness gradually decreases reaching the top level to minimize the building structural load, Figure 3 [12].

Figure 2. Shibam earthen skyscrapers [12].

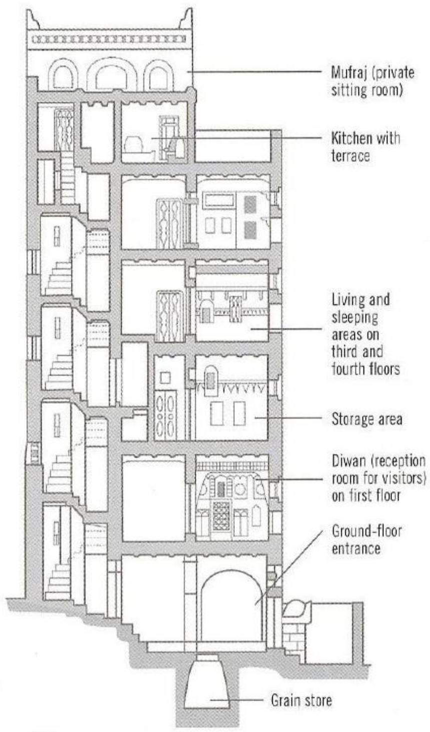


Figure 3. Shibam earthen skyscraper section [12].

The tower material and design achieve human comfort. Because of the high urban density, the sun exposure on the building surfaces is minimum, also all the exterior surfaces are covered with lime which has good reflective property in comparison to other materials. Earth creates high thermal insulation due to its thermal capacity which consumes double the time of concrete to conduct heat. This results from earth low density due to the air voids in the material after the water evaporation in the creation process. These features in addition to maintaining the airflow through placing the openings at different levels achieve substantial human comfort in its interior spaces and exterior alleyways [13].

2.2.2 The New Gourna by Hasan Fathy

Hasan Fathy is a pioneering Egyptian architect in creating architecture that responds to its context rather than adopting western principles. The Egyptian government asked Hasan to design a new neighborhood for peasants in the New Gourna, Egypt. He calculated the cost of concrete houses and found out that a peasant can't afford these houses, due to the material cost and the need to hire experts to implement the design. Therefore, government housing projects usually end up with vertical concrete slums and without territorial areas. Consequently, to provide space with minimum cost; gradually the area gets filled with duplicates without any individual variations. Comparing the peasant's life quality in the countryside, having green agriculture land, surrounded with sufficient daylight and well ventilation. This had triggered the questions: ʻʻ What if the vernacular was improved to upgrade the spatial quality of the interior spaces, without the need to import materials and hire expensive labor?ʼʼ, ʻʻWhat if the community had all the resources, while some guidance and upgrade was provided?ʼʼ Hasan Fathy [14].

Therefore, Hasan Fathy went on a trip around Egypt looking for craftsmen and builders that can solve some issues in earthen buildings. The two main concerns were the type of earthen block used and the method for constructing earthen roofs. The blocks were made of earth from the site, sand from the desert, in addition to straw and water. Sand is added to earth in a ratio of 1/3, once mixed 45 pounds of straw is added to each cubic meter. After that, water will be added and left to get socked and ferment for 48 hours [14].

Subsequently, the mix will get molded. Usually, the builder uses a rectangular mold that has neither a top nor a bottom, it is used to divide the mix and slide it up without pushing it. Such a technique requires a moist mix to reduce the fraction between the brick and the mold. However, moist mix faces high rates of shrinkage which results in cracks while drying out."I designed a hand press that enabled us to make bricks under pressure with a much drier mixture, thus obviating these disadvantages. The freshly molded bricks are left in the sun to dry, being turned on edge after three days and taken off to the brick stacks after six days. There they remain for as long as possible (all summer, preferably) to dry out thoroughly before being used in building" Hasan Fathy, Figure 4 [14].

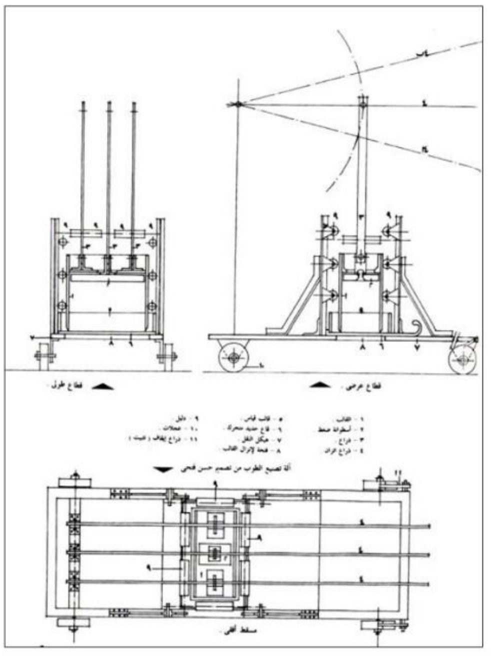


Figure 4. Architect Hasan Fathy earthen blocks compressor [14]

As for the earthen roof, vaulted roofs were the optimum solution to distribute the load gradually and minimize the weak points. To create a successful vault, the masons requested a different type of earthen brick with more straw. For a room which is 3 by 4 m, it costs 3.4 E.L, while concrete costs 16 E.L and 20 E.L for timber [14].

2.2.3 Earthship

''Earthship'' is a shelter model that was introduced by Michael Reynold in the 1970s. It started in New Mexico, USA, and has been gaining popularity in different countries since then. ''Earthships'' are off-grid solar shelters made of earth and upcycled materials. Earth is mainly used to give maximum thermal insulation, it is used on the north side to create wall support, and it is filled inside old tires to create the exterior wall itself, the interior walls are also built using earth. ''Earthship'' is a great example of a contemporary interpretation of earthen structures, that are affordable, efficient, and smart, Figure 5 [15].

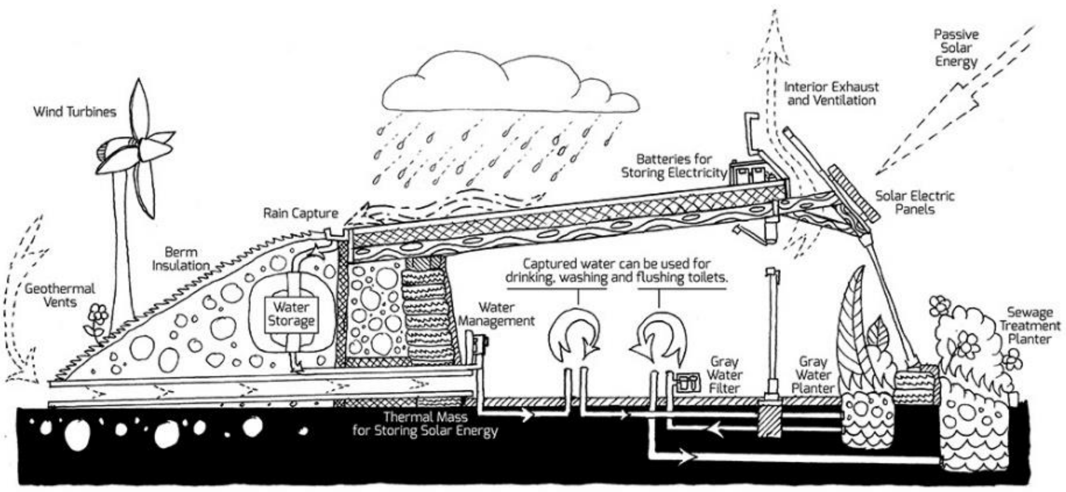


Figure 5. Earthship sectional diagram [16].

2.3 *Construction Methods*

Several companies and institutions have adopted and invented new techniques and technologies that aim to improve the materials' quality and efficiency, through enhancing its performance to achieve the required results. These technologies elevate the material properties, they also increase the life span of a building and minimize its construction time. Auroville Earth Institute has produced a clear manual for using earth in a building's foundation, blocks, and walls to ease earth incorporation into building design and to promote sustainable living [17].

2.3.1 Stabilized Rammed Earth Foundations

Stabilized rammed earth foundations were developed to be used for up to four stories buildings. To achieve higher measures of strength earth is combined with 5% cement of the total weight. Besides cement, sand is always added to soil, for instance for 500 liters of soil, 200 liters of sand, one bag of cement will be added (50 kg) in which achieves all the advantages of using earth and minimizes the use of cement. Moreover, the size of the foundation is determined by the height of the building starting from a minimum of half a meter. Deep foundations achieve more stability in areas where the soil is loose and has low load-bearing qualities. On the contrary, a wide shallow foundation has fewer stable qualities and is exposed to deterioration, Table 2, Figure 6 [17].

Table 2. Stabilized rammed earth foundation sizes based on the building floors. [17]

Building type	One-floor building	Two-floor building	Three-floor building	Four-floor building
Section size	50 x 50 cm	60 x 60 cm	75 x 75 cm	90 x 90 cm

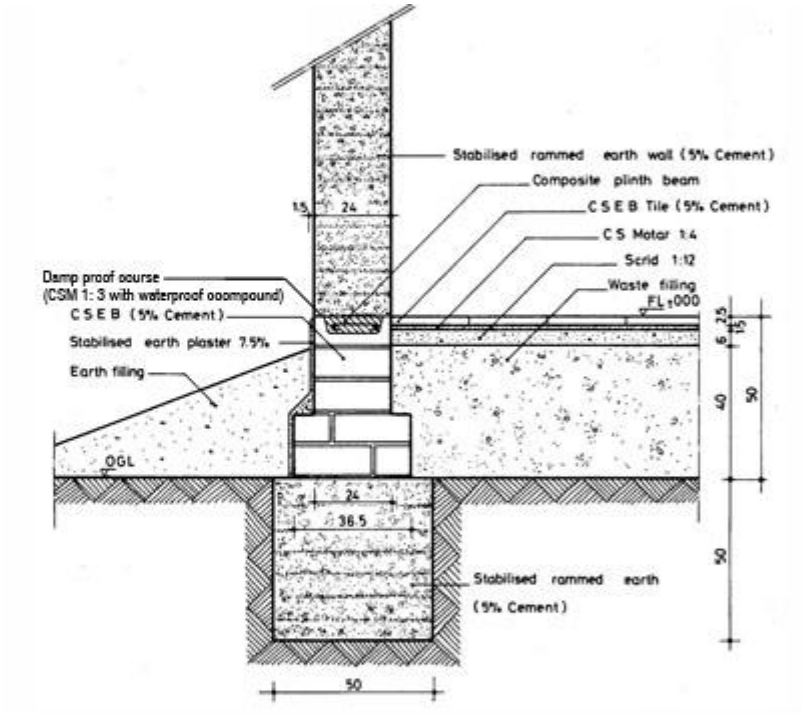


Figure 6. Stabilized rammed earth foundation section [17]

To increase the foundation strength, it can be reinforced by inserting horizontal layers of cement between non cohesive soil, Figure 7 [17]. A study was conducted to test the strength of the model for vertical and horizontal inserts, the model determined its resistance to horizontal pressure and its minimum soil vertical displacement [18].

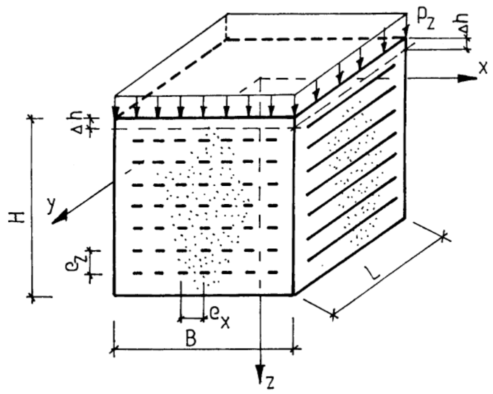


Figure 7. Reinforced soil foundation model [18]

2.3.2 Compressed Stabilized Earth Block

Compressed stabilized earth block (CSEB) is the developed version of hand-molded and sun-dried earthen blocks. In the 1950s, the first steel manual press was invented that created regular blocks in size and shape, also denser, water-resistant and stable blocks. Various molds are created up to 70 different types of CSEB which eliminates building restrictions and creates a flexible range to implement architectural designs [19]. CSEB consumes less energy and emits 80% less carbon dioxide than fired bricks. There are two types of stabilization: mechanical and chemical, mechanical stabilization compacts the earthen mix to reduce the voids, while chemical stabilization adds mediums to the soil such as cement, chemical binders, lime, waterproof agents, and industrial and natural products [20].

The block quality is determined by the soil type and the added stabilizer. Topsoil and organic soil are not applicable as CSEB components. Cement is usually a good stabilizer with sandy soil.

However, lime is preferable with clayey soil [19]. Combined lime-cement stabilization can be used to improve the block strength, because cement stabilizes the sand portion and lime stabilizes the clay portion of the soil. Cement stabilizer gave maximum strength with a mix of sandy and clayey soil, however lime-cement stabilizer is considered better for economic reasons, Figure 8 [20].

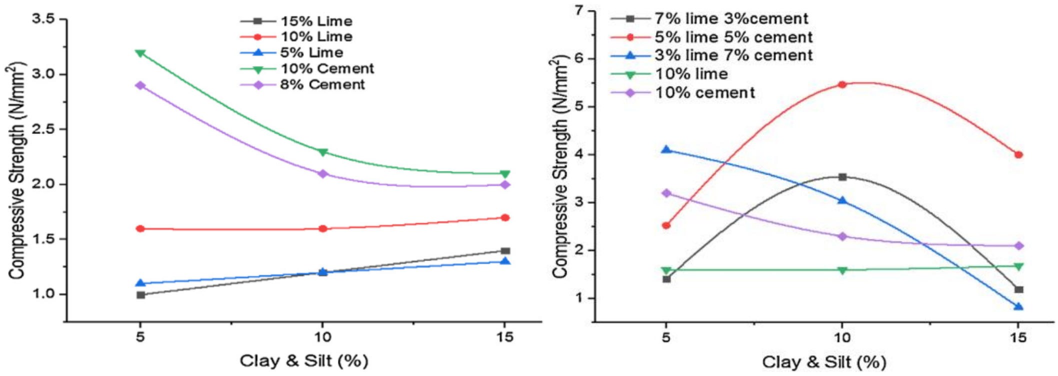


Figure 8. Compressive strength for CSEB with different stabilizer's type and percentage [20]

Even though CSEB has some limitations such as the use for high-rise buildings, or manufacturing defects caused by over or under stabilizing. Earth's is available at any site which saves shipment and transportation expenses, also earth is a biodegradable material that will blend into the ground and have trees growing on it. CSEB is suitable for mass production, Figure 9, and can be easily transferred. Also, it is socially acceptable and aesthetically pleasing, it can be kept exposed without any paint coatings, thus eliminates chemical paint, and maintains its natural components [19,21]. Collectively it is considered more efficient than any other block type, Table 3 [22].

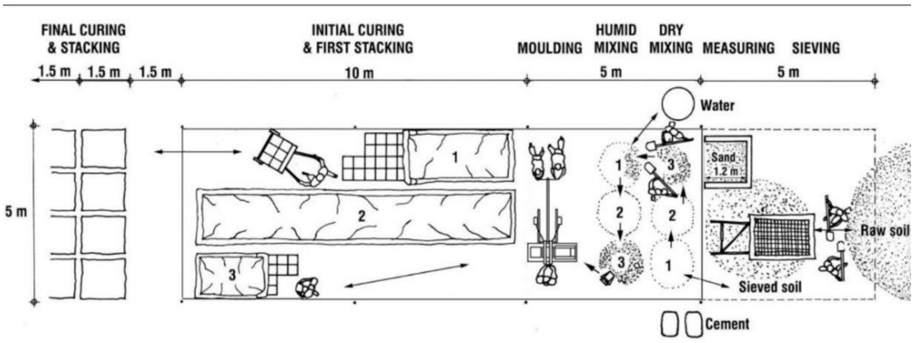


Figure 9. Block yard layout for Auram Press 3000 [21]

Table 3. Comparison of different types of blocks [22].

	Concrete blocks	Hollow bricks	Solid bricks	Machimbre (not insulated	Stabilized earth blocks
Dimension (cm)	40*20*20	33*18*18	30*6*15		28*9.5*14
Cost analysis Cost ($/m2	12.94	14.97	17.42	19.32	8.72
Thermo physical analysis Transmittance (W/m2°C	2.116	1.792	2.421	1.687	1.674
Front thermal capacity (KJ/ m2°C	131.9	207.6	253.0	53.0	197.1
Delayed heat transmission (h)	2.88	5.39	4.88	1.66	5.46
Attenuation factor (-)	0.85	0.63	0.56	0.93	063

2.3.3 3D Printed Earth

3D printing is the contemporary age technology that has been adopted with various materials that have high liquidity when printing and quick settling properties. Earth is relatively a low-cost material that has been getting more attention due to its eco-friendly characteristics. However, it has not been widely used due to its slow construction process, and the need for intensive labor. Which is suitable for community projects, where collective human resources collaborate to build. Therefore, to widen the range of using earth as a construction material; experiments shows that earth can be 3D printed if altered to monitor its physical qualities, where it can be poured yet hardens quickly. 3D printed structures are created using an automated robot by applying successive layers of the material. The stability of the structure is determined by the construction rate to the structural build-up rate and the material's endurance in carrying the increasing load of the layers. Research shows that earth must be combined with 40 -45% of water for it to be bumped with 20 bar bumping pressure. Also, earth hardens while drying which may take up to 24 hours, therefore a thickening medium is added to fasten the earth stability and allow a full section to be completed in a single day. Alginate is used as a thickener, which creates a higher resistance to the added load, Figure 10 [23].

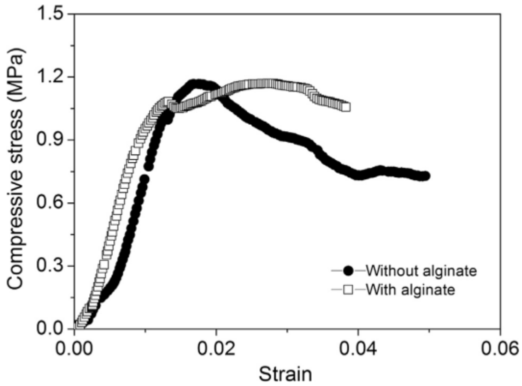
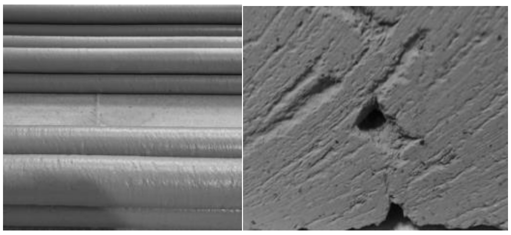
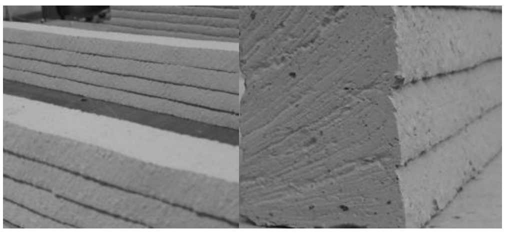


Figure 10. Strength measurements of printed earth with and without alginate. [23]

Two cross-sections can be used: round or rectangular. The round cross-section had some empty gaps between the stacked layers, while the rectangular is denser, Figure 11 [23].



(a)



(b)

Figure 11. 3d printed earth with a: round cross-section, b: rectangular cross-section [23].

Technology and clay (TECLA), the sustainable 3D printed homes company based in Italy has been experimenting with the world's advanced saving project (WASP), a manufacturer for 3D printers to create an ecofriendly community. It has combined the most ancient building materials with the most recent technology to create efficient homes. The created spaces are circular with rippled walls to maximize strength and introduce air cavities between the vertical layers, which can be used for electrical and plumbing work. Moreover, they can be filled with insulating materials such as waste from rice harvesting or thatch, Figure 12 [24].

Figure 12. 3d printed units using earthen walls with integrated voids for electrical and plumbing connections [25].

The interior experience combines material honesty with the sculptural form created by technological advancement, Figure 13. The used earthen material has a great thermal mass that maintains human comfort and simultaneously creates wall ventilation due to the breathable characteristics of the soil. [25].

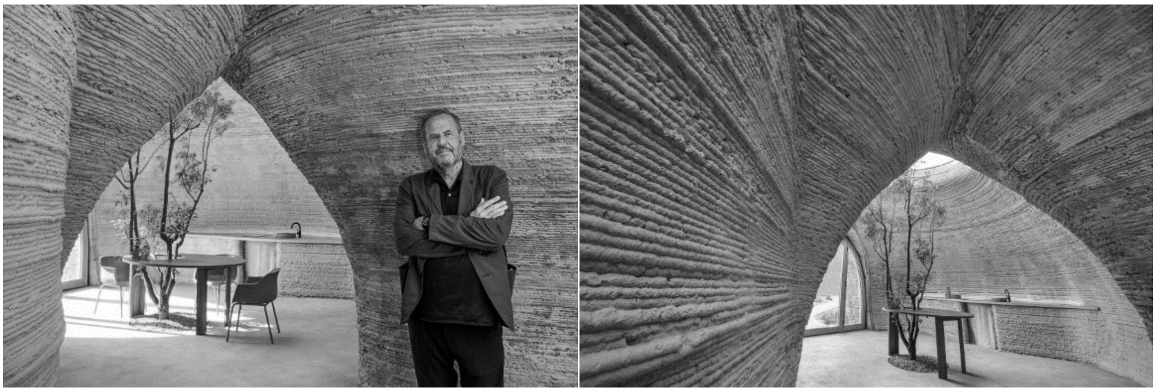


Figure 13. Italian architect Mario Cucinella inside the 3D printed house he designed [26].

3. Results

As a result of the collected data, Earth has proved its suitability to be used in some projects and its capability in adopting new techniques that would improve its strength and stability. The below guidelines are recommended to achieve the desired level of efficiency using earth as a construction material.

3.1. Earth Mixture

1. Earth (soil) cannot be used individually and must be combined with three main substances:
    - Water,
    - Sand,
    - Stabilizer.
2. There are two main options for a stabilizer depending on the type of soil (straw was used in vernacular structures):
    - Clayey soil: lime stabilizer.

- Sandy soil: cement stabilizer.

3. The additive stabilizer percentage varies based on stabilizer type:
   - Lime 10%.
   - Cement 5%.
4. A combination of cement and lime create better stability on the long-term.
5. Sand is added to earth (soil) in a ratio of 1/3.
6. The additive percentage of water varies between the following to create enough plasticity for efficient molding, based on the earth type:
   - 8% for regular earth.
   - 12% for semi-dry earth.
   - 18% for highly dry earth.

3.1. Earth Construction

1. Two main soil types are not suitable for creating CSEB:
   - Topsoil,
   - Organic soil.
2. The amount of water determines earthen blocks quality:
   - More water:
     - Wet: easy molding.
     - Dry: cracked blocks.
   - Less water:
     - Wet: harder molding using a traditional manual mold.
     - Dry: firm and strong blocks.
7. Earth waterproofing can be applied in three ways:
   - Cement coating.
   - Epoxy resin with bitumen.
   - Water, lime, tannin, and alum.
8. Rammed earth foundations vary in sizes based on the building height:
   - One level: 50x 50 cm.
   - Two levels: 60x 60 cm.
   - Three levels: 75x 75 cm.
   - Four levels: 90x 90 cm.
9. Reinforced earthen foundations can be used for higher stability.
10. Higher buildings require wider and water-resistant foundations.
11. Earthen foundation can be replaced with stone or concrete for buildings higher than four stories.
12. The earthen wall thickness decreases as the level increases.
13. The most stable earthen roof form is vaulted roofs that requires highly stabilized blocks.
14. Traditional building construction methods can be substituted with new technologies:
    - Sun-dried block can be replaced with compressed stabilized earth blocks using advanced automated compressors which achieves:
      - Higher stability,
      - Uniformed form,
      - Mass production,
      - Quicker process.

    - Rammed earth can be replaced with 3d printed earth which achieves:
      - Less manpower,
      - Quicker process,
      - Less waste,
      - Higher stability,
      - No human defects.

15. To 3D print earth, two change needs to apply on the mixture:
    - 40-45% water to allow pouring,
    - Alginate to thicken and settle quickly.

3. Discussion and Conclusion

Earth has been always a vital material in creating shelters. The material usage has evolved through time creating several versions that accommodate different needs. Earth has great adaptability to various construction techniques such as rammed earth, daubed earth, earthen blocks, earth hand coiling, and earthen roof. Each technique has its advantages and disadvantages. But all methods achieve environmental and economic sustainability, which encourage experiments and technological integration.

The earthen structures have performed substantially in dry climates and have survived for around 1700 years in Shibam, Yemen. Therefore, when the correct soil is used, the proportionate mixture and an adequate construction method are applied, sustainability is achieved. Moreover, structures located in a dry climate zone where earth is accessible, and few sustainable alternatives are locally available, earth can be the perfect material to be obtained especially after overcoming its fallibilities.

Material selection and treatment are highly relevant to the site resources, challenges, and the user's requirements. Earth provides a wide range of options and features that are exclusive to it. Therefore, using earth increases human comfort in the interior spaces, contributes to saving energy, and reducing waste. And consequently, realizing a healthier planet.

Earthen structures also help to create shelters for homeless members. Architect Hasan Fathy proved that earth is the only economic attainable material for penurious communities, in which they may remain homeless otherwise, or live in spaces with poor conditions. Moreover, in New Mexico Earthship introduced by Michael Reynold in the 1970s has been gaining popularity worldwide. The off-the-grid solar structures are made of earth and upcycled materials, that many individuals found convenient as it saves the material cost and can be built by the community members themselves, which creates personalized interior spaces without compromising the spatial quality. Furthermore, 3d printed earthen structures are an excellent solution for post-disaster shelters since the material is site-based and the building process can take up to 24 hours to be completed. Earth is a vernacular material, but it can also be the material of the future when the above considerations are taken into deliberation.

In conclusion, even though studies had improved earthen structure tremendously, further refinements should be implemented focusing on waterproofing solutions, and multiple stories build. These solutions will eliminate deterioration and will expand its use beyond low-rise residential structures.

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Applications of Digital Twins for Asset Management in AEC/FM Industry – A Literature Review

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Abstract: The concept of Digital Twins has recently emerged as a new advancement of technology-led processes to support the design, construction, and management of built assets. A digital twin exists as a digital model that provides simulations and bi-directional information link to a real-world entity (i.e., a physical twin), offering opportunities for data-centric decision making. Digital twins can have multiple applications in the asset management domain of Architecture, Engineering, and Construction/Facilities Management (AEC/FM), such as a digital twin of a constructed asset may be developed to show the working of its systems, and thus related data link will be established to capture the operations data and reflect the real-time information in the digital twin. However, technology and processes for the creation of Digital Twins and their potential applications are not fully known in the asset management domain. This research effort attempts to identify the process of Digital Twin creation and its potential applications to manage already built assets in the AEC/FM industry by presenting the findings of a systematic literature review of existing knowledge. This review concludes that the creation procedures are in their inception phase and highlighted potential applications in asset management during its lifetime, enabling sustainability retrofits and maintenance and restoration of heritage assets, and presented few recommendations for future research in this domain.

Keywords: Digital Twin; AEC Industry; Technology; Asset Management; Review

1. Introduction

The Architecture, Engineering, and Construction (AEC) sector witnessed many attempts to digitize in the 1990s since digitalization in that era focused on human communication with the launch and popularization of the internet and e-mail as this helped to reshape the workflow through technological development, new tools, and methods of exchanging information.

As shown in Figure 1, the digital revolution that began in the late eighties led to the transition from manual drawing to technical drawing, using Computer-Aided Design (CAD) software as a tool to improve accuracy and expand the creativity of engineers [1]. Therefore, computing and automation began to include design in virtual environments.

Followed in the new millennium by the ability to move from 2D CAD representation to 3D accompanied by Building Information Modeling (BIM), the Internet of Things (IoT), and the Digital Twin (DT) concept that allows the digital representation of buildings and the creation of databases and digital warehouses.

Unlike past times, the AEC industry is embracing the technological revolution at a significant pace, and the integration of DT into the Architecture and Construction processes is evident, but the extent of their potential and possible applications within the AEC industry is not fully explored yet.

This article aims at identifying the DT creation and its potential for asset management applications in the AEC industry by conducting an extensive state of the art systematic literature review.

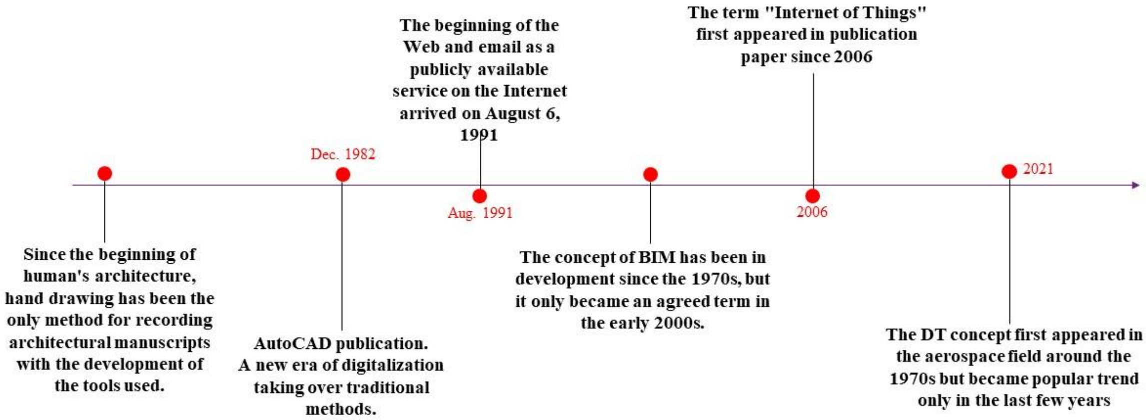

Figure 1. Evolution of Digital Twins [21]

2. Materials and Methods

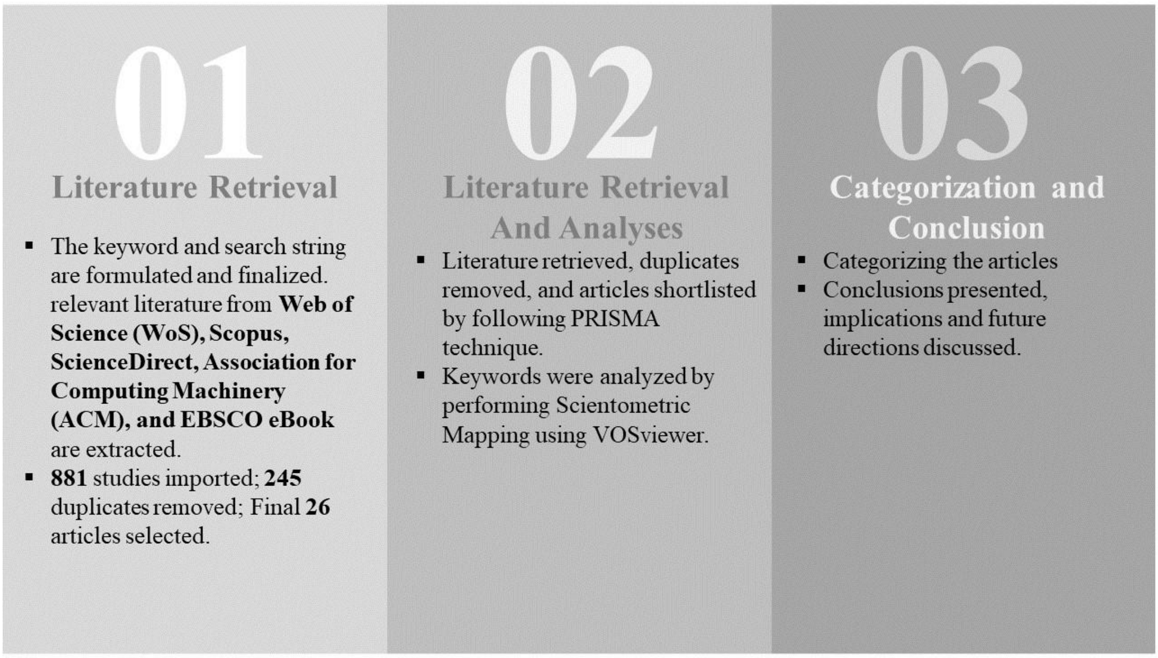

Figure 2. Methodology of the current systematic review.

Figure 2 illustrates and discusses the research methods used in the current research. It consists of three steps. In step 1, relevant studies from Web of Science (WoS), Scopus, ScienceDirect, Association for Computing Machinery (ACM), and EBSCO are extracted. In step 2, keyword analyses using Scientometric Mapping were performed for keywords retrieved from the articles searched through WoS and Scopus to highlight the interconnectivity of various fields of studies and interest of the public and researchers for DT for the current study. The Scientometric Mapping of keywords extracted from Scopus and WoS database is shown in Figure 3 and Figure 4 respectively, highlighting the potential areas and applications of DT. Finally, step 3 is the categorization of the relevant papers based on the area of focus, and the conclusion along with the future research directions are presented.

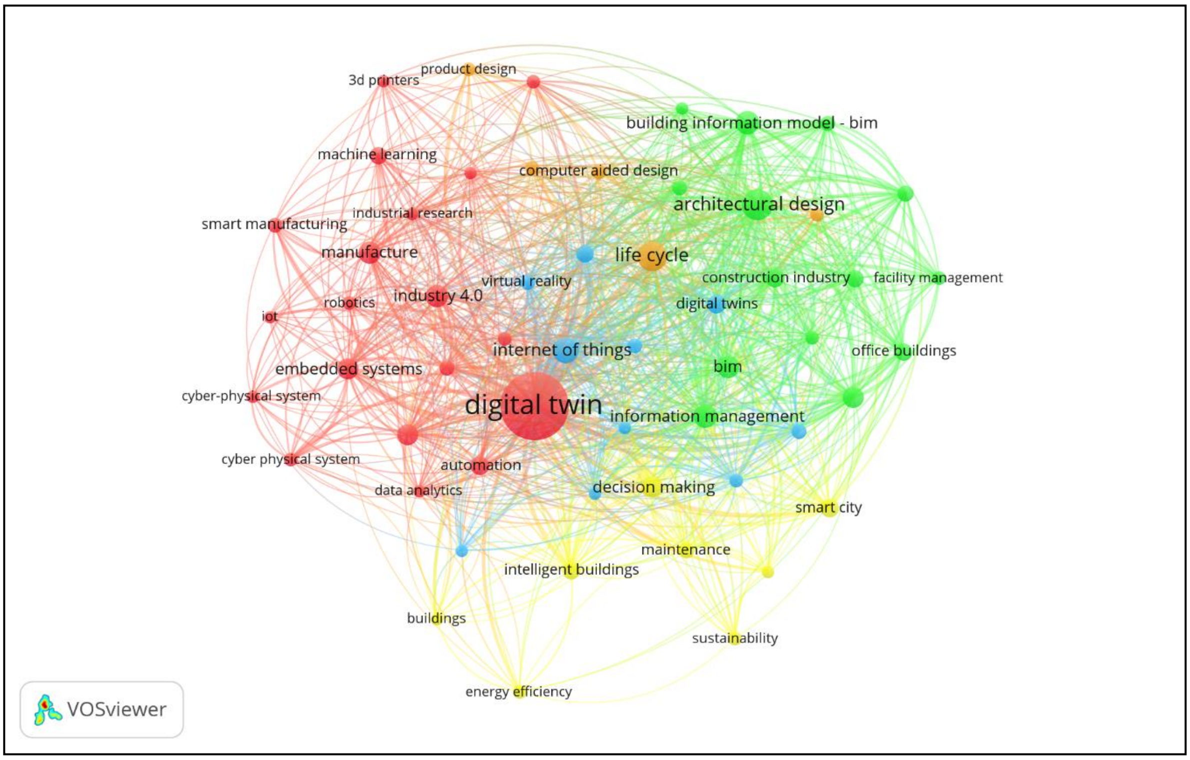

Figure 3. Scientometric Mapping of Scopus keywords.

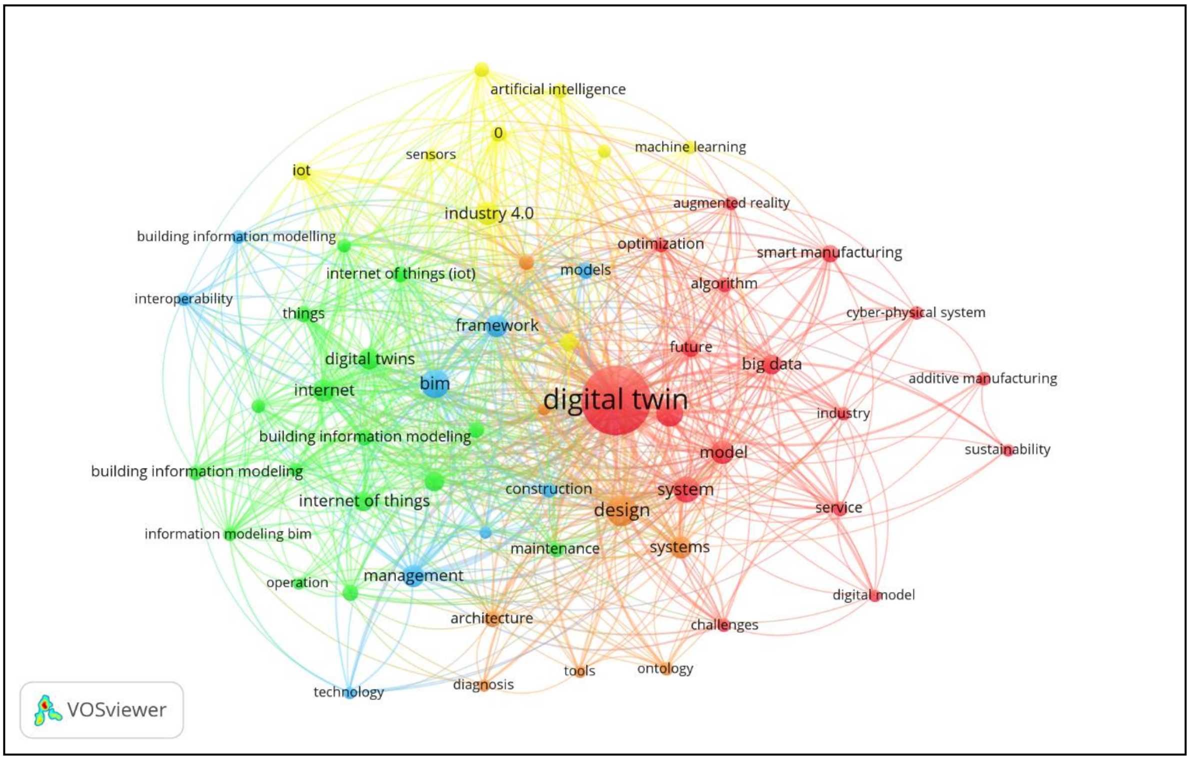

Figure 4. Scientometric Mapping of WoS keywords.

3. Results

In this section, we categorize the articles included in this study based on their area of focus. We classify the 26 included articles into 5 categories as shown in Figure 5. The categories and the articles' contributions are explained below.

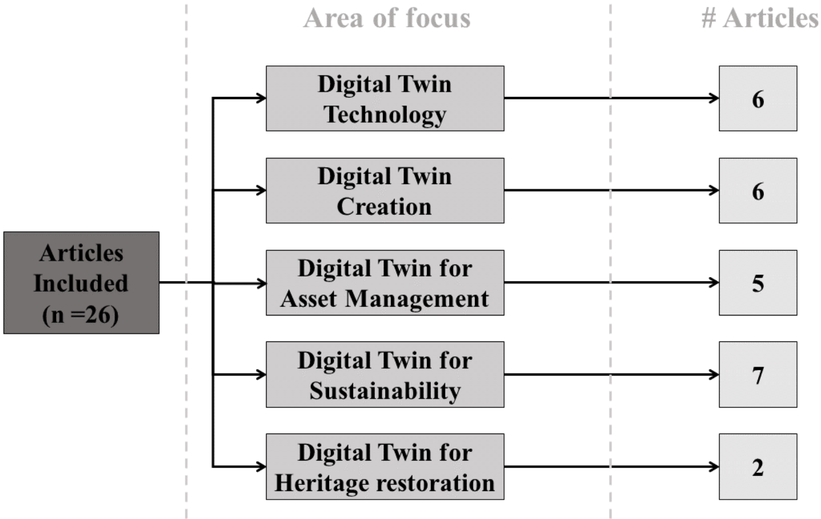

Figure 5. Categorization of selected articles.

3.1. Digital Twin Technology

The articles in this category focus on the digital twin technology concepts, their characteristics, applications, and challenges. Barricelli et al. [2] conducted a review of 75 articles to analyze the existing definitions of the DT. In addition, the authors presented the main characteristics of the DT and the different application domains in which the technology has been used in the literature. Based on the analysis, the authors grouped the application of digital twin into three categories: 1) manufacturing, 2) aviation, and 3) healthcare. The authors outlined two digital twin lifecycles. One where the physical object whose digital twin needs to be created does not exist, and the other where the object already exists but has no digital twin. In the former, the design process simultaneously includes both the physical object and its twin, while in the latter the design process aims at the connection of the physical object to its twin. Furthermore, the authors highlighted issues prevailing towards digital implementation, such as ethical issues, data security and privacy, cost of deployment, governmental rules and regulations, and technical limitations.

Camposano et al. [3] presented a qualitative study to analyze the understanding of DTs among Finnish AEC/FM practitioners. The authors conducted a semi-structured interview with 28 project managers, C-level executives, and practitioners working in equivalent roles during 2018 and 2019. Based on the response of the participants, the authors found that rather than knowing what exactly a digital twin is, the respondents were more likely to know the vision/implementation of digital twins for organizations. The respondents differentiated DT from a digital model based on the dynamic time, virtual representation, higher dimensional abstraction, bidirectional data flow between the physical object and its twin, technological components, and high actor interdependency attributes of the former.

Delgado and Oyedele [4] reviewed 54 articles to analyze the structural and functional descriptions of the DT for the built environment. The authors extracted three types of structural and functional models each. The structural model involves conceptual models, system architectures, and data models, whereas the functional model includes process and communication models. Based on the extracted descriptions, the authors defined four categories of conceptual models and six process models. The defined conceptual models' categories are: 1) prototypical, 2) model-based, 3) interface oriented, and 4) service-based. The process models' categories include: 1) digital twin creation, 2) digital twin synchronization, 3) asset monitoring, 4) prognosis and simulations, 5) optimal operations, and 6) optimized designs. The authors found that prognosis and simulation models are mostly applicable for Architectural, Engineering, Construction and Operation (AECO) implementations.

3.2. Digital Twin Creation

Articles in this category focus on the creation of the DT from a physical object and how to connect the physical entity/structure with its twin. Jiang et al. [5] proposed applying discrete event simulation modeling theory to the 3D digital twin model for rapid creation of twin and the connection between the physical production system and its twin. To create the digital model of the manufacturing system, the authors first identified the basic system elements such as controller, executor, processor, buffer, flowing entity, virtual service node, and logistics path. Later, the authors designed an interconnection and data interaction mechanism for connecting the physical system and the twin. The applicability of the proposed method is demonstrated using a real-world workshop DT.

To analyze the true potential of the investments in DT, Love and Matthews [6] highlighted the need of legitimizing the process of benefits management before making a financial investment to understand how digital twin will enhance the organization's overall efficiency. Based on the empirical findings from nine projects, the authors proposed a generic business dependency network to analyze the benefits of the DTs before considering its adoption. Khajavi et al. [7] implemented created a limited office building to show the steps involve in its creation and the technical issues occurring during the creation. The authors detailed the method of creating a DT using collected sensor data related to light, temperature, and humidity. The authors discussed the benefits of implementing DT, as well as explained technical shortcomings faced during the creation of DT along with possible solutions. The study revealed that most of the technical issues in the creation of DTs were related to the collection of data via sensors, such as disruptions of the data transmission channel, discharging of the sensor's battery, and optimal number and placement of sensors.

Lu et al. [8] and Lu et al. [9] presented an architecture for the creation of DTs at both the building and city levels, with emphasis on the operation and maintenance phase of the building development lifecycle. The authors demonstrated the practicality of the proposed architecture by developing a DT of the West Cambridge site of the University of Cambridge in the UK. The implemented use case integrated heterogeneous data sources with effective and efficient data query, analysis, and decision-making in the operation and maintenance phase. In addition, the authors highlighted the challenges involved in the creation of DT in real practices.

3.3. Digital Twin for Asset Management

The articles in this category mainly focus on the implementation of a DT for asset management throughout the asset's lifecycle. Asset-related decision-making is a crucial process in asset management. There is a need for informed decision-making, which requires data/information management. Digitization aids in asset management. For instance, sensors can help in data collection, whereas advanced digital controls ensure zero/unplanned downtime of assets with cost-effective management. To highlight the need for decision support in asset lifecycle management, and to reflect the potential of a DT for decision support, Macchi et al. [10] discussed the role of the DT in asset management, in particular in asset-related decision-making processes, via a conceptual article. The asset-related decision-making process consists of 4 principles and two aspects as follows:

Principles:

- Lifecycle orientation (the decision making should incorporate long-term objectives)
- System orientation (relevance of the decision on the system and not only on the individual components)
- Risk orientation: decision making should be followed by risk management approaches
- Asset--centric orientation: focus on asset's data and information

Aspects of the decision-making process (the following aspects should be considered while making an asset-related decision):

- Asset lifecycle: how the decision will affect the asset over the long term
- Asset hierarchical control level: at what level is the decision was taken (strategic/tactical/operative level)? To ensure that other levels are also aligned with the decision.

The decision-making process requires proper data/information management. Currently, data/information management is not fully linked to the lifecycle management of assets. The DTs can address this gap. The authors in the article explain the importance of DT in asset-related decision-making via use cases. The use cases are taken from the projects in which the authors participated in the past. These use cases are divided based on the asset control levels (i.e., strategic, tactical, and operational) and asset life cycle phases (i.e., beginning of life, middle of life, and end of life). The data from the digital twin can be used for asset configuration, asset reconfiguration, asset reconfiguration and planning, asset commissioning, and asset condition monitoring and health assessment.

Heaton and Parlikad [11] explained the design and development of DT using a BIM-based approach and developed an Asset Information Model (AIM) that enables the creation of digital twins. AIM is the data and information that relates to assets to a level required for the proper functioning of the asset management system. The authors have demonstrated the concept using a case study of the West Cambridge campus.

The approach of developing AIM to support the creation of digital twins consists of the following steps:

- Classification of assets (based on their output, such as heating, ventilation, power, and lighting) within a BIM model. Document the classification system using UML diagrams.
- Development of an AIM relational database derived from the UML diagrams of the developed classification system.
- BIM models linked to the database within a single federated model.

Lu et al. [12] analyzed the literature and industry-defined standards that impact the BIM and asset management within the operation and maintenance phase. The authors proposed a DT-enabled framework for smart asset management. The DT aids in the development of dynamic digital models that automatically learn and update the status of the physical counterpart asset. Bolshakov et al. [13] highlighted the approaches of organizing the lifecycle management of technical systems, assets, and infrastructures using DTs. In addition, the authors pointed the need for formal definitions and standardization for implementing DTs in real practices.

3.3. Digital Twin for Sustainability

The articles in this category focus on employing DT to analyze the sustainability of structures. Kaewunruen and Xu [14] analyzed the design, construction, and maintenance process of a railway station in London using BIM and DT. The authors transformed the 3D model of the structure into a 6D BIM model consisting of the time and cost schedule along with the carbon emission calculation. The authors showcased the use of BIM for predicting the sustainability of the structure during an emergency and critical situation. They simulated three renovation options in case of a fire emergency and revealed the best option based on cost and carbon emission. Kaewunruen et al. [15] introduced a DT-enabled lifecycle assessment for sustainability and vulnerability evaluation of a subway station in China. Using DT, the authors benchmarked the estimated cost and carbon emission at each stage of the project lifecycle. The simulation results revealed that the construction stage amounts for the highest cost, whereas the carbon emission is the highest in the operation and maintenance phase. The authors also evaluated the cost and carbon emission of different materials and simulated various renovation options to assess their efficiency in terms of cost and carbon emissions.

Tagliabue et al. [16] proposed a framework to shift the manual static sustainability assessment to a DT and IoT-enabled approach. The proposed framework is evaluated in a real scenario at an educational building of the University of Brescia. The authors showed the effectiveness of the DTs for sustainability-related decision-making. Orozco-Messana et al. [17] focused on the development of the procedure for developing a resource-efficient DT model of a neighborhood for evaluating its lifecycle analysis and sustainability assessment. Francisco et al. [18] leveraged the data from smart meters to develop daily building energy benchmarks, divided by periods such as the occupied period during the school year, the unoccupied period during the school year, the occupied period during summer, the unoccupied period during summer, and peak summer period. The simulation results revealed that across all the buildings under study, periodically segregated energy scores were significantly distinct from the score during the overall period. The authors suggested integrating segregated daily efficiency metrics into DT-enabled energy management platforms.

3.3. Digital Twin for Heritage Restoration

The articles in this category focus on the use of DT and BIM technologies to enable efficient and robust documentation, analysis, and restoration of heritage buildings. The documentation of heritage buildings is necessary to facilitate the preservation and safeguarding the valuable built heritage. However, the documentation procedure involves vast diversity of data interpreted in isolation by different stakeholders. Khalil et al. [19] reviewed the documentation areas for heritage buildings and categorized the data into four types: 1) archeology/historic data, related to the historical context of the building, 2) geometry data, related to the shape and characteristics of the building, 3) pathology data, related to the decay or damage of the building, and 4) performance data, related to the performance of the building in terms of energy, thermal, comfort, safety, and security. In addition, the authors highlighted the technologies related to the data types and their potential relations and connections. The authors discussed the need for Heritage BIM (HBIM) for documentation of historic building data, that can combine the qualitative and quantitative data while facilitating the integration of multiple stakeholders. Jouan and Hallot [20] presented the application of digital twin to enable site managers in the conservation of historic assets. The authors revealed that threats to site integrity can be predicted based on the onsite sensors' data.

4. Conclusions

The concept of DTs in AEC/FM is a novel field of study. Although many practical applications of DTs can be found in the aviation and manufacturing industries, only a few examples of DTs can be found in AEC/FM industry. This review study found literature reviews and few proofs-of-concept for the implementation of DTs in the AEC/FM industry. However, studies targeting DTs implementation in terms of asset management were very early research efforts trying to identify the areas and targeting the 'how' part of the implementation of DTs in the asset management domain.

Moreover, this systematic literature review identifies the potential applications of DTs targeting the asset management domain within AEC/FM and presented a detailed discussion. Three main areas were Asset management of already built facilities and infrastructures throughout their lifecycles, assessment and retrofitting for sustainability for existing facilities, and restoration of heritage buildings and their efficient management.

Future research efforts could further explore the true potential of DTs in the asset management domain by presenting practical frameworks, techniques, methodologies, and case studies of real-life projects. Such efforts will improve the understanding of the industry and open more avenues for research and technological development for revolutionizing the asset/facility management domain of the AEC/FM industry.

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Green Concrete from Palm Trees Waste

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Abstract: Concrete is the most widely used building and construction material. However, it is harmful to the environment due to the reliance on traditional cement as its main component. Many countries and research tend to rely on environmentally friendly components in the manufacturing of concrete instead of cement, or at least reduce the percentage of traditional cement. In this study, wastes of palm tree are processed with grinding, heat treatment and purification to prepare powder of palm ash with reduced carbon content and increased pozzolanic activity. To make green concrete; the cement content in concrete was substituted with palm ash in various proportions: 0%, 20%, 40%, and 60%. The samples are investigated to evaluate the possibility of partially utilizing the palm ash to replace regular cement in concrete, in which compressive test was conducted. The results showed that the palm powder/ ash exhibited a significant improvement in concrete strength, especially at the 40% substitution levels with a comprissive strength of 37 MPa. Moreover, the use of palm ash reduces water absorption in concrete, making it more durable. Thus, the as prepared green concrete can be used in construction applications. That will support the process of green economy and sustainable environment.

Keywords: Green concrete; Palm wastes; Date palm ash; Compressive strength

1. Introduction

Concrete is one of the most vital materials in the construction sector. It is the basic material most used for infrastructure and construction development for any project in any country. As the population grows around the world, the need for concrete increases in order to construct more cities and housing units and develop infrastructure. One of the disadvantages of this current form of concrete is that it leads to very high carbon emissions. It is also completely environmentally unfriendly and does not degrade in the soil. If the negative impact of concrete on the environment get compared, it is very huge compared to other building materials such as steel and wood. Several studies have indicated that cement contributes at least 8% of total carbon emissions. The production of cement used in conventional concrete consumes at least 3% of the global energy. Indeed, traditional concrete consumes a lot of fresh water under conditions that the world suffers from a shortage of drinking water. With the increase in the consumption of conventional concrete, the world will suffer in the future from more pollution and waste of important natural resources. This makes the search for an alternative so essential [1-3].

One study revealed that the production of a ton of portland cement is accompanied by the emission of (approximately 1.1 tons) of carbon dioxide and other harmful gases and fumes. Moreover, the production of a ton of cement leads to the emission of 164 kilograms of dust, which results in an increase in global warming, In addition to environmental and health damage, and an increase in the proportion of respiratory diseases, such as asthma, pulmonary fossilization, lung cancer, kidney failure, and other dangerous diseases [4,5].

The term green concrete refers to any type of concrete that consumes less energy than current, and emits less carbon than the current ratio) will save the natural environment resources due to the dependence of this type of concrete on the recycling of residues and waste. Therefore, green concrete can be made from many alternatives and wastes. But at the same time that green concrete should have a standard level of strength and durability. It is not possible to rely on green concrete with poor durability. There are many studies done on green concrete. Some of those studies have proven that green concrete is a must today [6-8].

The production of conventional concrete harms the environment and society very greatly, and it is one of the most energy-consuming processes. The importance of this study lies in getting rid of these negative effects. The development of green concrete will also contribute to reducing the cost of construction while preserving quality, especially since cement and concrete are among the most environmentally harmful building materials in terms of carbon emissions, as the traditional cement manufacturing process consumes dense energy and generates carbon dioxide in large quantities. This sector is responsible for about 5% of total gas emissions. In short, the importance of this study lies in listing the details of green concrete that support the process of sustainable construction, and its application affects significantly increasing the life of concrete installations and preserving the environment, health and safety [9-11].

2. Experimental methods

2.1 Preparation for palm powder

In order to obtain palm powder (palm leaf powder and fiber), the following steps are used; (i) completely dry palm leaves and fibers were collected, to ensure that they do not contain water. (ii)) burn the fibers and leaves in the oven until there was no smoke completely, and this is to get rid of all carbon dioxide, (iii) install a filter on the smoke nozzle to reduce the carbon emission to the air, in order to protect the environment, (iv) at the end, ash is obtained with a light gray color, then the ash is sieved twice to ensure that there are no impurities or plankton, and this is to be sure that it is pure. As shown in Figure 1. Sieve analysis of the as perpared palm powder/ash was carried out with sieve size No. 4, 10, 40, 100 and 200. The percentage passing of palm powder is shown in Figure 2. The as prepared was visualized under scanning electron microscope (SEM). *Chemical composition analysis* of the as prepared palm powder *was conducted using* mineralogical analysis technique.

Figure 1. Preparing the palm waste ash steps; (a) the different components of lignocellulose wastes of UAE date palm tree, (b) Oven, (c) Grinder, (d) the obtained powder (palm ash).

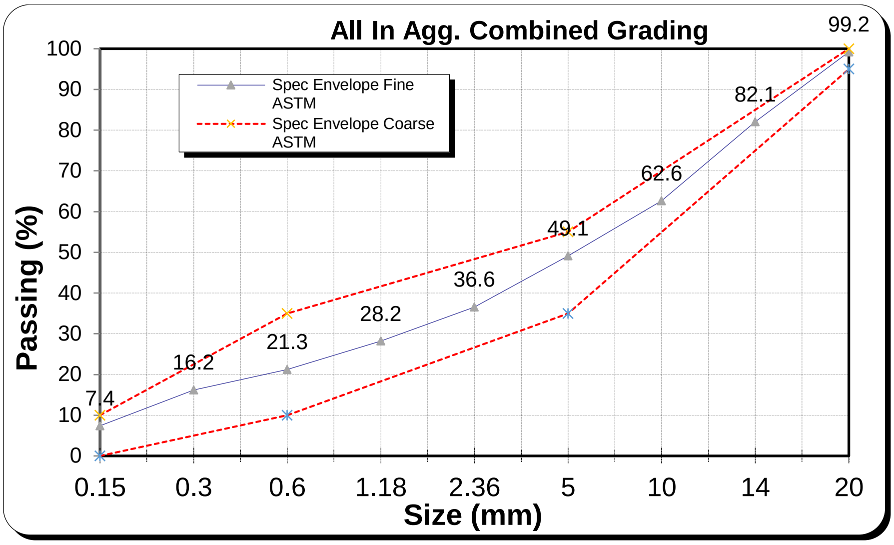

Figure 2. Sieve analysis of palm powder.

Preparation of the cement mix

The samples are prepared, and tested twice and the average of the results has been taken. (i) The mixture can be created in the standard methodby mixing all the ingredients together based on the standard amounts to prepare normal concrete. (ii) The dry concrete mix was loaded into the concrete mixer according to the required amount. Then, the required amount of water was added to the concrete mix. After that, the required amount of SP495X Sodamco was added to the concrete mix. Finally, the mixed concrete was poured into the molds. (iii) A cement mixer was used to mix the ingredients until a homogeneous mixture was created. (iv) The mixture then was poured into the molds, as shown in Figure 3.

All samples are sized to ensure the impartiality of the experiment. All samples are cube shaped with the following dimensions: 10 cm * 10 cm * 10 cm as shown in Figure 4. In the end, 8 molds were created with the following specifications; (a) Two cubes of normal concrete. (b) Two cubes of concrete 20% palm ash. (c) Two cubes of concrete of 40% palm ash. (d) Two cubes of concrete of 60% palm ash, as shown in Figure 4. The effect of date palm ash percentage on the concrete specimens were evaluated at the age of 20 days of curing, as per ASTM C 109 using compression testing machine at standard loading rate.

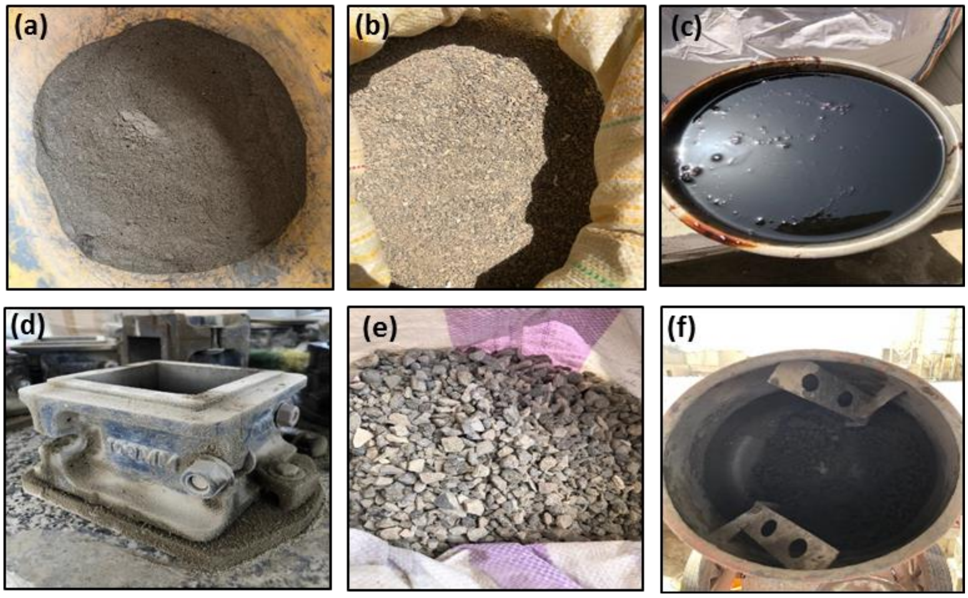

Figure 3. Components of ash powder;(a) Palm waste ash (b) Soft Aggregate (c) SP495X Sodamco/Fosroc (d) Mold 10 cm x10 cm x10 cm (e) Large aggregate (f) Mixer

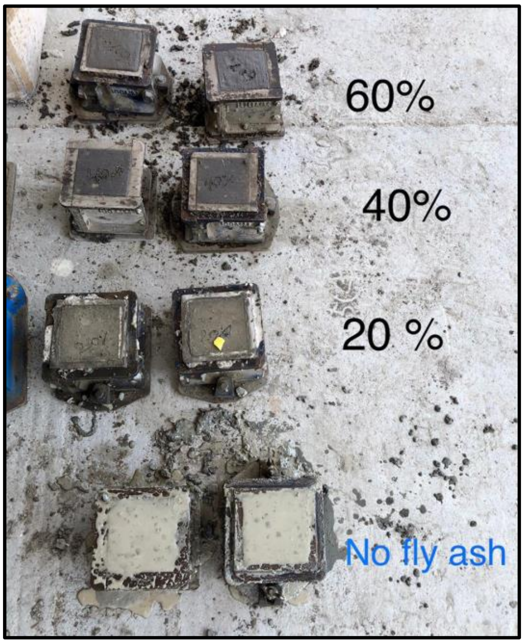

Figure 4. Image of the as prepared green concrete samples in the molds with different palm waste percentages.

3. Results and Discussions

3.1 Morphology and chemical structure of palm powder/ash

Figure 5 shows the SEM image of the as prepared palm powder, the images show the porosity of the as prepared palm powder. Table 1 shows chemical compositions table of palm ash via the citric acid solution leaching treatment with different concentrations. Phase analysis by x-ray diffraction shows that quartz (SiO_2), calcite ($CaCO_3$) and kalsilite ($KAlSiO_4$) in palm ash mainly exists as crystalline substance. SiO_2 is the most chemical composition by about 46%, followed by K_2O with 23.3%**.**

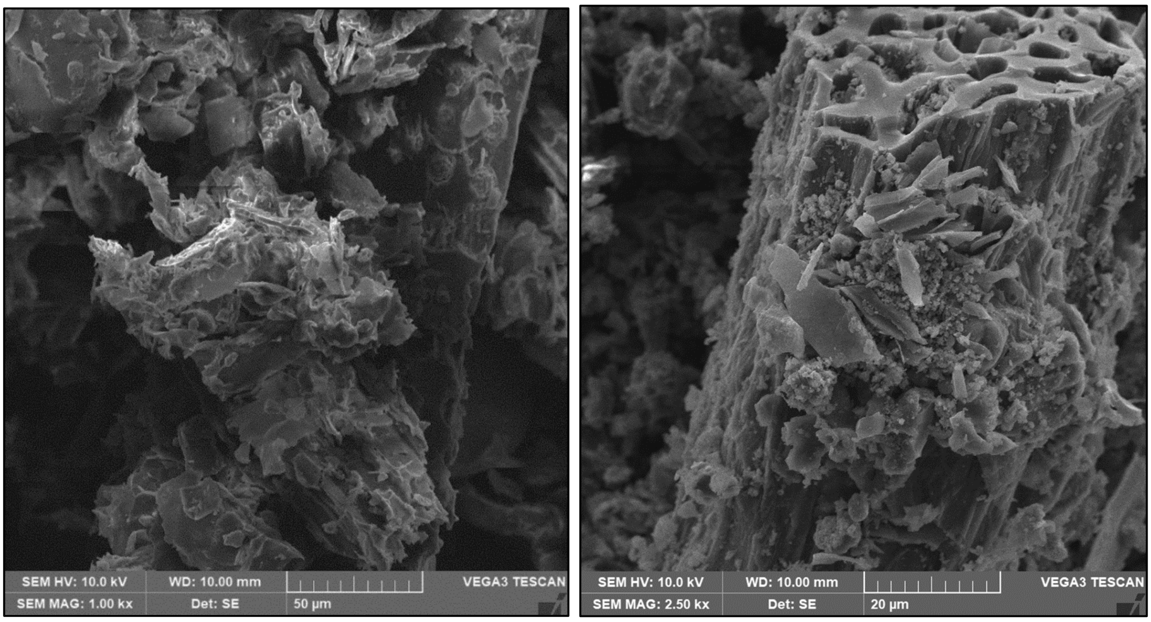

Figure 5. SEM image of the as prepared palm powder

Table 1. Chemical composition of palm powder

Element	Percentage (%)
SiO_2	45.50
MgO	3.20
P_2O_5	5.38
K_2O	23.30
Fe_2O_3	3.26
CaO	12.80
Al_2O_3	5.40
Others	1.16%

3.2 Compressive strength

All the samples were tested using the compression testing machine. The results proved that green concrete (powder of palm tree waste) is more compressive strength than conventional concrete that contains 100% cement. Also, palm soil and fibers have more fillers and gaps than pure Portland cement. The results also showed that the mixture containing palm soil and frond fibers was stronger than the traditional mixture. The results show that the best mix was the 40% palm powder/ash mixture because it has the best compression strength result as shown in table 2. By comparing the results, we find that the two highest results were the concrete mixture (0% ash, 100% cement), and the concrete mixture (40% ash, 60% cement). By setting environmental protection standards and the rest of the characteristics of green concrete, a sample (40% ash) becomes the ideal sample because it equals the strength of pure concrete. Ash gives concrete a number of qualities such as strength, permeability, and cracking. It also extends the life and increases resistance to weathering [12-14].

One of the primary benefits of fly ash is its reaction with available lime and alkali in concrete, producing additional cementitious compounds. The following equations illustrate the pozzolanic hydration reaction of palm powder with lime to produce additional calcium silicate hydrate (C-S-H) binder 10]:

$$\text{Cement Reaction: } C_3S + H \rightarrow C\text{-}S\text{-}H + CaOH$$

$$\text{Pozzolanic Reaction: } CaOH + S \rightarrow C\text{-}S\text{-}H$$

Table 2. Mechanical properties of palm powder

Mix	Spec. No.	Dimensions (mm)			Mass (Kg)	Density (Kg/m³)	Max Load (KN)	Comp. Strength (N/mm²)	Type of Fracture
		L	W	H					
0% Fly Ash	1	100	100	100	2.450	2450	374	37.5	Satisfactory
	2	100	100	100	2.300	2300	372	37.4	Satisfactory
20% Fly Ash	1	100	100	100	2.380	2380	327	32.5	Satisfactory
	2	100	100	100	2.370	2370	340	34.0	Satisfactory
40% Fly Ash	1	100	100	100	2.430	2430	370	37.2	Satisfactory
	2	100	100	100	2.410	2410	372	37.0	Satisfactory
60% Fly Ash	1	100	100	100	2.470	2470	242	24.0	Satisfactory
	2	100	100	100	2.370	2370	271	27.0	Satisfactory

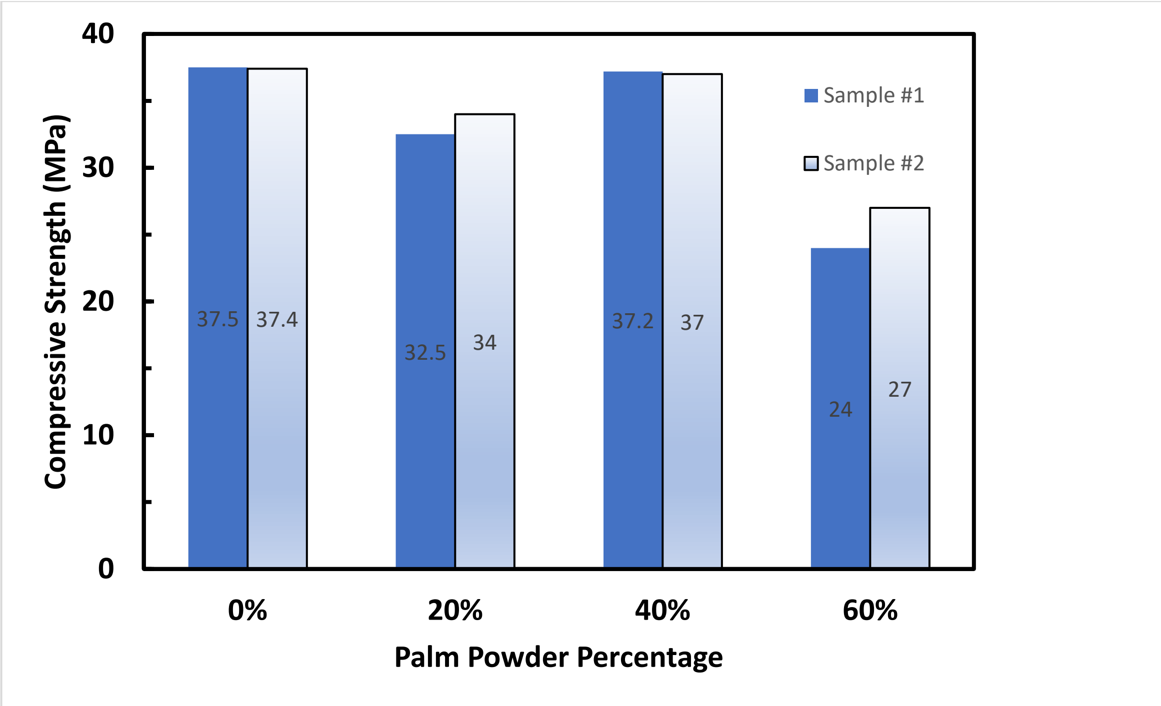

Figure 6. Compressive strength of the concrete samples

Pressure test results identify the samples that have the highest resistance to external pressure. The results of the samples for the same percentage of palm ash were very close, and this confirms the validity of the test and that the results are realistic. But by comparing the results of samples from different groups, we find that the strength of resistance to external pressure decreased to 34 N/mm^2 when we added 20% of the ash, and we reduced the percentage of cement to 80%. When we increased the ash content to 40%, and decreased the cement percentage to 60%, the compression results rose again to 37.2 N/mm^2, which are almost the same results as the concrete mixture with 100% cement and 0% ash. And the last sample with 60% ash returned the results to a very low value of 27 N/mm^2.

The study showed that green concrete is as strong, if not stronger, than traditional concrete. It is also environmentally friendly and has many benefits. Making green concrete from local waste contributes to environmental protection. Provide more amounts of concrete annually. Green concrete saves the fossil fuels required to make conventional concrete. Green concrete is environmentally friendly and reduces carbon dioxide emissions. Some types of green concrete are able to absorb carbon dioxide from the air. Green concrete does not need a lot of fresh water. Construction costs with green concrete are much lower than regular concrete. The palm tree is the symbol of the Arab Gulf Area, and today palm trees are essential for public road decoration. With the frequent cultivation of palm trees, whether for decoration or for the production of dates, palm waste is increasing continuously. The palm waste can be used environmentally instead of burning or burying it.

Green concrete is a sustainable and energy efficient building material. It produced from waste materials, specifically palm waste, creates long-lasting, rust-resistant structures that won't rot or burn. Concrete building products can have life spans that are double or triple that of other typical building materials. Because they take advantage of concrete's natural thermal properties such as ability to absorb and retain heat. Thus homes designed with green concrete walls, foundations, and floors are extremely energy efficient. This means that homes can save money on heating and cooling by installing smaller-capacity HVAC equipment. Green concrete reduces the impacts that contribute to the formation of urban heat islands. Light-colored concrete pavements and roofs absorb less heat and reflect more solar radiation than dark-colored materials like asphalt, resulting in lower summer air conditioning demands. Green concrete may be made in the exact proportions required for each project, resulting in less waste. After a concrete structure has served its original purpose, it can be crushed and recycled into aggregate for use as backfill or road base in new concrete pavements.

4. Conclusion

In this study, palm powder/ash has been made by grinding the burned palm wastes such as kernels, fronds, and palm tree wood to make (ashes) or granules that can be used as an binder in making concrete. Then ashes were mixed with the rest of the materials such as water, sand and a small percentage of the traditional cement material. Replacement of 40% palm powder/ash has produced compressive strength up to 37 MPa which is a high value compared to traditional concrete. Less cement can be used (approximately 10% to 20% of the usual rate will be saved), thus a more environmentally friendly mixture have been made. This mixture is expected to be strong enough to replace the cement boards that are used in construction. Date palm ash has been discovered to have a lot of potential, and it may be used as a construction material to reduce CO_2 emissions while also lowering building costs without sacrificing the structures' service life.

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3D Concrete Printing for Sustainable & Affordable Housing Construction-Comparative Study

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Abstract: The construction sector's contribution to environmental pollution is not hidden, which is evident from its staggering 50% share in global climate change. Therefore, changing the conventional construction methods to be more sustainable is the most sought-after topic in recent days. 3D Concrete Printing (3DCP) has become the center of attention due to its digital fabrication technology, resulting in low construction waste and high health and safety standards in the construction process. However, 3DCP is still a work in process and poses serious constructability challenges to be widely adopted in the construction market. One of the many challenges is the effect of 3DCP on overall building cost and global carbon emissions. This paper discusses the application of 3DCP on two-story residential construction in the UAE, where Precast Concrete (PC) construction is the popular practice for such buildings. For this purpose, a case study of 6 Unit Townhouse building in an existing mass housing project using PC construction in the UAE is selected and redesigned using 3DCP. Construction duration, cost, and CO_2 emissions were evaluated for both construction types. The findings of this research support the potential of 3DCP to be adopted for sustainable and affordable housing construction.

Keywords: 3D Concrete Printing; Comparative Study; Cost Analysis; Precast Concrete

1. Introduction

The affordable housing demand has been on the rise in the past few decades with developing countries particularly focusing on improving the living standards of lower and middle income households. The low-cost housing demand is also a result of population growth and urban migration, which is estimated at 440 million urban households required for 1.6 billion population growth by 2025 [1]. Moreover, with the economic volatility and the downsizing caused by COVID 19 pandemic, the lower and middle income households are further financially stressed with unemployment and salary cuts. According to residential ownership statistics [2], the affordability of the house measured in terms of house price to income ratio depicts a gruesome picture with the cost of the house as high as 30 years of accumulated income. Many irrepressible factors influence the ownership cost of the house amongst which the cost of construction has a significant share and is the subject of this research. In order to achieve the desired affordability, efficient construction practices utilizing digital fabrication can be implemented which have a minimum footprint in terms of wastage and resource utilization. Since the wastage induced in construction is directly associated with the raw material procured, the direct material cost can be reduced while also curbing the carbon footprint. In the context of the climate-related demands of decarbonizing the cement and steel industry, the implementation of digital construction can be an effective decarbonization strategy by minimizing the consumption of construction materials. Besides, fabricating digitally without the need for formwork enables the adoption of mass customization in construction without impacting affordability [3]. The mass customization aspect coupled with the environmental efficiency can make digital construction an extremely attractive proposition.

Digital construction, in essence, makes use of artificial intelligence and robotics to fabricate and construct buildings, ensuring minimum human intervention. 3D Concrete Printing (3DCP), being at the forefront of digital construction, employs extrusion-based techniques to fabricate buildings using concrete as an ink material. Gantry or robotic arm printers are used, which take input in the form of a CAD Model to create vertically extruded profiles using layer-by-layer manufacturing process. [4]. With the advent of new technologies, the equipment and processes are getting efficient with enhanced performance and economic viability. However, other aspects, including the validity for printing and long-term durability specified under a building regulatory framework, are of utmost importance for the technology to be a commercial success.

Compared with conventional concrete construction, the major advantage associated with 3DCP is the reduction of material usage and wastage, mainly due to automation. The digital fabrication carried out using computer-guided trowels not only cuts the use of formwork but also aids in reducing the wastage resulting from human error. Secondly, 3DCP construction practice has evolved around the idea of building structures with minimum use of reinforcement resulting in cost-effectiveness and rapid construction. Additionally, the technology utilizes CAD integration with the printer resulting in nearly perfect shaping of complex geometries. However, owing to constructability challenges and the structural complexities associated with the ink material, the use of 3DCP is so far limited to low-rise structure.

The comparative studies involving 3DCP and conventional construction are available in only a handful of publications which depict varied results largely due to the associated cost of printer and print material. Allouzi et al. [5] conducted the material cost comparison of 3DCP against conventional RC bearing wall construction for a Multi-purpose Hall building in Jordan. The figures obtained showed that 3DCP construction resulted in 48% lesser material consumption coupled with 67% savings in cost. Jagoda et al. [6] conducted the cost comparison to construct pyramid shaped military fortification using 3DCP and conventional RC construction. The elemental cost comparison showed that the labor cost for 3DCP was 70% less along with the printer cost, which resulted in a 37% reduction in the cost of formwork associated with RC construction. However, the mortar mix procured for the printer incurred almost 472% higher costs resulting in the cumulative total cost of construction for 3DCP which was 51 % higher than RC construction. Furthermore, Mohammad et al. [7] carried out a comparative life cycle assessment of 3DCP against conventional construction. They evaluated five different environmental impact categories for both 3DCP and conventional construction comprising RC frame construction with block masonry walls. They were able to conclude that using 3DCP with reinforcement resulted in higher Global Warming Potential (GWP) & Fossil fuel depletion (FFD). Therefore, novel reinforcement techniques should be developed for 3DCP to improve its environmental efficiency.

3DCP has also been compared to the Precast Concrete (PC) construction method in few publications with an aim to broaden the spectrum of the comparative studies involving the efficiency evaluation of the 3DCP method. For example, Weng et al. [8], based on constructed bathroom unit, concluded that 3DCP could achieve a reduction of 34.1%, 85.9%, and 87.1% in the cost, CO_2 emissions, and energy consumption, respectively, in comparison with the same unit constructed by PC method. PC construction involves off-site manufacturing methodology by prefabricating concrete elements in the factory, which are then transported and erected at the site [9]. With a high-quality finish, cost efficiency, fast-paced delivery, reduced weight of the superstructure and resource reutilization, PC construction offers an attractive solution for affordable and sustainable housing [10]. Owing to the popularity of PC construction in the context of residential construction in the UAE, the true potential of 3DCP can only be realized when compared with the prevalent practices of commercial value. Therefore, this paper aims to investigate the affordability and sustainability of 3DCP in comparison with PC construction.

2. Materials and Methods

To perform a comparative study between 3DCP and PC techniques, a two-story townhouse building comprising of typical units is selected from an existing mass housing project built using PC construction in UAE. This section discusses the methodology adopted for the design, including the building geometry, design considerations and the construction methodology in detail. Furthermore, the mechanisms for evaluating construction cost, duration and CO_2 emissions are discussed along with the wholesome comparison of the two construction practices.

2.1. Building Geometry

A typical townhouse building comprises units paired in the form of clusters. An individual unit comprises two stories with a 3.5 m story height connected by an internal staircase. Each unit has a typical architecture illustrated in Figure 1; with a built-up area of 302.16 m^2 for end units and 284.28 m^2 for middle units. For this study, a 6-unit cluster is selected as illustrated in Figure A1 (Appendix A) with a total built-up area of 1765.8 m^2. However, in order to simplify the design, following modifications are made to the original architectural design:

- The architectural design shall be limited to two levels only, considering the limitations of 3DCP to print up to a limited height. This means that the private covered terrace at the upper roof level shall not be available.
- The doors and window width on the ground & first floor have been optimized to minimize the requirement of structural beams at lintels.

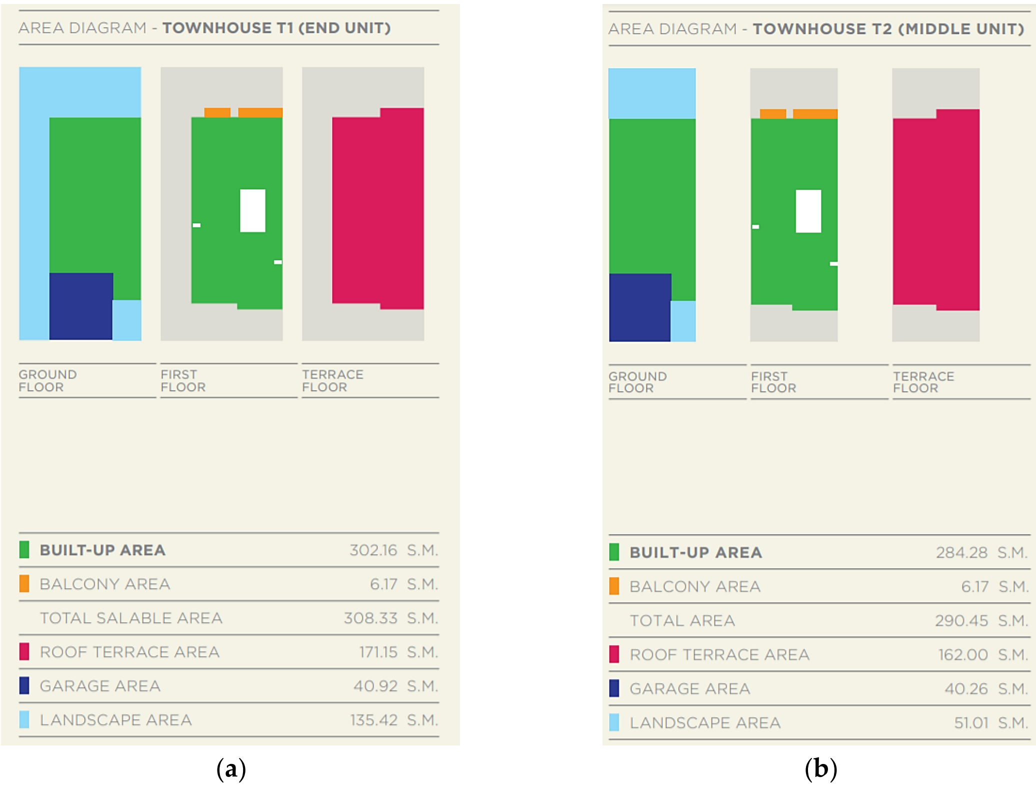


Figure 1. Townhouse Building Area Diagram (**a**) End Unit; (**b**) Middle Unit [11]

2.2. Design Considerations

The occupancy design is carried out in line with the Green Building Regulations and Specifications of Dubai Municipality [12] for the thermal transmittance, acoustic control, vibration and fire endurance limitations. The structural design shall be carried out using limit state design methodology against the loads and actions specified in Section 2.2.1. For PC construction, PCI Design Handbook [13] is used to carry out a detailed structural design. For 3DCP construction, 3DCP walls are used to support PC floor and placed over Cast-In-Place (CIP) footings. The structural design for 3DCP walls can be idealized based on the properties of plain concrete and referenced from the existing literature [14].

2.2.1. Loads & Actions

The loads and actions for occupancy include gravity, wind and seismic loads. Since it is a low-rise construction, the loads from wind and seismic shall be insignificant and gravity loads shall govern the design, including dead and live loads. Dead loads result from the self-weight of elements forming the permanent part of the structure specified in Table 1. Live loads are variable actions resulting from the use and occupancy as per ASCE standards [15].

Table 1. Gravity Loads applied to the building

Floor	Dead Load		Live Load [15]	
	Type	**Value (kPa)**	**Type**	**Value (kPa)**
Ground / First	Mortar Bed & Tiles (75 mm)	1.25	All other areas except stairs	1.92
	Partition walls	1.75	Stairs (one & two family dwellings)	1.92
	Ceiling + Services	0.5		
Roof	Built up Roofing	2.5	Ordinary Flat Pitched & Curved Roofs	0.96
	Ceiling + Services	0.5		

2.2.2. Material Properties & Structural System

The structural system adopted for both 3DCP and PC is a bearing wall system supported over strip footings. The superstructure consists of concrete floor supported directly on the walls which shall be designed to withstand and transfer loads to the supporting elements. Additionally, the concrete floor shall ensure the diaphragm action by monolithically tying the walls together. The substructure comprising of concrete strip footings shall be laid on compacted soil and designed to withstand all the loads from the superstructure.

The materials adopted for PC and CIP is normal weight concrete reinforced with ASTM A615 Grade 60 reinforcement [16]. 3DCP uses a specialized concrete mix with rheological properties suitable for printer and print environmental conditions. In this study, the 3DCP ink with a mix composition specified in Table 2 is selected, referenced from the existing literature. As shown in Table 2, the superplasticizer counts 1.48% from the mass of the binder. The material properties for both PC and 3DCP are specified in Table 3.

Table 2. 3DCP Ink Mix Composition [17]

Material type	Cement	Fly Ash	Silica Fume	Fine Aggregate	Water	Superplasticizer
Quantity (kg or Liters/m^3)	579	165	83	1167	261	12.2

Table 3. Material Properties

Methodology	Material Properties	Value
PC / CIP	Compressive Strength (28 Day) f_c'	32 MPa
	Unit Weight γ_c	2400 kg/m^3 [18]
	Reinforcement (Grade 60) f_y	420 MPa [16]
	Unit Weight γ_s	7850 kg/m^3 [16]
3DCP	Compressive Strength (28 Day) f_c'	40 MPa [14]
	Unit Weight γ_c	2200 kg/m^3 [17]

2.3. PC Construction

PC construction comprises superstructure made up of external insulated sandwich panels and internal solid panels supporting Prestressed Hollow Core Slab (HCS) flooring topped with CIP concrete screed. HCS flooring is quite popular owing to its low self-weight and longer spans [13]. Partition walls shall be non-load bearing and shall also be made using PC. The substructure includes PC footings with solid up-stand walls supporting superstructure walls. The grade slab shall be CIP which shall be connected to PC elements by means of dowel connections. The PC elements at the story level are connected horizontally through PVL loops and vertically by dowel sleeve connections filled with concrete grout at the site. PC elements do not require any finishing at the site as all the MEP fixtures are embedded in the factory. The typical layout for PC building along with wall sections is illustrated in Figure A2 (b) (Appendix A).

2.4. 3DCP Construction

3DCP construction comprises of superstructure walls made up of two leaves with a cavity in between, filled by a chevron pattern. Leaf thickness of 40 mm is selected based on the existing literature [19]. The external walls are insulated with an extra leaf required to accommodate the layer of insulation as illustrated in Figure A2 (a) (Appendix A). Similar to PC construction, HCS flooring shall be adopted for 3DCP along with CIP grade slab; however, for the substructure, CIP strip footings are used unlike PC construction. The concrete grout shall be used at the connection interface of 3DCP walls and CIP footings. 3DCP walls shall be plastered and cut at the site for finishing and MEP fixtures incorporation.

2.4.1 Selection of Print Method

The print methodology available for on-site printing is contour crafting technology using robotic arm or gantry printing. The robotic arm printer exhibits improved quality and soundness due to its 6 axis rotation resulting in increased mobility [20]. Alternatively, the gantry printing system comprises actuator-controlled trowels which translate in the 3 dimension along X, Y & Z axes in Cartesian coordinates. For this study, a gantry printing system using contour crafting methodology has been selected due to the following reasons.

- Gantry-based systems have lower operation and maintenance cost per hour and are easier to operate [21]
- Gantry-based systems have a higher reach and are suitable for the large-built up area.
- The material wastage associated with the robot arm printer due to unstoppable printing is also a very decisive factor in selecting the gantry-based system.

2.4.2 3DCP Constructability Challenges

The main complexity in the 3DCP lies around the provision of openings since the application 3DCP is so far limited to vertical elements only; therefore, the lintel beams around windows and doors require other alternatives. As per one manufacturer Apis Cor [22], Precast U lintels have been successfully employed in 3DCP around windows and doors. Precast U lintels with sleeves are connected with rebar running in the hollow unit which is later grouted with concrete to form a composite section (Figure 2).

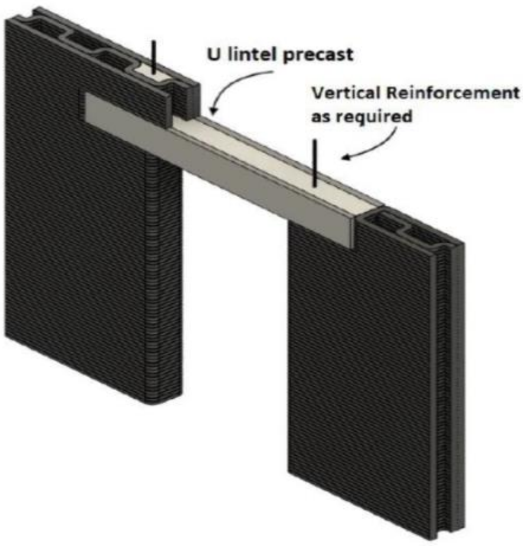


Figure 2. 3DCP Wall Opening Detail [22]

2.5. Cost Analysis

The cost analysis for PC and 3DCP was performed based on the quantity takeoff estimated for each construction methodology in Tables B1 & B2 (Appendix B). The quantity takeoff data includes estimating the volume of concrete consumed and weightage of reinforcement which are then used to evaluate the cost using unit rates specified in Table 4. It is noteworthy to mention here that the construction cost of 3DCP shall include the cost of finishing and cutting of wall for MEP fixtures to draw a fair and meaningful comparison with PC construction. Moreover, the unit cost of construction for 3DCP specified in Table 4 covers the cost of the gantry printer, which was selected for the reasons addressed in Section 2.4.1.

Table 4. Unit Cost Data (UAE Market)

Methodology	Cost	Subtype	Unit Cost
PC	Material	PC	410~431 AED/m^3 [1]
		HCS	87.5 AED/m^2
	Construction	Production	901~1364 AED/m^3 [2]
		Erection	1174 AED/element
3DCP	Material		950 AED/m^3
	Construction		1650 AED/m^3 [3]
CIP	Material	Concrete	250 AED/m^3
		Reinforcement	2450 AED/ton
	Construction		750 AED/m^3

1 Unit cost is calculated inclusive of 87 kg/m3 reinforcement and varies with maximum for insulated concrete.

2 Unit cost varies with maximum for insulated concrete.

3 Unit cost is inclusive of the 3D printer cost.

2.6. Duration Evaluation

The duration evaluation is carried out for all the construction activities based on the manpower productivity data specified in Table-5. The man-hours required per built-up area are evaluated for the quantity estimated in Tables B1 & B2 using the manpower productivity for an 8-hour working day. Similar to cost analysis, the construction duration evaluation for 3DCP shall also include the man-hours incurred to finish and cut 3DCP walls.

Table **5.** Manpower Productivity Data (UAE Market)

Methodology	**Activity**	**Subtype**	**Productivity**
PC	Production	PC	25 man-hour/m^3
		HCS	0.5 man-hour/m^2
	Erection	PC	3.5 man-hour/element
		HCS	0.28 man-hour/element
3DCP	Printing		2.22 man-hour/m^2
	Cutting & Finishing		2.42 man-hour/m^2
CIP	Substructure		28 man-hour/m^3
	Concrete Deck		2 man-hour/m^3

2.7. CO_2 Emissions Calculation

Table 6 shows the CO_2 emissions for the materials involved in each construction technology. The values shown in Table 6 were taken as supported by the references.

Table 6. CO_2 emissions for the materials used in this study

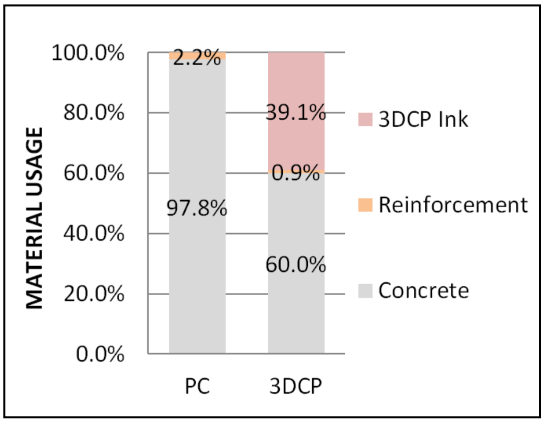
Material type	**Concrete for PC and CIP (kg CO_2/m3)**	**Concrete for 3DCP (kg CO_2/m3)**	**Steel Reinforcement (kg CO_2/kg)**
CO_2 emissions	346 [23, 24]	450 [23, 24]	1.83 [25]

The CO_2 emissions for 3DCP ink has been achieved based on the mix composition specified in Table 2 and the CO_2 emissions for each component material [23, 24]. The total CO_2 emission for each construction methodology is the sum of CO_2 emissions of the materials being used.

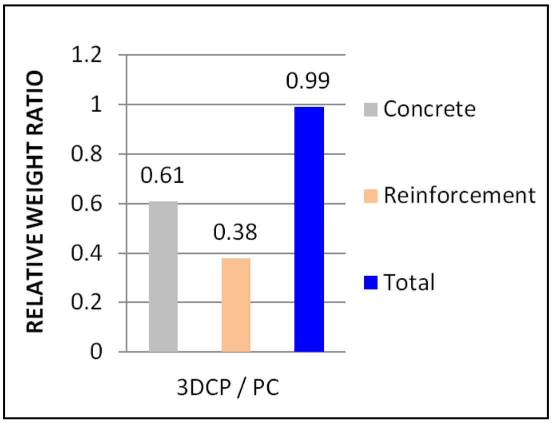
3. Results & Discussion

3.1. Material Quantity & Building Weight

The material consumed for all structural and non-structural elements can be quantified in terms of the building's total weight. The results of the material usage in terms of their contribution in total building weight and the relative weight ratio are illustrated in Figure 3.



(**a**)



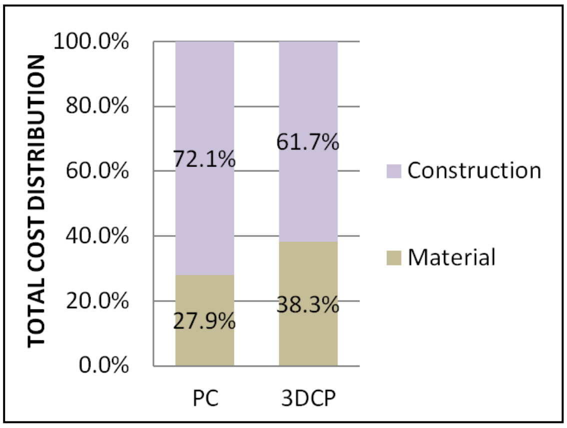
(**b**)

Figure 3. (**a**) Material Usage; (**b**) Relative Weight Ratio

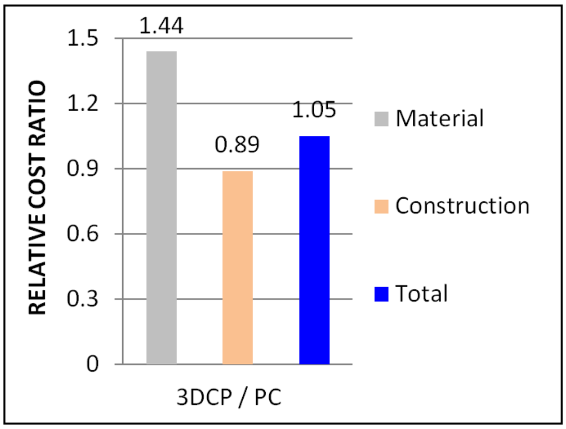
It is quite clear from Figure 3 (a) that the contribution of reinforcement to the total structural weight of the building in both PC and 3DCP construction is minimal, which stands at 2.2% for PC and 1% for 3DCP. For 3DCP construction, the material usage of 3DCP mix in terms of total building weight is 39.1%, which is considerably less owing to quantitative distribution of 3DCP elements in comparison to 60% share of the concrete. Furthermore, the relative weight ratio depicted in Figure 3(b) throws light on the reduction of material usage in 3DCP when compared with PC construction. A reduction of 39% in the concrete consumed is observed in 3DCP, which is replaced by 3DCP superstructure having slightly lesser unit weight. However, the reduction in the reinforcement utilization is noteworthy, which is dropped by 62%. Resultantly, the 3DCP construction tends to be 1% lighter than PC construction over the same built-up area.

3.2. Cost & Duration Comparison

The cost comparison is conducted for the material, construction and total cost over the built up area in Figure 4. As per Figure 4 (a), the contribution of material cost in the total cost is merely 27.9 % in comparison to 72.1% for construction cost for PC construction. The high percentage associated with the construction cost in PC construction is due to the additional activities related to handling and transportation of individual structural elements to the site, which requires cranes and trailer. Therefore, 6% additional costs for equipment hire are also included in the PC construction total cost comprising production and erection costs as shown in Figure B1 (a) (Appendix B). For 3DCP construction, the total cost distribution depicts a share of 38.3% for the material cost and 61.7% for the construction cost. The higher percentage of construction cost in 3DCP construction is associated with the high rental cost of the printer which accounts for 37% of the total cost as shown in the Figure B1 (b) (Appendix B). Furthermore, the relative cost ratio is discussed in Figure 4(b) which compares the material, construction and total cost of 3DCP against PC construction. The relative cost ratio depicts an increase of 44% in the material cost and a reduction of 11% in the construction cost for 3DCP compared to PC construction. The increase in material cost for 3DCP is quite obvious, as the material used for 3DCP ink is expensive and constitutes 22% of the total cost of 3DCP construction, as shown in Figure B1 (b) (Appendix B). The reduction in the construction cost of 3DCP depicted in Figure 4(b) is due to the reduced number of activities in 3DCP construction employing onsite digital fabrication in comparison to offsite manual fabrication of PC construction. Resultantly, a slight increase of 5% in the total cost per built-up area for 3DCP construction in comparison to PC construction can be seen which quite a reasonable figure considering the fact that the 3DCP construction practice is still making its headway into the construction market. However, the high material cost for 3DCP, which affects the total cost, may reduce depending on the printed element configuration. For example, in the current study, a wall of 3 leaves was selected for external walls as depicted in Figure A2 (a) (Appendix A), resulting in more consumed concrete than a 2-leaf wall.



(**a**)

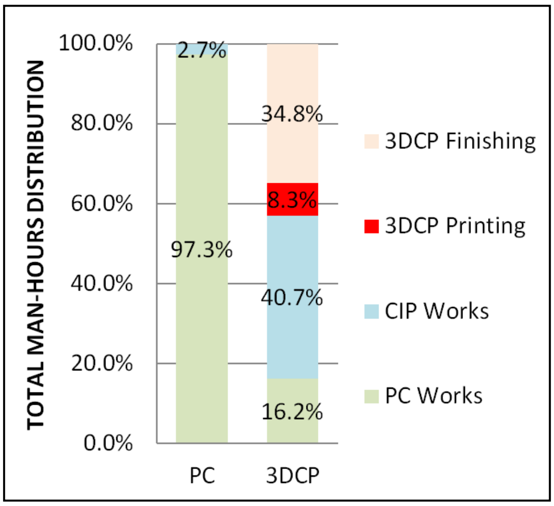


(**b**)

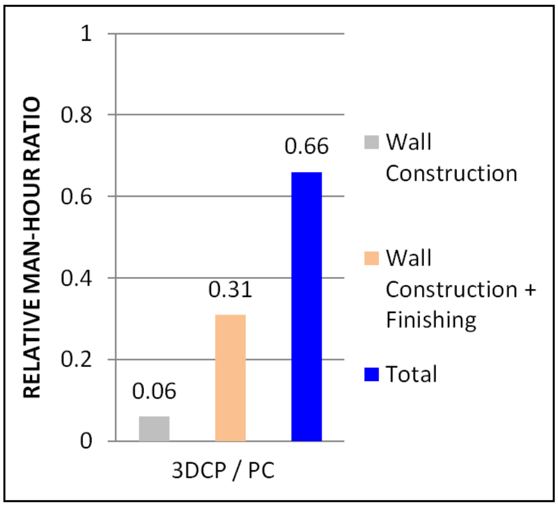
Figure 4. (**a**) Total Cost Distribution; (**b**) Relative Cost Ratio

The construction duration comparison was carried out in terms of man-hours required per built up area for 3DCP and PC construction in Figure 5 which shows the distribution of man-hour for different construction activities in Figure 5(a) and relative man-hour ratio in Figure 5(b). As per Figure 5(a), the trends for PC construction depict that a major share of 97.3% man-hours is allocated for PC works in comparison to 2.7% spent in CIP works for connection and grouting of PC elements. However the man-hour trends for 3DCP are quite uncharacteristic with the highest number of 40.7% man-hours allocated for CIP works and 16.2% man-hours for PC works. The remaining 43.1% man-hours were allocated for 3DCP works with only 8.3% spent in printing of walls and remaining 34.8% in the finishing and cutting of walls. The relative man-hour ratio in Figure 5(b) depicts that the 3DCP is 94% more efficient than PC for the activities related to the wall construction. However, 3DCP is 69% more efficient than PC when finishing 3DCP walls is also taken into consideration. Resultantly, the construction duration evaluation in terms of man-hours required shows that 3DCP is 34 % more efficient than PC (Figure 5b).

The results achieved highlight the benefits of digital fabrication to achieve efficient construction with minimum manpower employed resulting in low man-hours. However, if the duration evaluation in terms of the project completion time is to be carried out, PC may be faster than 3DCP considering faster delivery rate with the PC production capacity benchmarked at 200 m^3/ 8 hour day (UAE Market).



(a)



(b)

Figure 5. (**a**) Total Man-hours Distribution; (**b**) Relative Man-hours Ratio

3.3. CO_2 Emissions Comparison

The comparison of CO_2 emissions is carried out in Figure 6 which shows the distribution of CO_2 emissions per construction material. As per Figure 6(a), the CO_2 emissions for the concrete material are the highest, which stand at 77.5% for PC construction and 47.1% for 3DCP construction. The contribution of the reinforcement in CO_2 emissions is quite significant for PC construction with a share of 22.5%. However, for 3DCP construction, it is only 8.6%. The contribution of 3DCP ink material in the CO_2 emissions is 44.3% which is quite high considering its quantitative distribution in the overall structural volume of the building. In terms of the relative ratio for CO_2 emissions depicted in Figure 6 (b), the CO_2 emissions for 3DCP construction show a reduction of 40% in concrete replaced by 3DCP superstructure. However, the 62 % reduction of CO_2 emissions associated with reinforcement material is noteworthy, highlighting the benefit of 3DCP construction with no requirement of reinforcement. Resultantly, the CO_2 emissions of 3DCP construction are merely 1% less than PC construction due to the high carbon footprint related to the 3DCP ink material. Additionally, the configuration of printed elements that use less quantity of concrete ink plays an important role in reducing the CO_2 emissions. For example, using a 2-leaves instead of 3-leaves for external wall in this study may decrease CO_2 emissions.

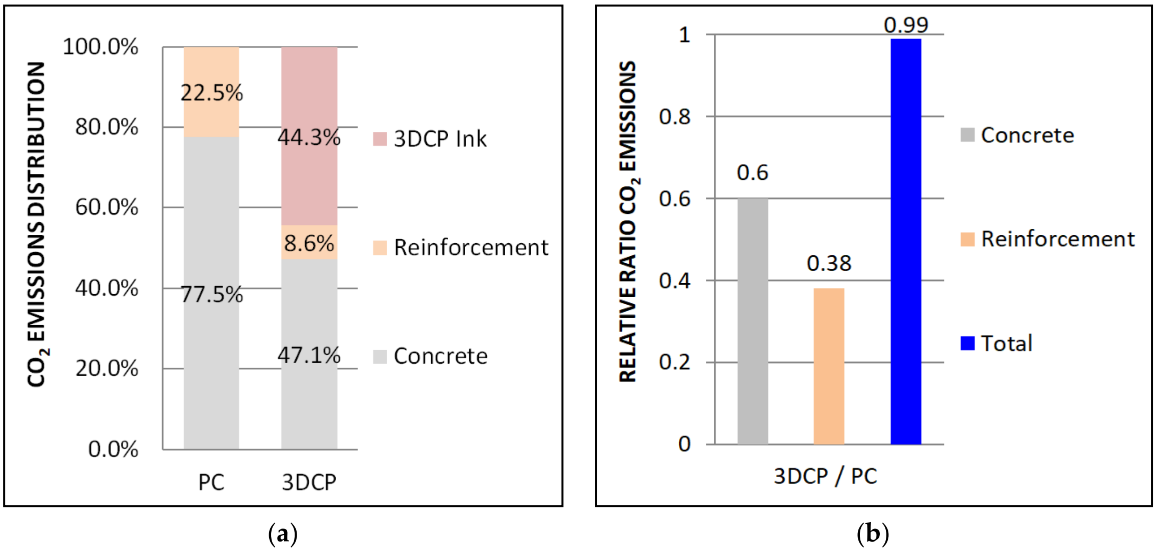


Figure 6. (**a**) Total CO_2 Emissions Distribution; (**b**) Relative Ratio for CO_2 Emissions

4. Conclusions

This work investigated the potential of 3DCP for affordable and sustainable housing construction in comparison with PC. In this regard, a case study of 6 Unit Townhouse building from an existing mass housing project built using PC in UAE was selected and redesigned using 3DCP. The quantity take-off, cost, duration & CO_2 emissions for both PC and 3DCP were evaluated and the findings obtained can be summarized as follows:

- The 3DCP unit shows to have almost the same weight as the PC unit.
- The material cost analysis shows that 3DCP is 44% costlier than PC.
- The construction cost analysis depicts opposite trends with 3DCP cheaper than PC by 11 %.
- In terms of the cumulative total cost of material and construction, 3DCP is 5% costlier than PC.
- The construction duration analysis shows that 3DCP requires 34% fewer man-hours than PC.
- The CO2 emissions calculations show that 3DCP is only 1% more efficient than PC.
- It is to confirm that the configuration of the printed elements plays a significant role in making 3DCP more affordable and sustainable by reducing the quantity of the used printed material.

5. Recommendations for future work

It is recommended that further research is to be conducted on optimization of the configurations of the printed elements to minimize the utilized printed concrete and confirm the mass customization theme. In addition, a comparative study between 3DCP and cast-in-place technique where formwork, brick and mortar walls are in use is recommended. These recommendations are significant to understand the impact of 3DCP technology in reducing the CO_2 emissions of concrete production and the cost of mass housing construction.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A: Building Drawings for PC & 3DCP

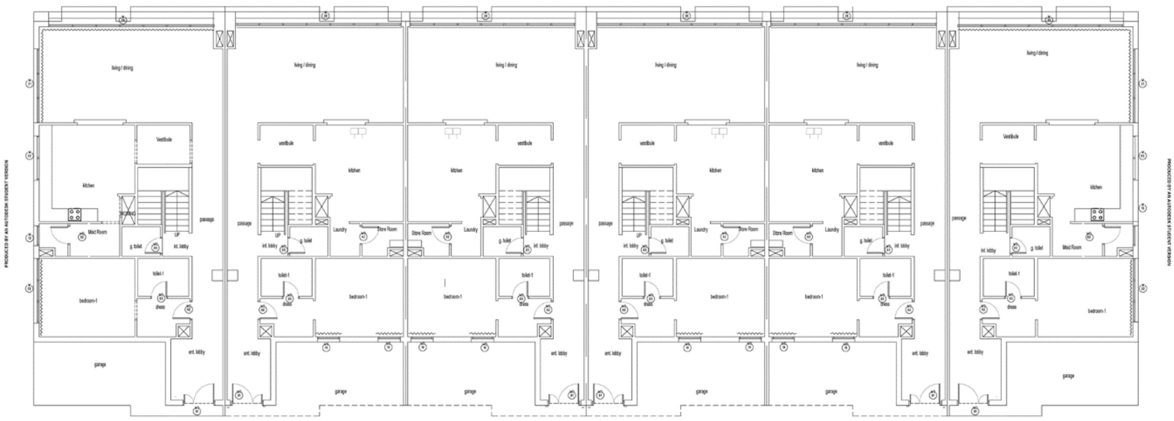


Figure A1. Architectural Layout of 6 Unit Clusters [10]

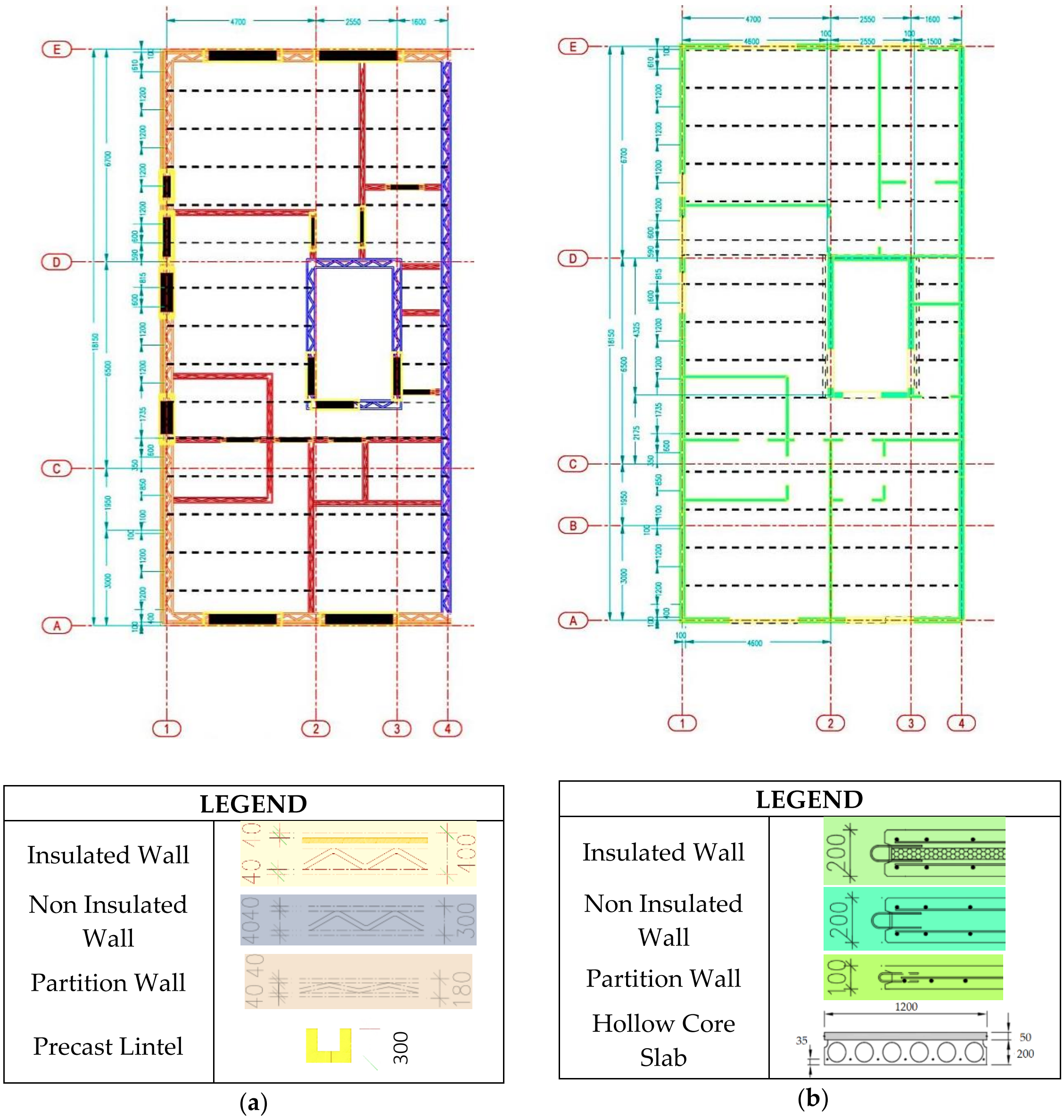


Figure A2. Plan View of Single Unit with Sections (a) 3DCP Building; (**b**) PC Building

Appendix B: Quantity Takeoff Estimation & Total Cost Breakdown

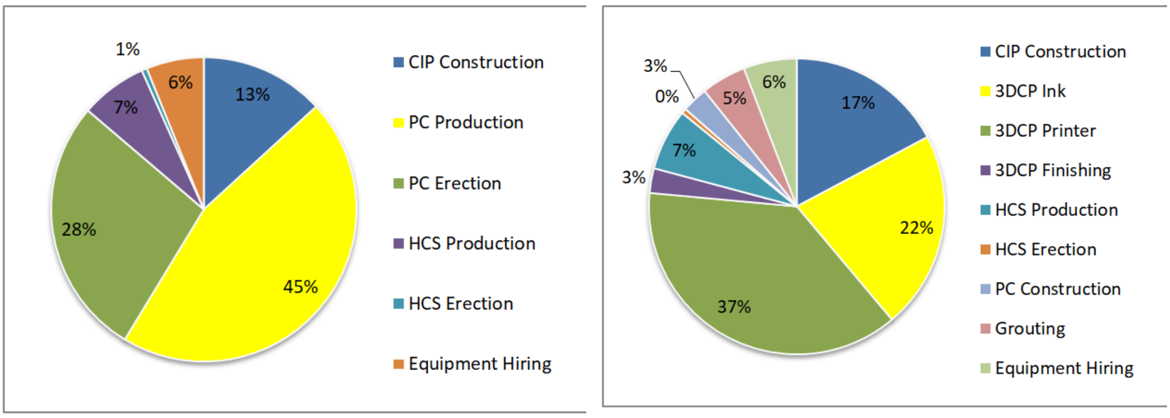
Table B1. Quantity Takeoff for PC Construction

Material	Element	Quantity (No.)	Thickness (mm)	Volume (m^3)	Reinforcement (kg/m^3)
PC	HCS	186	200	188	-
	Insulated Wall	70	200	122	87
	Non Insulated Wall	88	200	227	87
	Partition Wall	204	100	155	60
	Parapet	32	120	20	30
	Strip Footing	82	200	133	81
CIP	Grade Slab	-	150	141	40
	Screed	-	50	88	49
	Blinding	-	100	38	-

Table B2. Quantity Takeoff for 3DCP Construction

Material	Element	Quantity (No.)	Thickness (mm)	Volume (m^3)	Reinforcement (kg/m^3)
3DCP	Insulated Wall	-	400	135	-
	Non Insulated Wall	-	300	142	-
	Partition Wall	-	180	187	-
	Parapet	-	180	20	-
PC	HCS	186	200	188	-
	Lintel Beams	124	300	12	203
CIP	Grade Slab	-	150	141	40
	Screed	-	50	88	49
	Strip Footing	82	200	133	70
	Grout [1]	-	-	70	16
	Blinding	-	100	38	-

[1] The quantity of grout to be filled at connection is calculated as 15% of the total volume of 3DCP walls



(a) (b)

Figure B1. Total Cost Breakdown (**a**) PC Construction; (**b**) 3DCP Construction

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Optimal Fast Charging Station Development Model Using Real Time Traffic Information

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Abstract: Carbon emissions from conventional vehicles have significantly damaged the ecosystem balance, and have pushed the transportation sector to switch towards cleaner fuel sources that can power vehicles more efficiently. Electric vehicles (EV) offer an excellent substitute for fossil fuel-fired vehicles; however, the availability of publicly accessible charging stations is essential for wider adoption and acceptance of electric vehicles by customers. This paper presents an optimal fast charging station planning method to determine station location and station capacity. The method aims to minimize the overall station cost that includes investment costs, operation costs, and EV charging costs without compromising the EV user benefits and distribution network performance constraints. In addition, queuing theory based station capacity estimation is employed to ensure adequate station efficiency. Furthermore, this planning methodology uses Google Map Services to estimate the average time a user is required to access the charging station from the demand point, taking into account real road traffic flow information. The developed model is solved and optimized using a Binary Particle Swarm Optimization algorithm. The simulation result validates the novelty and feasibility of the developed charging station model.

Keywords: Electric vehicle; Fast charging station; Queuing theory; Traffic flow; Distribution network

1. Introduction

Transportation sector is responsible for approximately 20% of global greenhouse gas (GHG) emissions, of which around 75% emissions come from road transport [1]. Low emission electric vehicles (EVs) are promoted as a sustainable substitute to reduce the dependency on fossil fuel-based internal combustion engine (ICE) vehicles. With the dynamic rise of EVs over the globe, the need for charging stations (CS) is also increasing. Thus, systematic planning on selecting suitable charging station locations and sizing is essential for the widespread use of EVs.

In light of this fact, many studies in the past have targeted developing CS planning models for EVs, analyzing various modeling techniques, objective functions and constraints of the CS optimization problems [2]. In [3], optimal CS locations are identified considering environmental factors and CS service radius, and thereafter, total cost associated with CS is taken as the objective function to solve CS capacity problem. In [4], the charging station placement problem is formulated as a multi-objective model to ensure maximum charging service and, at the same time, minimize power loss and voltage deviations. A social cost-based planning model that benefits EV users is proposed in [5], which includes EV travel cost for charging. However, the model estimated the travel cost using Voronoi diagram and a similar approach can be observed in [6], where the cartesian plane distance formula is used to calculate the distance between CS and EV positions. From the above literature review, it is evident that researches mostly discussed distribution grid impact, station economic concerns, and EV user concerns, but many of them have ignored the importance of queuing theory in CS planning. Therefore, queuing theory based CS planning models are proposed in other research works [7-9].

In charging station planning, queuing theory is mostly used to analyze station congestion, predict waiting time for charging, for station capacity determination, and for power demand estimation. In [7], a charging station planning model employing an M/M/s/k queuing system is proposed for Plug-in Electric vehicle(PEV) and is used to analyze station congestion issues that affects the station's quality of service. In [8] authors applied M/M/s queuing theory to determine station capacity with waiting time as a constraint, and in [9], the queuing theory is utilized to estimate the charging power demand at a station.

In general, previous research formulated CS planning problem as a single or multi objective-optimization problems with the objective of minimizing either EV travel cost or station cost or power loss cost, or a combination of these. However, as can be seen in the literature, different authors attempted diverse mathematical modeling to optimize CS location and sizing. For example, [5] and [6], estimated EV travelling distance using Cartesian coordinates which is not reliable and accurate. However this paper applies Google Map API to determine travel time and distance that takes into account real traffic flow information. Moreover, some of the previous researches estimated station capacity using queuing theory that minimizes EV waiting time, but ignored the aspect of station utilization. Meanwhile, this paper determines CS capacity considering both station utilization and waiting time. Above all, this paper develops a fast charging station (FCS) planning model taking into account key factors such as EV traffic flow information, EV user comfort, station investor benefits and distribution network impacts. The objective is to minimize total costs associated with CS installation and operations. The location and the capacity problem are solved using the binary particle swarm optimization method. Finally, the presented FCS model has been applied to Al Ain city, in the United Arab Emirates (UAE), in order to evaluate the performance characteristics of the planning model.

2. Modeling of EV Charging Demand and Charging Station Capacity

2.1. Estimation of EV charging demand

Electric vehicle charging demand at any station is related to the behavior of EV users'. For EV users, the charging station should be easily accessible, for fear of EV driving range. For example, when the charging stations are located far from the EV demand point, drivers are concerned about draining the battery before reaching the station. Therefore, reaching the station with a minimum travel time is the constraint for EV users when determining optimal FCS locations. In this work, travel time from the EV charging demand point to the charging station location is determined using Google Map Distance Matrix application programming interface (API)[10]. Since real-time traffic data is used for travel time estimation this could result in more reliable and accurate travel time estimation. In this work, a road network with m electric vehicle charging demand points and n FCS locations are considered. The travel time (T_{travel}) from the charging demand point to the FCS location can be expressed as

$$T_{travel} = \begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ T_{m1} & T_{m2} & \cdots & T_{mn} \end{bmatrix} \quad (1)$$

$$T_{\min} = \begin{bmatrix} \min(T_{11}, T_{12} \cdots T_{1n}) \\ \vdots \\ \min(T_{m1}, T_{m2} \cdots T_{mn}) \end{bmatrix} \quad (2)$$

The time matrix T_{travel} in Eqn. (1) provides the time taken to travel from the EV location/demand point to the FCS location. The Minimum time matrix, $T_{\min}$ in Eqn. (2), determines the most convenient and nearby charging station for each EV and provides travel time from the EV demand point to the closest CS. Thus, EV charging demand at each station can be obtained by evaluating T_{travel} and $T_{\min}$ matrix, i.e. the number of EVs that goes to a station j can be determined by the following relation,

$$\text{if } T_{\min}^{i} = T_{ij} \ \ \forall i = 1,2,\ldots N_{EV} \ \text{ and } \ j = 1,2\ldots N_{CS\max} \tag{3}$$

The sum of all EVs that satisfies the above condition goes to station *j*. Here, $T_{\min}^{i}$ represents the minimum travel time for EV i and T_{ij} represents the travel time for an EV i to reach FCS *j*. N_{EV} and $N_{CS\max}$ denotes the total number of EVs and FCSs respectively.

2.2. Determination of FCS capacity

EV users expect charging stations to function similar to those of gasoline stations, but the charging time of EVs is much greater than refueling traditional vehicles. This frustrates users due to the long waiting time for charging. Therefore, the waiting time needs to be considered while determining the number of chargers at each station, i.e. station capacity determination. Another important criterion for capacity determination is the station utilization factor, where the station utilization factor is defined as the proportion of time the station will be busy. Therefore, each station should meet the waiting time constraint and station utilization constraint, thereby benefiting both EV users and station investors. In this regard, queuing theory is used to determine FCS capacity. In this work, each CS is modeled as an $M_1/M_2/c$ queuing system, whereM_1 denotes the EV arrival rate that follows a Poisson process, with a mean rate λ; M_2 denotes the charging service time that follows an exponential distribution, with a mean rate μ and c denotes the number of chargers at the station. In this work, EV arrival is characterized as an exponential distribution because EVs are exponentially distributed in the real road network, and therefore, we assume that EVs arrive at a FCS randomly and both are independent of each other.

Based on the information on the EV arrival to FCS, the minimum number of chargers required in the i^{th} FCS ($c_{\min}^{i}$) can be computed as [11]

$$c_{\min}^{i} = \frac{\lambda^{i} \times c_{\max}}{N_{EV}} \tag{4}$$

Where λ^{i} is the EV arrival rate at FCS, $c_{\max}$ is the maximum number of chargers allowed at a FCS.

Once the minimum number of chargers is determined, the initial utilization factor (ρ_{ini}) is computed using the relation,

$$\rho_{ini} = \frac{\lambda^{i}}{c_{\min}^{i}\mu} \tag{5}$$

Where μ denotes the charging service rate, i.e. the number of EVs that get charged in an hour.

For the stable operation of the charging station, the initial utilization factor should satisfy the inequality condition given by (6). The unstable queue model implies that customers are arriving faster than they can be served, and so the queue length will grow without bounds.

$$\rho_{ini} \le \rho_{\max} \tag{6}$$

If the above condition is not met, the number of chargers ($c_{\min}^{i}$) is incremented until the updated utilization factor is less than the maximum utilization factor. The average number of EVs waiting to be charged is as follows

$$L_q^i = \frac{(\rho^i c^i)^{c^i+1} \times P_0^i}{(c^i - 1)!(c^i - \rho^i c^i)^2} \tag{7}$$

Where

$$P_0^i = [\sum_{n=0}^{c-1} \frac{(\rho^i c^i)^n}{n!} + \frac{(\rho^i c^i)^c}{c^i!} \times \frac{1}{(1-\rho^i)}] \tag{8}$$

Here, P_0^i denotes the probability of no EVs waiting for charging service. Accordingly, the average waiting time can be computed as

$$W_t^i = \frac{L_q^i}{\lambda^i} \tag{9}$$

3. Optimization Model Formulation

Previous works on CS planning have established that CS cost, which includes station installation cost and operation cost, have a significant influence on deciding optimal CS location and capacity[3,4,6,12]. In this regard, an economic planning model has been developed here that minimizes station installation and operation costs, taking into account EV users' aspects of travel time and waiting time, and distribution grid impact.

3.1. Objective Function

The main goal of this work is to develop a FCS planning model with a minimum economic burden on station investors, i.e. to reduce the overall station cost. The station cost includes the initial investment required to set up the charging station and the running costs needed to operate the station. Therefore, the overall station cost for any FCS, *i* can be expressed as

$$C_{st}^i = C_{in}^i + C_{op}^i \tag{10}$$

$$C_{in}^i = C_{fix} + (A_c C_{lan}^i + C_{ch} P_r) c^i \tag{11}$$

$$C_{op}^i = C_{ele} \times P_d^i \tag{12}$$

$$P_d^i = P_r \times \beta^i \tag{13}$$

$$\beta^i = \frac{\lambda^i}{\mu} \tag{14}$$

Where C_{st}^i is the total station cost, having two parts: C_{in}^i is the installation cost and C_{op}^i is the operational cost for a single FCS. C_{fix}, C_{lan}^i and C_{ch} are the fixed cost, land cost, and charger cost, of the FCS *i*, respectively. The fixed cost represents the initial infrastructure setting up cost and the land cost is a variable cost that depends on the location of the charging station. A_c is the land area required for the installation of one EV charger, P_r is the rated power of a charger, and c^i is the number of chargers allotted to a station. C_{ele} is the unit cost of electricity, P_d^i is the power demand at a station, P_r is the rated power of a charger and β^i is the expected number of busy chargers in the FCS *i*.

The final objective function for the minimization of the overall station costs can be represented as follows:

$$f_{CS} = \sum_{i=1}^{N_{CS}} (C_{in}^i + (C_{op}^i) \tag{15}$$

3.2. Constraints

1. Power flow constraint

In this work, we confine that the maximum power loss after the installation of FCSs should not exceed 50% of the base power loss, i.e. power loss without considering FCSs. For any distribution network, the active power loss is given by the backward/forward based load flow equations as follows [13]:

$$P_{loss} = \sum_{\substack{i,j=1 \\ i \neq j}}^{n} g_{i,j}[V_i^2 + V_j^2 - 2V_iV_j \cos(\theta_i - \theta_j)] \tag{16}$$

Where $g_{i,j}$ is the branch conductance, n is the total number of buses, V_i is the voltage magnitude of i bus and θ_i is the phase angle of i bus.

2. Bus Voltage Constraint

The acceptable voltage margins for each bus are as follows:

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad \forall i \in n \tag{17}$$

3. Waiting time constraint

The waiting time for an EV user should always be less than the maximum waiting time, $W_t^{\max}$.

$$W_t^i \leq W_t^{\max} \quad i = 1,2,\ldots\ldots N^{CS} \tag{18}$$

4. Charging station constraint

The limitation on the number of charging stations installed in any region is given by:

$$0 < N^{CS} \leq N_{\max}^{CS} \tag{19}$$

4. Charging Station Location Optimization Using PSO

In this work, binary particle swarm optimization (BPSO) is used to find the optimal FCS location and capacity. BPSO is an evolutionary computation algorithm based on the movement and intelligence of swarms [14]. Many of the previous CS placement problems had applied BPSO, due to its effectiveness in optimizing complex multidimensional problems. The algorithm is initialized with a randomly generated population of individual particles in which an optimal solution is obtained by updating individual generations. Each individual represents the position of candidate charging stations as expressed below.

$$X = [l_{cs1}, l_{cs2}, l_{cs3} \ldots . l_{csn}] \tag{20}$$

Where l_{cs} indicates the FCS location.

For every individual, the number of chargers is estimated based on the queuing model described in section 2.2. Then individual fitness value is evaluated using the objective function defined in Eqn. (15). The best fitness value obtained for each individual along with their corresponding position is recorded. Then, the velocity and position of all individuals are updated using the equations given below:

$$V^{new} = w \times V^{old} + c_1 \times rand() \times (p^{best} - X^{old}) + c_2 \times rand() \times (g^{best} - X^{old}) \tag{21}$$

$$X^{new} = X^{old} + V^{new} \tag{22}$$

Here V^{new} and X^{new} are the updated velocity and position of the particle respectively, similarly V^{old} and X^{old} are the current velocity and position of the particle respectively, p^{best} and g^{best} are the individual best and best of all particles respectively, w is the inertia weight, c_1 and c_2 are the acceleration constants. The objective function evaluation process is continued until the iteration reaches its maximum limit and the best solution obtained so far corresponds to optimal FCS locations.

5. Case Study System

The FCS placement problem presented in this paper is tested on the real road network of Al Ain, UAE. EVs are randomly distributed in the study area and the existing gas station locations are taken as candidate charging station locations as shown in Figure 1. 18 charging station locations and 100 EVs are taken for the case study simulation.

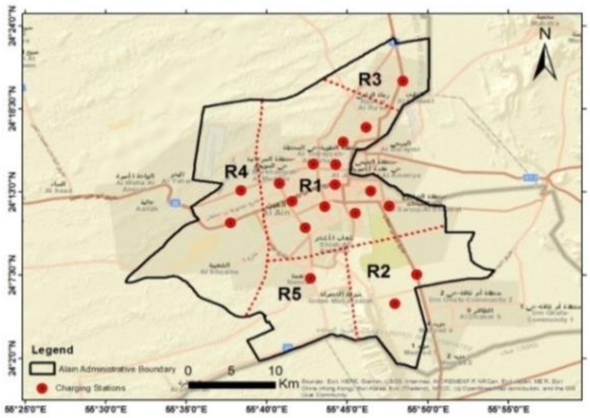

Figure 1. Charging station location in different regions of the study area [11]

In the present study, the IEEE 33 bus distribution system was used as the test electricity network for obtaining optimum FCS locations and capacity. Figure 2 shows the test distribution network with FCSs positioned on different buses. The line and load data for this system are taken from [15].

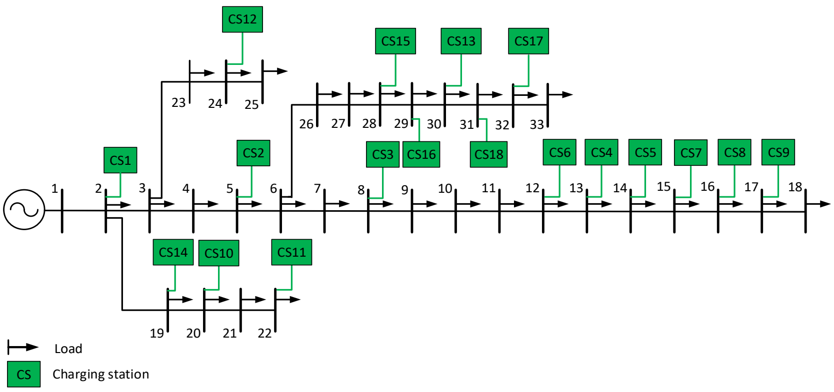

Figure 2. 33-Bus distribution system with EV charging station locations [11]

6. Results and Discussions

The presented FCS planning model is solved using BPSO in the MATLAB environment and this section analyses the optimal solution from the perspective of EV users' convenience, station cost, and distribution system impact. Table 1 shows the optimal combination of charging station location and capacity (number of chargers) obtained, along with other performance parameters such as EV user waiting time, station utilization, station cost value, and power loss.

Table 1. Optimal solution of CS placement problem

CS location	Number of chargers	Arrival rate (EVs/hr)	Waiting time (min)	Station utilization (%)	Station cost f_{cs} ($)	Total power loss(kW)	Power Loss percentage
1	4	11	2.58	61.11	146102	212.44	20.45
10	9	30	1.79	74.07			
14	10	35	2.16	77.78			
18	7	24	3.27	76.19			

Four FCS locations, 1, 10, 14 and 18, were chosen as the optimal locations with 4,9,10 and 7 chargers at each station respectively. With the station cost minimization objective, the optimum station cost required to install four charging stations is 146102 $. Moreover, EV users' waiting time at all the charging stations is acceptable. The longest waiting time is 3.27 min at station 14, and more than 75 % of EV users wait less than 3 minutes in the queue for charging. In addition, station 14 has the highest EV arrival rate at 35 EVs per hour. Hence, this station has the highest utilization rate of 77% and all the four stations are utilized above 50%, resulting in better system utilization, and without compromising waiting time constraint. The above results confirm that the queuing algorithm based station sizing balances station utilization and waiting time together, thus the planning model is advantageous to EV users and FCS investors.

Apart from waiting time, another important concern for EV users is travel time from the demand point to the FCS location. Figure 3 demonstrates the travel time for all the 100 EV users. Referring to the figure, it is clear that 70% of EVs have a travel time of less than 15 minutes and only a few EVs take more than 30 minutes to reach the station.

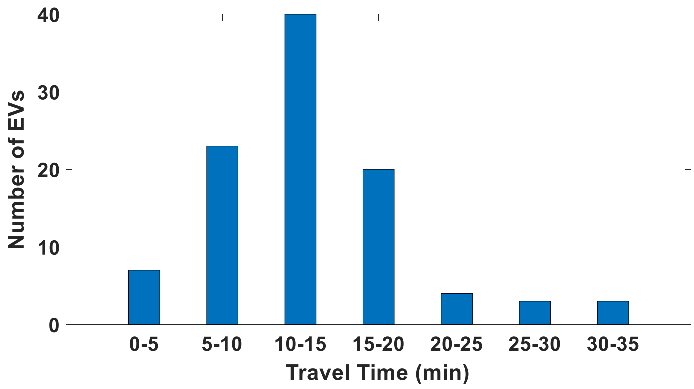

Figure 3. EV user travel time frequency distribution

Seeing distribution grid impact, the base case power loss when no FCS is connected to the network was 176.36 kW. However, after the placement of FCSs, the power loss increased to 212.44 kW, which accounts for 20.45% of the base power loss. Furthermore, the bus voltage profiles are also affected by FCS placement as shown in Figure 4. For example, as station No. 18 is located on bus no. 31, bus 33 records the minimum bus voltage of 0.9126 p.u. Thus, the results imply that both the power loss and voltage profile of the distribution network after the positioning of FCS are within acceptable limits.

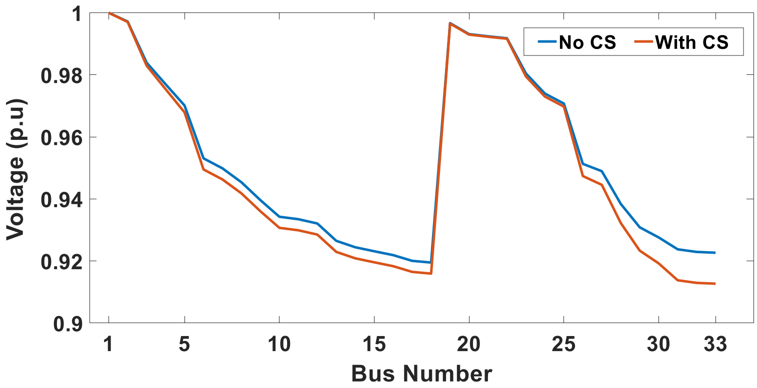

Figure 4. Bus Voltage profiles before and after the placement of CSs

7. Conclusion

This paper presented a FCS planning model that simultaneously considers EV travel time, station cost, and distribution system characteristics such as power loss and voltage profile. EV travel time is estimated using Google Map services that use real road traffic information. Another feature of this model is that the FCS capacity is determined using a queuing system that improves station efficiency and, at the same time, benefits EV users by recharging EV within a tolerable waiting time. The station location is optimized in a way that the model achieves minimum station costs. The simulation results demonstrate that the FCS model could achieve satisfactory performance from the perspective of EV users, station investors, and grid operators. In the future, like traffic data, real distribution data will be incorporated into the system to analyze the effect of FCS installation on the distribution grid.

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Session 5:

Building Performance Evaluation/Simulation

Investigate Building Morphology to Self-shade Facades for Energy Reduction in Hot Climates Using Thermal Imaging Techniques.

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Abstract: Creating sustainable buildings in hot climates requires specific consideration to the several stages of realizing the building (design, construction, usage, and demolition) to minimize the reliance on electricity for the provision of cooling and lighting. The design phase is more critical than other phases, during which most decisions that determine the building morphology are made. The priority in creating energy-efficient sustainable buildings should be given to the building form and facades' design. The impact of the building form and the building façade on energy consumption was studied separately while they are closely related, the morphology of the building shape, regardless of its compactness and geometry, can have a self-shading impact on the building façade and hence an impact on the overall energy performance. This research investigates the impact of pockets on the thermal behavior of the building using thermal imaging techniques for building diagnosis. Results of thermal imaging demonstrate that all pockets have a significant reduction in surface temperature regardless of the time, aspect ratio, and orientation of the pocket. Generally, the average reduction varies between 3%-30%. Pockets serve as vertical shading devices. Hence the most massive temperature reduction was recorded in East orientation during morning time and West orientation during the afternoon.

Keywords: Building morphology; Thermal imaging; Pockets

1. Introduction

Energy consumption reduction has been one of the highest properties in the UAE. Statistics showed that UAE's electrical consumption in 2017 was almost 127,000-gigawatt-hours (GWh), and this places UAE among the highest consumers per capita in the entire world [1]. Moreover, most electrical energy generated in UAE in 2018 (98% of the total generated electricity) was generated from natural gas-fired [2]. The buildings' sector is responsible for 80% of the total consumed energy in the UAE [3].

The factors affecting the buildings' energy performance were discussed in numerous studies [4-7], especially since they are varied and connected. Some of these elements are controllable. These include the building façade, shape, and orientation. One of the most critical elements affecting the energy performance of buildings is the building shape. The proper building shape or form has a high potential to reduce energy consumption with relatively low cost, compared to upgrading the thermal insulation of a wall or air conditioning for example. However, optimizing the building form requires more investigation and study at the building design's early stages. Building form can be measured using different methods; compactness of the form is the most common [8,9]. The increase in the building compactness results in the decrease in energy consumption [4,7-9]. The larger the range of compactness between the different forms, the larger the difference in the energy performance [8-11]. A study conducted in Toronto, Canada concluded that a combination of form, encloser, and WWR could reduce the Energy Usage Intensity (EUI) to 60% [6]. On the other hand, a review study concluded the opposite of the previous research: shape, orientation, and compactness are the most critical and essential factors affecting the energy performance of a given building [4]. On the local level, a study that was conducted in Abu Dhabi, UAE concluded that the impact of verticality of the form (represented by the number of floors) on energy performance is more significant than the horizontality of the form (represented by the aspect ratio and the spacing between the building masses) [12].

Another important controllable element that can be manipulated to improve the building's energy performance is the design of the building skin. The building skin impact is significant as it is the part of the building being exposed to the harsh climatic conditions that can directly affect its performance; this was proven in several previous studies [13-16]. Building envelope that contains walls, roof, doors, windows, and foundations has the most significant influence on energy consumption in buildings, especially during heating and cooling periods [13]. The importance of the building envelope with regards to the energy performance lays within the fact that it works as an energy exchanger between the indoor and the outdoor, the main target from the optimization of the building envelope is to decrease the thermal gain during summer and the thermal loss during winter [14]. Enhancement of the building envelope in terms of its thermal performance relies on the building type and its use; residential buildings, for example, require lower WWR (window to wall ratio) compared to office buildings or commercial buildings. It is well known that reducing WWR if combined with the best thermal insulation level, leads to a reduction in energy demand [15,16]. A study conducted in Turkey to test the impact of building envelope on the total energy consumption concluded that 40% of energy savings could be achieved by appropriate building envelope (thermal insulation, shading devices, type and size of glazing) [14].

Shading in buildings plays an essential role in controlling the amount of solar radiation that is being transmitted into the building; moreover, shading is more efficient when applied on the building cavities because cavities are responsible for transmitting the largest amount of solar radiation within the building [4]. Isolated buildings that cannot benefit from neighboring shading are more exposed to direct solar radiation, hence, more heat gain. Designers can create specific building designs in hot climates to provide shading to the building itself without reliance on exterior shading sources. The inverted pyramid is the most common example of self-shading building forms [17]. Some designers used slant inwards walls as an example of self-shading techniques [4]. Generally, studies about self-shading forms and their impact on energy consumption are limited.

The impact of the building form and skin on energy performance were studied separately while they are closely related, the morphology of the form can have a shading impact on the building skin and, hence, impact the overall energy performance. This paper is part of a bigger research project that investigates the thermal behavior and daylighting in pockets. This paper covers the first stage of the research and deals mainly with the thermal imaging diagnosis of the pockets.

2. Materials and Methods

The main target of this study is to identify comprehensively which building form aspects have a better potential to save energy, and hence worth investigation. From the literature, it was found that Self-shading forms if applied properly can provide shading on the building façades and hence can achieve a significant reduction in energy consumption. However, self-shading techniques are numerous, and the amount of shading that can be provided varies according to many other variables such as the self-shading technique adopted in the design, the orientation, the aspect ratios, etc. Thermal imaging technique was selected for this study as it can provide quickly and accurately the required surface temperatures of any given building. This will allow a fair comparison between the shaded and non-shaded parts with similar properties and hence can help understand the effect of the provided self-shading on the building surfaces. Thermal imaging techniques were used and validated extensively in building diagnosis studies.

The methodology is divided into two sequenced phases; the first phase is a survey and analysis of all educational buildings in the United Arab Emirates University (UAEU) campus while the second phase is an investigation of the thermal behavior of pockets during the daytime to capture the heat gain as follows:

2.1 (Phase 1): Survey educational buildings in UAEU.

2.1.1 Step 1: Carry on the thermal imaging survey to cover all educational buildings in UAEU (See Figure 1). Building morphology is a vast term that contains an uncountable number of forms, to decide which building morphology worth investigation it was necessary to find a quick and reliable tool. Thermal imaging for building diagnosis was chosen for this task. Thermal images can be used to measure the surface temperature of buildings, and then identify which parts of the building have less surface temperature compared to the other parts with similar properties (construction materials, orientation, skin color…etc.). The parts that receive more self-shading through the building morphology are expected to have more potential to save energy. The parts of buildings being exposed to exterior shading (trees, neighboring buildings) were eliminated to ensure the accuracy of the readings, any parts with reflective properties were eliminated as well for the same reason. The thermal images were taken from different sides to cover each building entirely and hence cover all the orientations. The images were taken at three different timings; 9 a.m., 12 p.m., 3 p.m. The thermal camera parameters allow changing the distance between the camera and the building manually. Such an option is very important as it is impossible to fix the same distance among all buildings due to the existence of many obstacles such as trees, neighboring buildings, and shading devices that might block the view. The process starts by searching onsite for a suitable location to take the thermal image, once this decided a laser meter was used to measure the distance between the object and the camera, then the parameters of the camera are set accordingly, this was repeated with every image being taken (201 times). A landmark was fixed on the ground previous to the experiment to make the process easier and more accurate among the 3 measurements (at 9 a.m., 12 p.m., and 3 p.m.). It was necessary to take some images from long distances to capture the entire façade, while the images taken from small distances were to capture the details of the façade when needed. The features of the thermal camera used are as below:

1. Cameral model: FLIR E4 WIFI
2. Lens: FOL 7mm
3. IR resolution: 80 x 60
4. Radiometric JPEGs maintain all temperature data within the thermal images
5. "Picture-in-Picture" Overlaps a fixed section of a thermal image onto a digital photo to help define the problem locations and enhance the documentation.

2.1.2 Step2: The thermal images were analyzed using FLIR Tools software. This process starts by selecting the darker colored parts in the image which indicate less surface temperature compared to the other parts with similar properties but with lighter colors. The architectural drawings were then used to define the exact location of the darker parts found in the thermal images (which represent the façade level) on the floor plans level to link them with the building morphology. This helps to understand which parts of the building morphology have the potential to save more energy through self-shading. The number of buildings understudy in this phase is 12. The software allows to see and analyze the images using several image modes which helps to identify specific areas within the building and hence facilitate the analysis process (See Table 1).

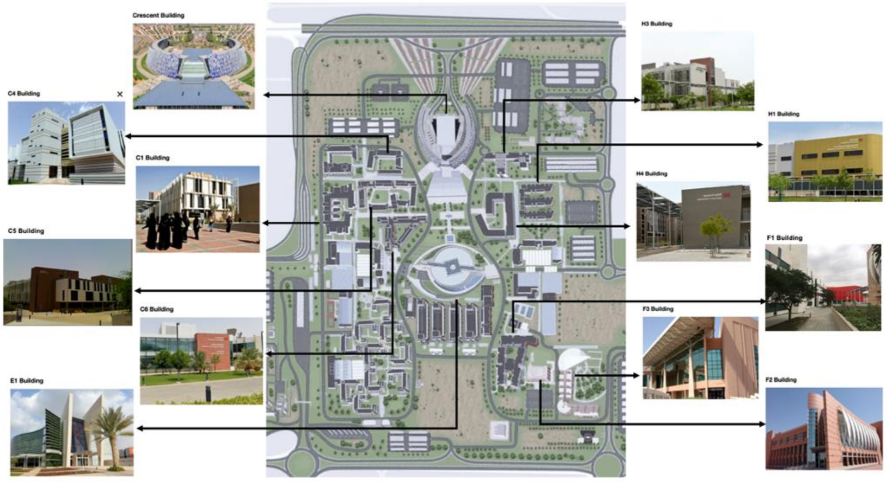
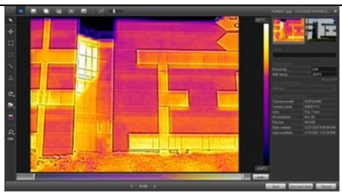
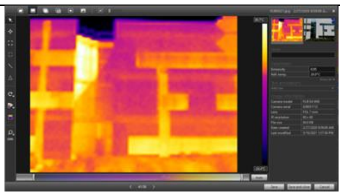
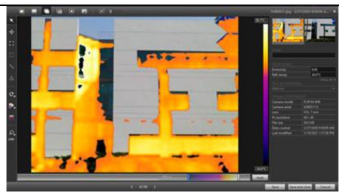
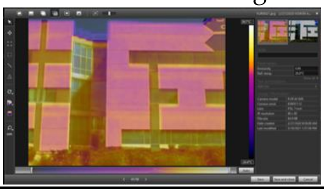
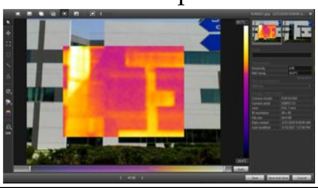
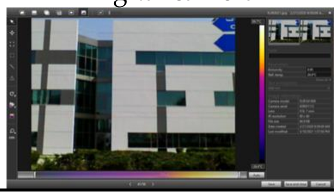


Figure 1: Map of UAEU indicating the buildings under study.

Table 1: Types of image modes applied on F1 building as an example

Thermal MSX	Thermal	Thermal fusion
		
Thermal blending	Picture in picture	Digital camera
		

2.2 (Phase 2): Investigate the thermal behavior of the pockets during daytime (Heat gain)

2.2.1 Step 1: Based on the results from phase 1 which indicated that the "pockets" have a better potential to save energy, a more detailed thermal imaging for the F1 building was carried out at three different timings; 9 a.m., 12 p.m., 3 p.m. to understand the behavior of the pockets during daytime (Heat gain).

2.2.2 Step 2: Analysis of the thermal images of the F1 building; the temperature measurements were taken at different spots in the thermal image to ensure accuracy, then the average temperature was calculated. The target of this analysis is to compare the surface temperature between the glass on the pockets and the glass on the flat windows next to it (similar properties). The architectural drawings of the F1 building were used as well to identify the orientation, aspect ratio, and location of the pockets.

3. Results

3.1 Results of phase 1:

A total number of 201 images of the 12 educational buildings from different sides at different timings were analyzed (See Figure 2). Results indicate a negligible variation of surface temperature among the parts with similar properties in the majority of buildings. However, the thermal images of buildings F1, H1, and H4 revealed a remarkable variation of the surface temperature (See Figure 3). The parts in blue recorded less surface temperature compared to the parts in red even though both had similar properties, these parts were analyzed by linking them with the architectural drawings (See Figure 4). The lowest surface temperature is attributed to the “pockets” which can be defined as recessed parts in the building façade, pockets can be created by manipulating the building form; they serve mainly as atriums to provide lighting (See Figure 5). Based on the findings from this phase, F1 building was chosen for further analysis with regards to its pockets in phase 2 as this building with its variety of pockets’ designs (20 design configurations based on different orientations and aspect ratios) would provide a greater chance for more understanding of the problem dimensions.

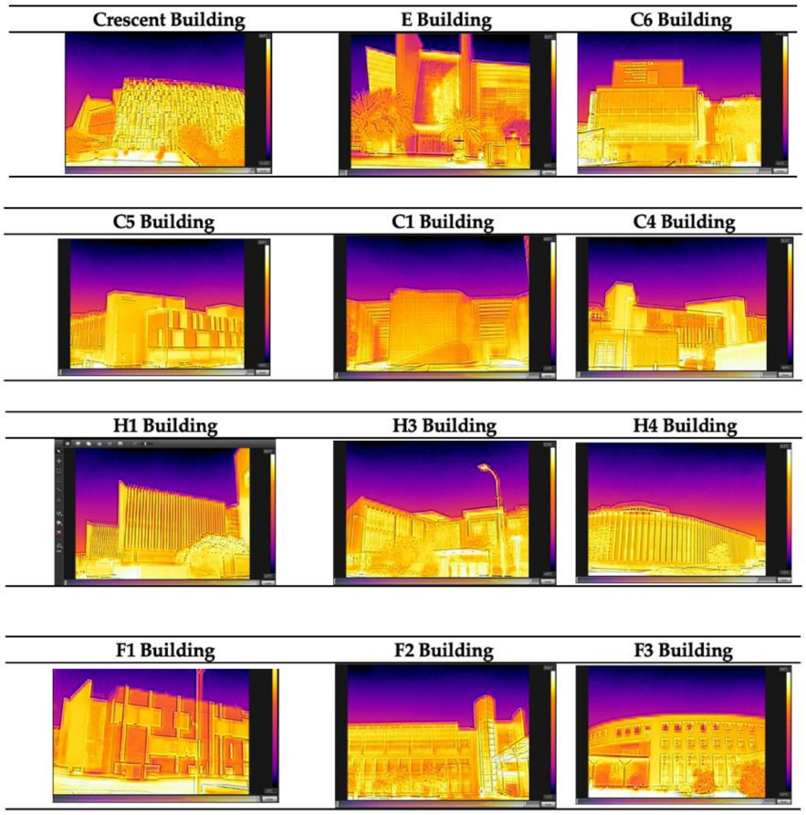


Figure 2: Thermal images of UAEU educational buildings.

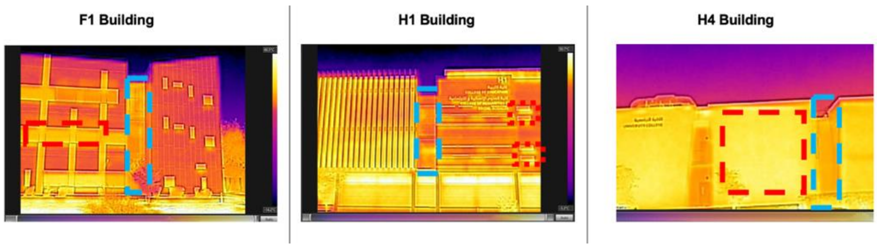


Figure 3: Thermal images of selected parts from buildings F1, H1, and H4 showing the variation of temperature.

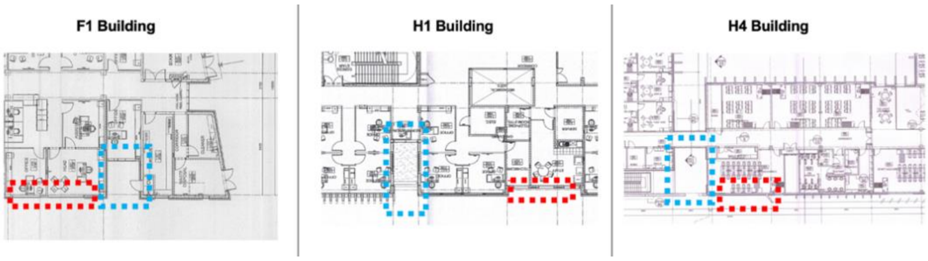


Figure 4: Selected parts from floor plans of buildings F1, H1, and H4 indicating the locations of the selected parts.

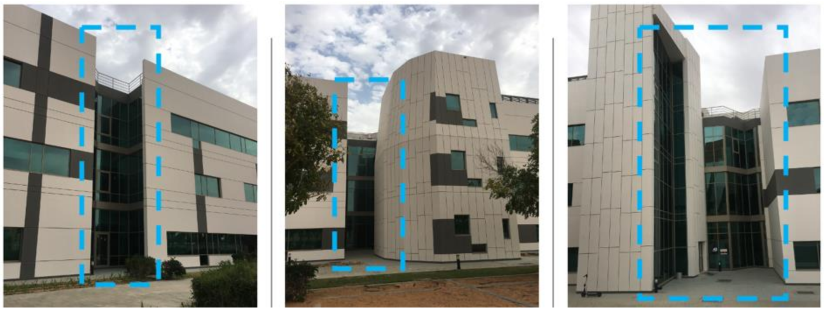


Figure 5: Digital images of pockets in F1 building.

3.2 Results of phase 2:

The thermal images of the F1 building were taken on the 21st Sep 2020 at three different timings; 9 a.m., 12 p.m., 3 p.m. using FLIR thermal camera. The thermal images were analyzed using FLIR Tools software; the temperature measurements were taken at different spots to ensure accuracy (See Figure 6), then the average temperature was calculated.

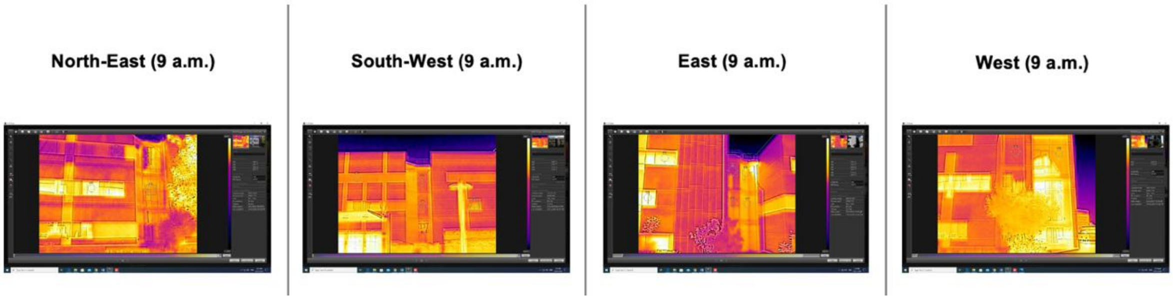


Figure 6: Thermal images analysis of selected pockets using Flir tools (9 a.m.)

The architectural drawings obtained from FDM were used to define the pockets' orientation to understand their behavior. A total number of 18 pockets were defined (See Figure 7).

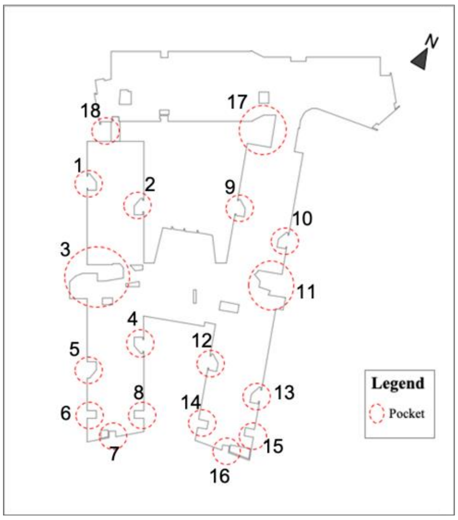


Figure 7: Pockets, F1 building.

Results of surface temperature recorded in each pocket were classified based on their orientations; the following charts illustrate the percentage of reduction in surface temperature between the pocket glass and the flat window glass of identical properties. Moreover, the average reduction in surface temperature of all pockets of the same orientation was calculated at different timings (9 a.m., 12 p.m., and 3 p.m.).

3.2.1 South-West Orientation:

- The results indicate a significant reduction in surface temperature attributed to the windows placed in the pockets compared to the windows placed on the flat façade. The highest reduction was recorded at 9 a.m. and 3 p.m., while the lowest reduction was at 12 p.m. (See Figure 8).
- An average surface temperature reduction of 7%, 4%, and 8% at 9 a.m., 12 p.m., and 3 p.m. respectively.

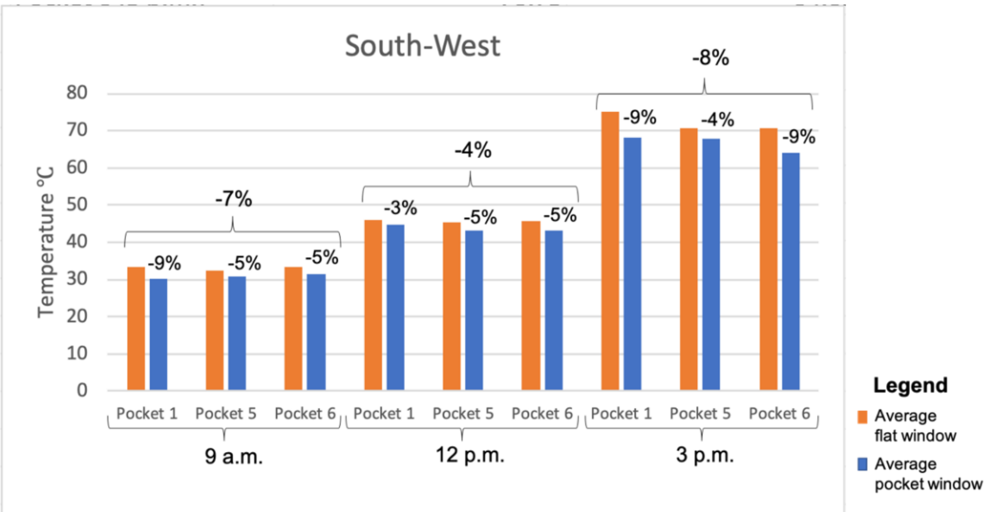


Figure 8: Results of surface temperature in flat and pocket windows -South-West orientation.

3.2.2 West Orientation:

- The results indicate a significant reduction in surface temperature attributed to the windows placed in the pockets compared to the windows placed on the flat façade. The highest reduction was recorded at 3 p.m., while the lowest reduction was during 12 p.m. (Figure 9).
- An average surface temperature reduction of 7%, 5%, and 20% at 9 a.m., 12 p.m., and 3 p.m. respectively.

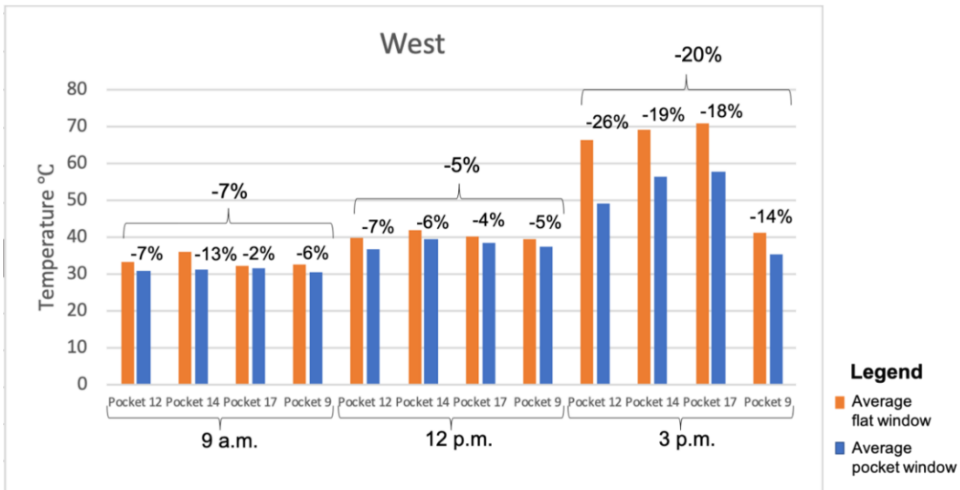


Figure 9: Results of surface temperature in flat and pocket windows – West orientation.

3.2.3 North-East orientation:

- The results indicate a significant reduction in surface temperature attributed to the windows placed in the pockets compared to the windows placed on the flat façade. The highest reduction was recorded at 9 a.m. and 12 p.m., while the lowest reduction was at 3 p.m. (See Figure 10).
- An average surface temperature reduction of 9%, 7%, and 3% at 9 a.m., 12 p.m., and 3 p.m. respectively.

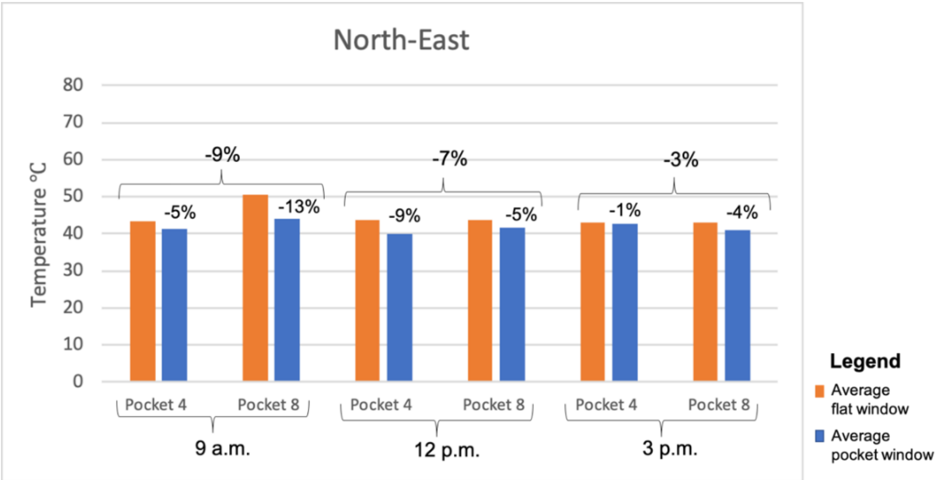


Figure 10: Results of surface temperature in flat and pocket windows -North-East orientation.

3.2.4 East orientation:

- The results indicate a significant reduction in surface temperature attributed to the windows placed in the pockets compared to the windows placed on the flat façade. The highest reduction was recorded during the morning at 9 a.m., while the lowest reduction was at 12 p.m. and 3 p.m. (See Figure 11).
- An average surface temperature reduction of 30%, 7%, and 8% at 9 a.m., 12 p.m., and 3 p.m. respectively.

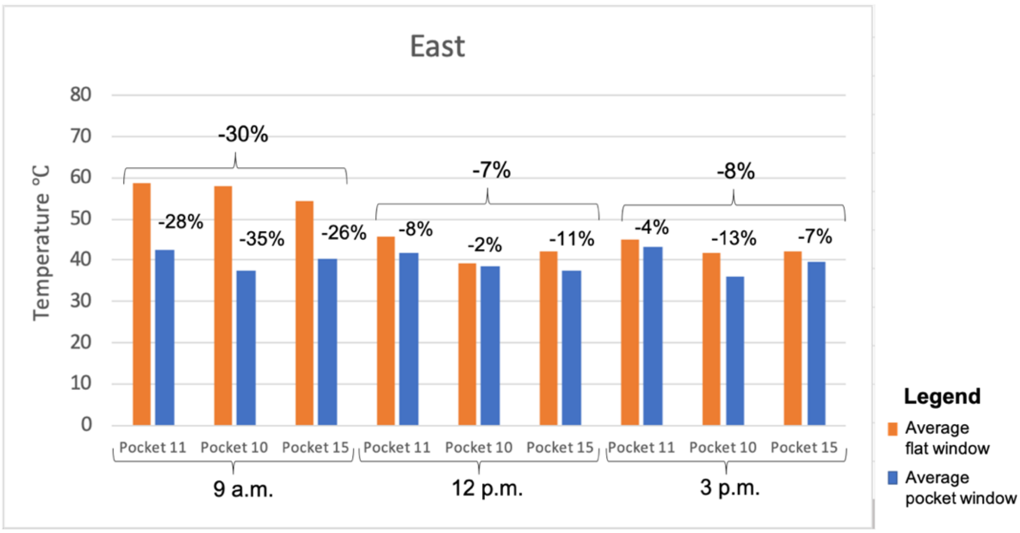


Figure 11: Results of surface temperature in flat and pocket windows - East orientation.

4. Discussion

All pockets demonstrate a significant reduction in temperature regardless of the time, aspect ratio, and orientation of the pocket. Generally, the average reduction varies between 3%-30%. Pockets serve as vertical shading devices. Hence the most massive temperature reduction was recorded in East orientation during morning time and West orientation during the afternoon. The shading provided by pockets covers the glass parts, which is known to be the weakest point in the building envelope. Hence the chances to save energy by optimizing the design of pockets are high.

According to many previous studies regarding the impact of the building form on energy performance, it was found that the more the building was compacted, the less energy it consumes. The implementation of the pockets might lead to an increase of the exposed surface, which means a decrease in the form's compactness, and hence, an increase in energy consumption. However, the morphology here is not calculated; the morphology can add a new variable to the equation, which is the self-shading. The building has several components, and they all affect each other, so the building, after all, performs as a whole unit, and the shading effect can compensate for the increase in energy consumption due to the increase of the overall surface. Yet, the implementation of "pockets" should consider this to avoid a massive increase in the surface area being exposed to the harsh climate. Pockets, if appropriately applied (in terms of their dimension, orientation, and position) to provide suitable self-shading, and improve daylighting might create a better potential to save energy.

The difference of temperature between the pockets of the same orientation might be due to the surroundings (e.g. trees or another building that can impact the results by shading or reflection) or the irregularity of the pocket's aspect ratio. Building simulation must be done to control all variables for a better understanding of the pocket's thermal behavior.

5. Conclusion

UAE university buildings were examined in terms of their surface temperature using thermal imaging techniques. Buildings with pockets revealed a good potential to save energy as the surface temperature recorded in pockets was lower compared to the surface temperature recorded in other parts with similar properties (construction materials, orientation, skin color…etc.). The reduction in surface temperature was recorded in all pockets regardless of their orientation and form. The reduction varied between 3 to 30%. Pockets can be seen as vertical shading devices; results indicate that the highest temperature reduction was recorded in East orientation during morning time and West orientation during the afternoon.

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Investigating Optimal Window to Wall Ratio towards Reducing Cooling Energy Consumption of Offices in the UAE

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Abstract: With the widespread use of curtain walls especially among office buildings, offices stand to be in an abundance of light and are among the largest consumers of electricity. According to previous research, more than 50% of the energy losses happen through the building envelope. The window-to-wall ratio (WWR), or the percentage of glazing in a building's envelope, has a great impact on multiple performance aspects of an office building across its life cycle, including energy consumption, daylighting, material use, and occupant comfort. Major concerns arise in the local extreme hot climate regarding the lack of consideration of WWR causing an increase in offices' cooling energy consumption coupled with recurrent occupant discomfort. A higher education (HE) office building located in United Arab Emirates University (UAEU) campus has been selected as a case study, to focus on the area bounded by the west façade. Model simulation by means of DesignBuilder software investigated the optimum WWR towards minimizing annual cooling load and solar heat gain, whilst maintaining adequate daylighting levels indoors. Furthermore, daylighting levels were validated by complying national and international standards such as Estidama and WELL building standard. Results found the optimum WWR for the south façade as 20% which achieves the best building energy use performance, with 14.5% reduction in overall building energy consumption from the existing baseline model. In parallel, indoor lighting levels were comparatively enhanced throughout the WWR range 20%-30%. These findings provide design recommendations to promote applying passive energy optimization strategies towards improving occupant comfort in office buildings.

Keywords: Window-to-Wall ratio (WWR); Office building; Solar heat gain; Cooling energy consumption, Energy optimization, Occupant comfort, Passive strategy

1. Introduction

Since climate change is now evident, it is not only crucial to achieve high levels of energy efficiency for new buildings but also to study retrofit strategies on existing buildings to mitigate the negative impacts of climate change and to further enhance indoor environmental quality for the building's occupants. Globally, the building and the construction sectors contribute to 39% of the energy-related emissions [1]. In the UAE, these emissions are expected to be considerably greater due to the high cooling demand and inefficient energy performance of the existing buildings. Commercial buildings in particular account for the largest end user energy consumption at 35.9% [2]. The conventional façade design for office building in the UAE consists of fully glazed external skin in which sunshade devices are rarely installed, this triggers overheating caused by excessive solar heat gains and also excessive indoor light levels [3]. Moreover, it correlates with increasing the cooling load and cooling energy needed in order to achieve suitable thermal comfort levels in the office environment.

This research scope focuses on identifying the optimal window to wall ratio (WWR) to be adopted in office buildings in the UAE to reduce cooling energy load as well as enhance daylighting and indoor thermal conditions to meet adequate occupant comfort levels according to Estidama and

WELL building standard. By taking into consideration the local climate, WWR, window properties, indoor temperatures, and daylighting levels; ideal WWR will be correlated through model simulation to reveal the best opportunities for energy savings in an existing office building through cooling energy reduction. The main findings of this research contributes to providing WWR design recommendation to reduce cooling energy consumption whilst maintaining user comfort concerning the harsh UAE climate.

1.1. Energy Status in UAE

Currently, there is a global pathway to carbon reduction as the core basis for climate change mitigation [4]. Worldwide energy demand has increased by nearly 2.3% during 2018, which was recorded as the greatest increase in the decade. This growth in energy demand is correlated with higher cooling and heating demands in several regions around the world. Particularly in the UAE, rapid economic and population growth of the UAE caused the electricity consumption to reach 127,000 gigawatt hours (GWh) in 2017, ranking the UAE among the largest electricity consumers per capita in the world [5]. The increase in electricity consumption is still ongoing at an annual rate of 5% over the past five years. Where the power sector in the UAE is dominated by the oil and gas power plants, accounting for over 95% of the total power generation in 2018 [6], which adds upon challenges in reducing greenhouse gas emissions and overall environmental impact.

1.2. Climate Specific Holistic Facade Design

Designing the façade of an energy efficient and comfortable building involves coordinating and optimizing various interconnected design principles. When it comes to hot arid climate, literature suggests highly insulated building envelope, low WWR with very low U- value, sun shading, and high reflectivity of exterior envelope surface [7]. Moreover, when it comes to the occupants' comfort and user satisfaction, the building envelope serves a high level of significance since it has a direct influence on the indoor conditions. Uncomfortable or dissatisfied occupants may intervene with the intended envelope design which results in energy waste and probable damage to building envelope components, while comfortable or satisfied occupants account for higher work productivity levels in office buildings[8].

A holistic approach to façade design is essential to provide adequate comfort levels with minimum annual energy consumption [9]. Facade design parameters mainly consider orientation, wall type, window type, WWR, glazing properties, and shading [10]. The design of windows substantially affects the energy performance of a building relative to solar heat gain; additionally, it affects the occupants' comfort relative to indoor daylighting levels and thermal distribution [11]. Table 1 shows occupant comfort influences by WWR.

The purpose of windows in office building is to bring in daylight and provide a suitable view while minimizing thermal loss [12]. The optimal WWR is the window area that uses the least amount of energy for cooling, heating, and lighting over the course of a year [13]. Furthermore, the orientation and climate offer significance for window placement. Research in hot arid climate, finds the placement of the window systems on the west façade to have the highest unfavorable impacts on annual energy consumption, followed by placement on the east, south, and north faces. This summary of the literature review drives the aim of this study to determine the optimal WWR of the west façade in an extreme hot arid climate such of the UAE, whilst seeking improvements in occupant's comfort and satisfaction levels [14].

Table 1. Occupant Comfort Influences by WWR and their parameters.

Occupant Comfort Influences	Parameters	Control Methods	Issues	Parameter Measures	Standards & Regulation
Daylighting	Daylighting factor Illuminance Color temperature	Daylighting integration Luminance distribution	Glare Reflectance Artificial lighting energy use	Daylight Illuminance	300-500 lux (75% of occupied area) [1]
Thermal Comfort	Temperature Relative humidity Radiant Temperature User activity	Air conditioning system Building design Operable windows	Cooling/heating energy use	Indoor Temperature	24°C - 26°C [1]
				Relative Humidity	30% - 60% [1]

[1] WELL Building standard v.1[15] [2] Pearl Building Rating System for Estidama[16]

2. Methods

This research is part of a 2-stage methodology to optimize cooling energy load in office buildings in the UAE through a comprehensive experimental process. The case study selection looked for an appropriate office building that meets accessibility requirements and provides essential yearly energy consumption data and relative building drawings. The first stage included a field assessment that took place as a form of a comprehensive post occupancy evaluation (POE) that applied objective and subjective measurement methods through physical monitoring and satisfaction surveys. Following that, model simulation adopts the gathered information and real issues found to test upon it several scenarios towards reducing the annual energy consumption for the selected office building. This paper focuses on WWR optimization in west facade, as a passive design solution to improve the building energy performance.

The 2-stage experimental process has taken place as follows:

Stage1: POE Assessment
  a. Physical Monitoring
  b. Satisfaction Survey
Stage 2: Model Simulation

2.1 POE Assesment

A comprehensive POE assessment took place from the beginning of 2020 and ended when experiencing the Covid-19 office implications in March 2020. Physical monitoring included continuous and spot field measurements that have been arranged to record physical parameters in accordance with thermal comfort and lighting quality. Continuous measurements were performed to obtain profiles of air temperature (°C) and relative humidity (RH in%), using specified devices such as the HOBO U12 data logger in selected open workspace areas and closed offices. Lighting levels were measured by means of spot measurement using a hand-held environment meter to obtain a realistic approximation of the illumination (lux) received by the occupants on their work surfaces using the PRECISION GOLD Multi-Function Environment Meter (Model N09AQ) via a walkthrough manner. This stage helps gather real data of the indoor conditions experienced by the occupants.

In parallel, a survey questionnaire was developed and distributed with the aim of exploring the perception of the building's occupants and detecting sources causing discomfort and dis-satisfaction towards the office indoor environment. The perception of the occupants was measured using a standardized 4-point Likert scale of frequency. Adopted by the Indoor Environment Quality

Handbook [17], a set of survey questions have been modified to fit the context and individual characteristics of the case study building.

2.2 Model Simulation

Seeking the optimal WWR, the second stage employs the gathered information with model simulation, coinciding with international and local recommendations such of LEED and Estidama regulations in Abu Dhabi. Today’s technological developments qualify for investigating building energy optimization via advanced simulation tools [10]. DesignBuilder software was used to create a set of alternative model scenarios and compare them relative to the existing baseline building model. The simulated model included a typical block of the building which contains the main workspaces, closed offices, lounge area, and corridor bounded by the west façade. Each tested scenario has a different percentage of window size on the west façade from 0% up to 100% WWR. The tested scenarios were then correlated with the average daylight illuminance to meet adequate daylighting comfort levels according to WELL building standard. This software was selected as it implements EnergyPlus analysis engine and can accurately calculate the solar heat gain, annual energy consumption, and daylighting illuminance distribution based on the local weather data. The combination of the 2-stage process allows for deep findings extraction and achieves results validation that reinforces the study and provides evidence-based design recommendations. Although, the stages adopted for this methodology have been formerly used and shown recognition in worldwide building energy optimization practice [5], this study aims to find interconnection of passive facade design strategies and occupants’ comfort against the harsh climate of UAE.

2.3 Case study building and Climate

The case study building selected for this research is located in United Arab Emirates University Campus, Al-Ain, UAE. Where Al-Ain is a sub-urban city within Abudhabi. Characterized as hot-arid desert climate, it is featured by its long, extremely hot summers (38 °C average) and warm winters (18 °C average), with average relative humidity at 60% [18]. The building is a higher education office building with the name of F1 building that consists of 3 floors housing open workspaces, closed offices, lecture rooms, meeting rooms, labs and several more functions to serve an estimated number of 600 occupants that include faculty, students, researchers, and other staffs.

Figure 1. Case study building typical floor plan and exterior photos (west facing selected block indicated in red)

Table 2. Case study building information

Architecture	**Site**	**P.O. BOX 15551, Al-Ain, UAE**
	Use	Offices, labs, and lecture rooms
	Building area	7,120 m²
	Gross floor area	21,360 m²
Mechanical	Cooling	Campus district cooling
	Air Handling Unit	13 AHU on the roof
	Control	VAV
Electrical	Lighting	T5 flounce lamp (offices)

3. Results and Discussion

3.1 Post Occupancy Evaluation Summary

Results of the POE assessment presented several issues and complaints particularly about the indoor thermal and lighting conditions. The indoor thermal conditions revealed key issues with the indoor temperature (average temperature 21.5°C), as 99% of the logged temperatures were below the recommended range set by WELL building standard in hot arid climate (24°C - 26°C). The survey results similarly highlighted the issue with 55% of respondents reporting "too cold" for the indoor thermal conditions. These results emphasize an issue with the cooling set point temperature set by the facility management that indicates unfavorable loss of cooling energy that is further causing discomfort to the occupants. On the other hand, indoor lighting levels were found excessive (average 703 lux), above the recommended range for office buildings (300-500 lux). Moreover, the highest relative occupants' complaints indicated "too much artificial light" and "daylight reflection or glare". Most of these complaints came from occupants facing the west windows. These results again show operational loss of lighting energy that is contributing to discomfort of the occupants.

3.2 Baseline Model

The baseline model for adopted the existing conditions of the case study building. The indoor data acquired from the POE assessment along with the as built construction drawings helped calibrate and validate the baseline model according to the annual electric bill record for the building total energy consumption for 2019 of 1,385,878 kWh (shown in figure 2). Where the energy use intensity (EUI) of the case study building is 194.6 (kWh/m²) according to the total conditioned floor area (7120 m²). After plugging in the set of data for the actual conditions including set point cooling temperature, HVAC operation, lighting schedule, envelope construction details, and specifying zones; the simulation model attained EUI of 197.4 (kWh/m2) (only 1.5% error). Yet, the case study building's energy use confirms to be higher than UAE best practice for energy efficient buildings consuming 110-160 (kWh/m²) [19]. The simulated baseline block shown in figure 3 reveals the existing west facing elevation with an average WWR of 51%.

2019 Monthly Electric Consumption (in Kwh)													
Building	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
MALE ACADEMIC BUILDINGS													
F1	110395	110401	101082	113351	113320	121622	118032	111632	127863	124297	119809	114074	1385878

Figure 2. Case study building energy consumption report for 2019

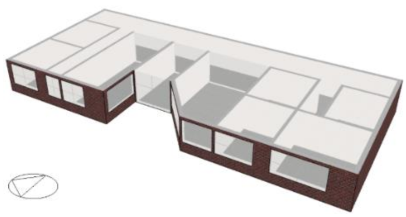

Figure 3. Baseline simulation model typical block bounded by the west façade (average WWR 51%)

The energy use distribution (shown in figure 4) reveals HVAC as the highest consumer of energy (cooling) with 139.8 (kWh/m²), accounting for 71% of the total building's energy use. Typical HVAC energy consumption in office building range from 39- 55% [20-22], through different climatic zones. This could mainly be traced down to 2 issues. The first being the low set point and setback temperature (21°C and 24°C respectively) that are set by the facility management. The second issue is the increased WWR that is consequently contributing to the loss of cooling energy and the increase in total cooling load of the office building. Moreover, the internal heat gain sources (shown in figure 5) showcase the severity of the solar gains from the exterior windows as it is responsible for an annual heat gain of 91.5 kWh/m², ranking the highest internal heat source. These initial findings highlight the existing issues that are driven by the POE assessment.

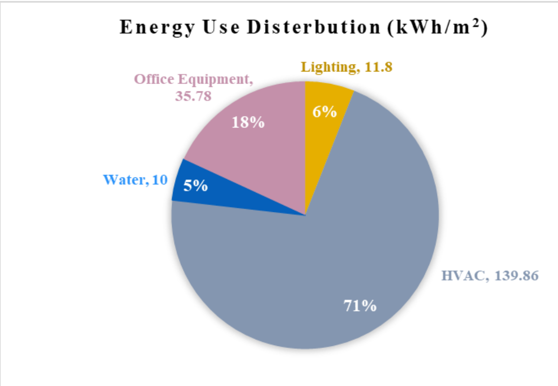

Figure 4. Baseline model energy use distribution

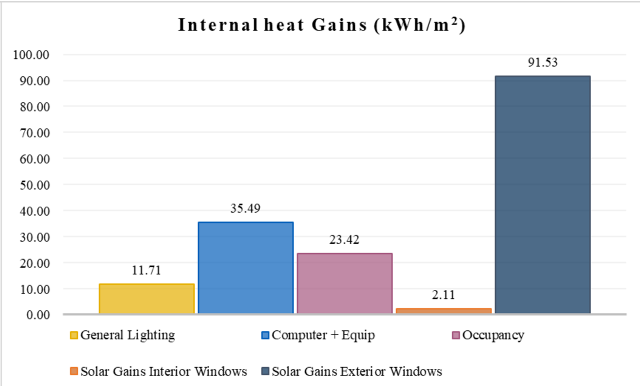

Figure 5. Baseline model internal heat gain sources

3.3 WWR Optimization

DesignBuilder software aided in the WWR optimization assessment through EnergyPlus computation. After plotting all the energy simulation data through Microsoft excel, figure 6 summarizes the trend for key building energy use sources as the WWR varied from 0%-100%, in 10% increments. The overall trend presents a more prominent increase in HVAC (cooling) energy consumption compared to a slight decrease of artificial lighting energy, as the WWR progresses accordingly. The optimum WWR when it comes to solely the balance between the HVAC (cooling) and lighting energy consumption to achieve the least EUI is 20%, achieving 14.5% energy use reduction from the baseline model. On the other hand, figure 7 presents the effect of WWR on the average illuminance (lux) experienced by the occupants in the office. As per lighting comfort standards mentioned in the literature, 300-500 lux are met through the range of 20% to 30% WWR. Therefore, the optimum WWR for the west façade in an office building situated in the UAE is between 20%-30%.

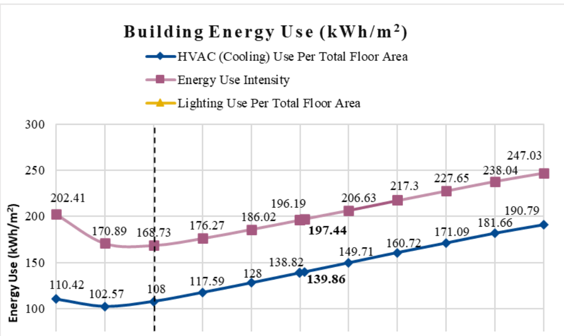

Figure 6. Effect of south facade WWR on building energy use per total floor area. (Baseline simulation values highlighted in bold)

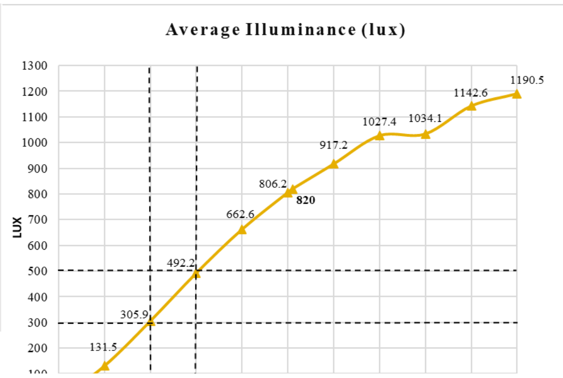

Figure 7. Effect of south façade WWR on the average illuminance (lux) in a typical office

These findings tie gaps between other research work based in similar hot and dry climate. A recent study (2020) in Saudi Arabia recommended the optimum WWR for southwest façades in school building to not exceed 20% to optimize the energy performance[23]. Conversely, a comprehensive analysis between WWR and the distribution of illuminance, in hot and dry climate case of Iran, states the most appropriate values for WWR for better daylight efficiency to not be less than 30% [24]. This study adopts a real case study of a higher education office building in the UAE and runs a comprehensive POE assessment and simulation study to reveal the optimum WWR for the west facing facade regarding both building energy performance and occupants comfort between the range of 20%-30%. Such recommendation adds evident knowledge to this area of research as well as supports architects to achieve better energy performance of new office building designs in hot and dry climate whilst ensuring excellent occupant satisfaction levels.

4. Conclusion

The aim of this study is to investigate optimal WWR towards reducing cooling energy consumption for west bounded offices in the hot and dry climate of UAE. The specific scope was driven by early POE assessment findings that took place in a case study of an existing higher education office building in Al Ain, UAE. Occupant's satisfaction surveying along with active indoor environmental measurements found prominent issues in thermal and lighting comfort especially along the office area bounded by the west façade. This study adds on by utilizing computational modeling to run an energy simulation, using DesignBuilder software, that tests an array of WWR (0%-100%, in 10% increments) to find the optimum WWR towards reducing cooling energy consumption as well as enhancing existing indoor daylighting conditions. Results found south façade WWR of 20% to provide the best building energy use performance, that showed a 14.5% decrease from the existing baseline model. Moreover, indoor lighting simulation depicted enhanced lighting levels, to meet with Estidama [16] and WELL building standard [15], throughout the WWR range from 20%-30%. These results promote applying passive energy optimization strategies for upcoming office designs as well as existing buildings retrofits with respect to hot and dry climates.

Although this study only focuses on the single factor of WWR and its effect on the energy cooling load, several other factors such as wall insulation, window type, glazing properties, and shading require further investigation to reach even better energy performance. Furthermore, thermal comfort assessment was limited in this study as the issue was associated with the facility management and operational settings of the office building and thus need to be resolved before being able to provide an accurate comparison or design solution. Future work of this study aims to find a comprehensive retrofitting solution to this case study to redesign the façade towards better energy performance responding to the occupants needs.

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Exterior CFD Analysis to Study Natural Ventilation Strategies for A Prototype House in Dubai, UAE

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Abstract: In recent years, the UAE Government has endorsed initiatives that aim at ensuring a sustainable future development of its built environment. Focus is put to preserve energy resources, minimize consumption, and improve indoor environmental and air quality. Among the different actions promoted by recent regulations and initiatives, passive strategies have become increasingly interesting for current designers, who often propose complex building forms to specifically tackle passive cooling via natural ventilation. This paper presents the preliminary results of a computational fluid dynamics (CFD) study on a prototype house designed at the University of Sharjah for the participation to the international academic competition Solar Decathlon Middle East 2021 in Dubai (SDME). Considering the location where the house will be built, the site layout, and the weather conditions, the design tackled the use of the prevailing wind to activate passive cooling strategies, with the final objective of enhancing the façade back-ventilation and ventilating the indoor spaces. Due to the particular morphology of the house, characterized by an outer fence surrounding it completely, the airflow behavior has been studied to understand in what capacity it crosses the fence itself, and it reaches the inner volume. The type of finishing used for the outer fence is the focus of the study: several alternatives have been tested, including perforated panels and louvers with various orientation and tilt. No outstanding difference was found; nevertheless, the layout with vertical louvers showed a marginal increase in airflow pressure and velocity at selected observation points and was therefore considered preferrable. The result of this study highlights the quality of airflow, assisting the future steps of the research in studying the house's passive cooling strategies by means of natural ventilation.

Keywords: CFD; Computational fluid dynamics; Natural ventilation; Passive cooling; Solar Decathlon; Prototype house.

1. Introduction

1.1. Background

The United Arab Emirates (UAE) is a fast-growing nation with an active construction industry that is experiencing massive expansion. Especially, Dubai is one of the fastest growing cities in the world. As this uncontrolled construction market often results in high-energy demanding buildings, the government is promoting policies to boost sustainable development and meet global energy demands. The UAE vision [1] and the UAE Green Growth Strategy [2] are recent initiatives that aim at making the UAE the one of the most innovative and sustainable countries worldwide. In particular, they introduce local green building codes (i.e., Estidama [3] and Sa'fat [4]) that promote both the implementation of efficient active systems (renewable energy devices, air conditioning, etc.) and passive strategies.

Due to the frequently complex morphology of contemporary buildings and to the growing interest in improving their passive performance and environmental impact, the understanding of natural phenomena in relation to buildings is becoming increasingly important in architectural design. It is the case of natural ventilation, with regards to internal and external air flow, that can be used to improve indoor air quality, remove contaminants from spaces, and remove heat from a building during the day or night. Natural ventilation strategies, enhanced by the wind pressure, may prove valuable to assist the active cooling systems (air conditioning) and save energy. Furthermore, they offers the possibility to improve indoor air quality (IAQ) and grant a healthy environment.

1.2. Problem Statement

This study presents the preliminary results of a computational fluid dynamics (CFD) analysis of a prototype house, to assist the design phase in adapting the building's morphology to the external conditions, with particular regard to using the wind to enhance natural ventilation strategies.

The house, once built, will participates to the Solar Decathlon Middle East 2021 in Dubai (SDME), an academic competition where teams of students and instructors design, build, and operate a solar-powered, energy efficient, and low-carbon building that mitigates climate change, grants high indoor comfort standards, and promotes an environment-aware lifestyle.

As further detailed in Section 2.1, the house is made of a rectangular conditioned-volume surrounded by a circular fence, which creates two main external courtyards and represents an obstruction to the wind flow coming from different directions.

This paper presents the first phase of a research aimed at gathering the initial information on the quality of airflow in different areas of the house, toward achieving the following final scopes:

A. Enhance wind flow in the courtyards (the North and South spaces contained between the house thermal envelope and the outer louvers fence).
B. Increase the back-ventilation efficiency in the building's ventilated façades, with the aim to maximize hot-air removal by stack-effect and consequently reduce heat transfer toward indoor spaces.
C. Directly channel wind-driven airflow inside the building to assist passive cooling strategies.

1.3. Literature Review

Previous studies have highlighted that natural ventilation can improve indoor air quality by 20–47% [5], potentially reduce energy consumption by 8–78% [6], and provide a high level of thermal comfort for the occupants [7]. Unfortunately, natural ventilation cannot be used in all climates due to harsh weather conditions [8]. In fact, the challenges of introducing natural ventilation can vary depending on the location and the wind flow that could be employed to induce it [9, 10], the relation between indoor and outdoor environments (especially in unsteady wind conditions) [11], irregular urban geometry [12], and variations in outdoor air quality [7]. The driving force for natural ventilation is the pressure differential created by wind and thermal buoyancy. Therefore, it is necessary to obtain reliable meteorological wind information (speed and direction) [13]. Then, natural ventilation can be assessed by various methods, such as the analytical method, semi-empirical models, the wind tunnel method, and computational fluid dynamics (CFD).

The CFD method, utilized in this study, can account for major influencing factors. Although CFD is computationally demanding, its accuracy and reliability in determining the ventilation rate makes it an ideal tool for studying natural ventilation [14-16]. Natural ventilation design for buildings requires profound knowledge and accurate prediction of air flow in order to quantify the naturally-driven ventilation rates as well as the associated effects on building space temperatures. To this regard, CFD can provide a robust prediction of natural ventilation.

It has been used to simulate natural ventilation under a variety of conditions, including wind- and buoyancy-driven flows as well as those with combined forces [17]. CFD is mostly used to perform simulations on portions of a building [18], particularly where spatial temperature variations exist, and in specific time-ranges. In fact, performing annual CFD simulations of an entire building is impractical, due to the computational complexity and time demanded by the average CFD software. Reduced-order airflow models such as network models have been developed to quickly predict airflows throughout a building. A variety of different network models have been developed, such as

MIX by Li et al. [19] and AIOLOS by Allard and Santamouris [20], many of which are used internally by the developer. Several studies comparing these models to each other are found in literature [21-23]: the general conclusion of these studies is that the models are similar, with minor functional differences separating the tools.

1.4. Research phases and objectives

In order to make use of natural ventilation and assist the final scopes of the project (listed in Section 1.2), the effect of the external obstruction must be studied, to verify in what capacity it limits the amount of natural air flow reaching the house. For this reason, this preliminary study has the objective of analyzing different morphologies of house fence, identifying the most efficient option toward:

i. Analyzing the quality of airflow in the courtyards and proposing design improvement to assist scope (A) while preserving privacy (visual screen indoor-outdoor), safety (confining and securing the external courtyards), and providing shade (to grant thermal comfort to the external courtyards).
ii. Analyzing the quality of airflow reaching the façade of the house, and proposing design improvement to assist scope (B) and (C).

1.5. Limitations

Simulations yield instantaneous volume data. However, it suffers inherently from the discretization of the governing equations of fluid dynamics combined with the modeling of the initial boundary conditions. Some flow phenomena exhibit an extreme sensitivity to these conditions. These current limitations to using CFD are often misinterpreted as a major hurdle to its adoption as a standard practice in many industries. Yet CFD is used successfully in the aerospace, automotive and many product design industries; this fact alone stresses the compelling possibilities of CFD for architectural design [24].

The used software runs only a steady-state CFD simulation. Any CFD analyses in different moment of the day/year, or with different wind conditions require a dedicated software set up and simulation. This does not account as a limitation per se, but it requires longer time, and does not provide a global dynamic output.

2. Materials and Methods

2.1. Test-Building Desccription

The test-building used for the CFD analyses is an 85 m^2 prototype house designed for the participation to the international competition SDME and, for this reason, following the competition stringent building code and rules; these include but are not limited to: limited buildable area and volume, resulting in a very compact shape; single story, to ease the construction on competition site (allowing only 14 days to assemble the house).

Considering the above-mentioned indications, the house is defined by 2 main architectural/construction features: an internal rectangular conditioned volume, and an external circular fence. The conditioned mass is enclosed in a rectangular sealed thermal envelope (dimensions: 12.80 m in width, 7.45 m in length, and 3.30 m in height). Instead, the outer round fence (dimensions: 16.20 m diameter and 3.50 m in height) defines the house's private courtyards and is made of discontinuous elements (that are the main objects to be assessed by the CFD simulations) (Figure 1).

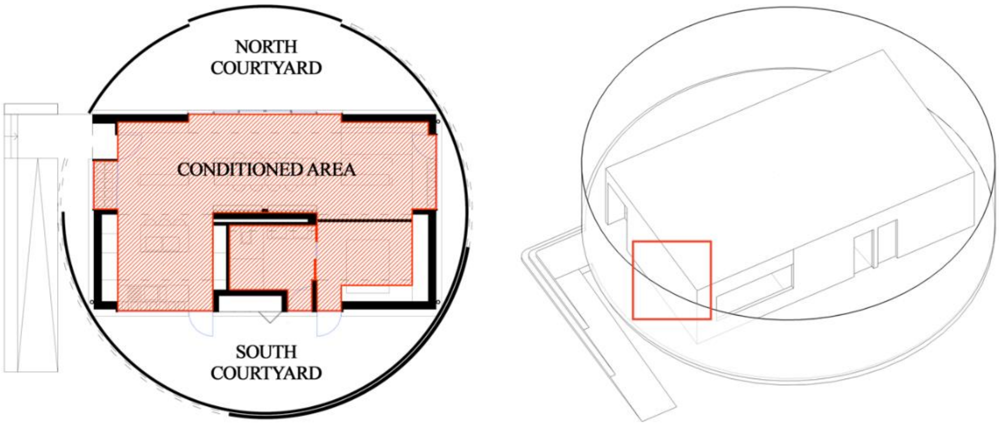


Figure 1. Left: house architectural plan showing the conditioned area (red hatch) and the semi-circular North and South courtyards. Right: isometric schematic view (the red box serves as a reference for the diagrams in Table 1).

2.2. Research phases and design options

In order to reach the stated objectives, this study followed 2 phases:

1. Testing different types of finishing for the outer fence to identify the solution that allows maximizing air flow while preserving privacy, safety, and providing shade (Figure 2a):
   1.1. Perforated aluminum cladding panel (i.e. metal mesh), 30% perforation.
   1.2. Vertical louvers (40 cm depth, 3 cm blade thickness).
      1.2.1. Open (always parallel to the ground plane).
      1.2.2. Close (always perpendicular to the ground plane).
   1.3. Horizontal louvers (40 cm depth, 3 cm blade thickness)
      1.3.1. Open (always perpendicular to the circular fence).
      1.3.2. Close (always tangent to the circular fence).

2. Development of the preferable option from phase 1 and testing of different shapes and orientations to assess potential increase/decrease in the efficiency (Figure 2b). Phase 2 of the study has only been carried on for the North-West wind scenario, found to be more significant in phase 1.
   2.1. Increased depth of the vertical louvers (to 60 cm) to verify if, and how much it would further obstruct the wind flow from crossing trough.
   2.2. Vertical louvers tilted according to the prevailing wind direction (North-West) to verify if the alignment to the airflow produces significant improvement in the wind crossing through.
   2.3. Vertical louvers coupled and moved into a "V" position (for architectural/functional reasons), to test if the funnel-like shape improves significantly the air velocity and therefore the pressure on the destination surface (house thermal envelope).

   Table 1 shows graphic diagrams representing each above-described fencing option.

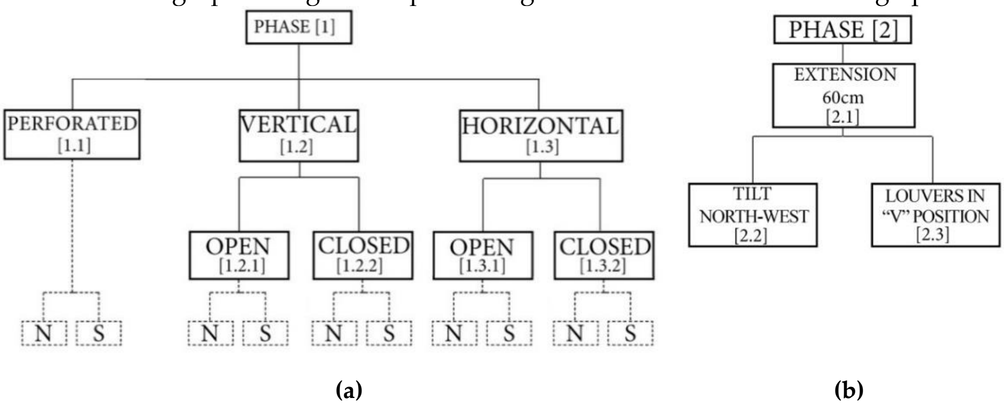
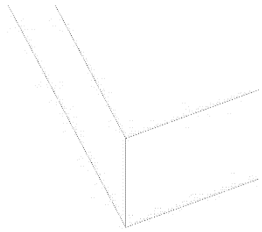
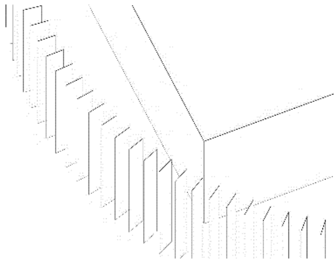
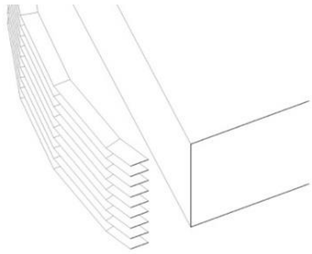
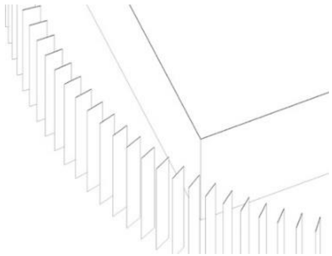
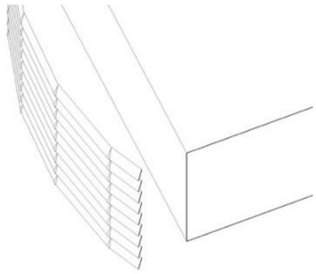
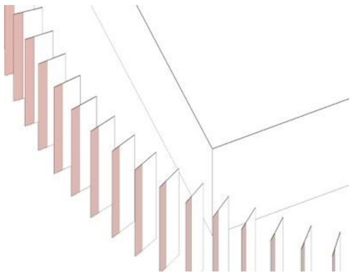
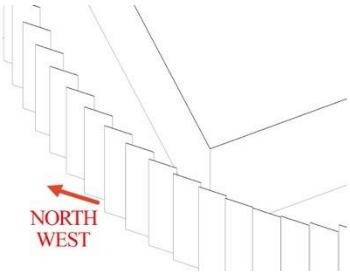
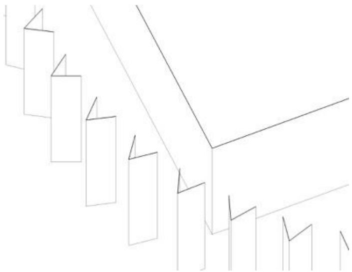


Figure 2. (a) Phase 1; (b) Phase 2. See detailed description of the different geometries in section 2.2.

Table 1. Graphic diagrams of the different tested fencing options (see Figure 1 as reference).

PHASE 1		
1.1 Perforated cladding	1.2 Vertical louvers	1.3 Horizontal louvers
	1.2.1 Open	1.3.1 Open
		
	1.2.2 Close	1.3.2 Close
		

PHASE 2		
2.1 Vertical louvers extension to 60 cm	2.2 Vertical louvers tilted to North-West direction	2.3 Vertical louvers coupled and in "V" position
		

2.3. CFD software

The commercial software Design-Builder [25], mounting the simulation engine Energy Plus [26] was employed in this study to run the CFD analyses. While Energy Plus is a full dynamic-state energy performance simulation tool, Design Builder' CFD module follows a steady-state computational procedure. CFD simulations are run for internal or external environments, given a-priori wind/boundary conditions, for a unique moment in the year: fed by Energy Plus, the CFD module can run simulations for any moment in the year (therefore allowing the user to test the building's features at any desired time), but one at the time. No dynamic flow animation is finally generated by the software, but only a steady section providing the information of wind direction, pressure, and velocity for the simulated moment.

2.4. CFD Model Setup and Boundry Conditions

Setting up proper boundary conditions and wind properties is essential to accurately study the flow pattern through and around the target building.

First of all, the geometrical extension of the analysis must be defined: a 'boundary box' (twice the height of the test-building and 3 times the length and depth) aligned with the chosen wind direction (see below) that inscribes the test-building and is further divided in tridimensional finite elements by a grid, self-generated by the software according to the notable points in the model. As simulations have been run for two different moments of the day, with two different prevailing wind directions, two boundary boxes have been used, each one aligned with the relative analyzed wind (Figure 3a).

Then, the two main variables to input to the software are velocity and direction at origin (considering the 'origin' the side of the boundary box where the perpendicular airflow vectors will generate from. See Figure 3a). Temperature is not a necessary variable, as this part of the study only works with outdoor CFD analysis, which does not affect IAQ in any way.

Given the limitation of the software (see above section 2.3), the specific day and time in the year, for the simulations, needed to be identified. In this case, end of October/beginning of November seemed a reasonable period of the year, since it matches the SDME contest period (when the house will be monitored by the competition jury) and since it is the end of Autumn, when outdoor maximum temperature starts decreasing to comfort level (around 26°C) and can be used for partial indoor passive cooling (one of the final scopes of the project).

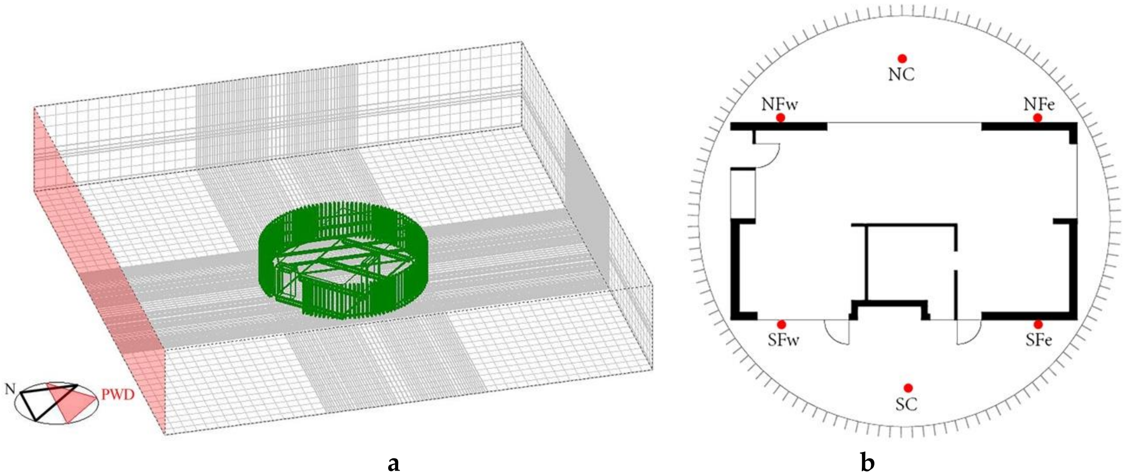


Figure 3. Boundary box for CFD analysis with the house model at its center (**a**), showing the North direction, the prevailing wind direction (red arrow), and the wind 'origin' side (red-hatched side). Observation points of velocity and pressure values (**b**).

To scientifically validate this random day/time selection, weather data was collected from Al Maktoum airport (located near the SDME contest site), including a thorough analysis of the wind conditions (Figure 4), and a detailed dynamic-state energy simulation was run with Energy Plus to verify the average air pressure reaching the building surfaces exposed to the prevailing wind direction. The data analysis showed that the competition site is characterized by North-West prevailing wind from 12:00 pm to 4:00 am (16 hours) with an average velocity of 6 m/s, and by South wind from 4:00 am to 12:00 pm (8 hours) with an average velocity of 4 m/s.

Once verified the initial assumptions, the related values of velocity and direction at origin have been inputted to the software for two separated simulations: North-West wind and South wind.

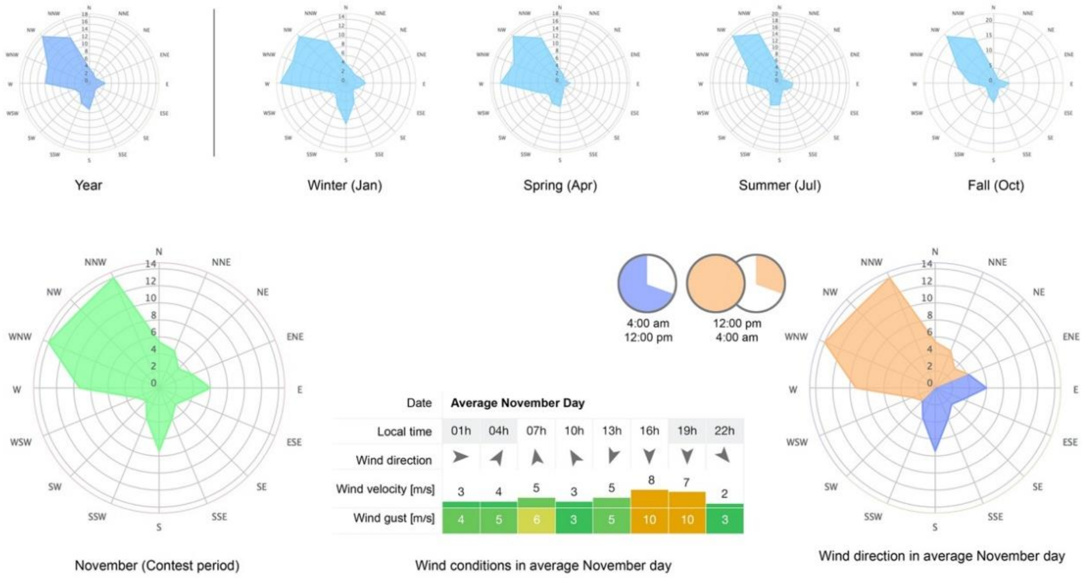


Figure 4. Wind analysis. Annual and seasonal average. Focus on the month of November (test period).

1.5. Analyzed Paramenters

Velocity and pressure have been observed at six selected reference points in the northern and southern external areas of the house (Figure 3b). The values measured at these points are considered the best indicators for evaluating and comparing the different options. The specific points are labeled as follows:

- NC – North courtyard: 1.7 m above the horizontal plane.
- NFw – North façade, West: 1.7 m above the horizontal plane.
- NFe – North façade, East: 1.7 m above the ground level.
- SC – South courtyard: 1.7 m above the ground level.
- SFw – South façade, West: 1.7 m above the ground level.
- SFe – South façade, East: 1.7 m above the ground level.

3. Results and discussion

3.1. Sample Simulation

Figures 4 and 5 show the horizontal and vertical sections of the CFD analysis of option 1.2.1 'open vertical louvers' subject to North-West wind (hereby represented as sample simulation), highlighting the distribution of the velocity vectors at a 1.7 m above the horizontal plane, in the regions of interest. The near surrounding louvers affect the prevailing wind direction slightly changing the wind angle of incidence and decreasing the velocity in the center of the north courtyard. Due to the prevailing wind, the wind flow passes between the louvers before reaching the façade of the building (thermal envelope) and being deflected by it.

The magnitude of flow acceleration is strongest in the North courtyard than in the South one. This is even more marked in the region just passed the North-West louvers, due to the direction of the prevailing wind and most likely because it is the first zone receiving the approaching flow. As a result, the wind pressure measured on the West façade observation point (NFw) is higher than that on the East façade observation point (NFe).

This CFD simulation acts as a sample of the work done for all the others. To avoid repetitiveness, this paper only details this one, as a representative example of the methodology applied to all the others.

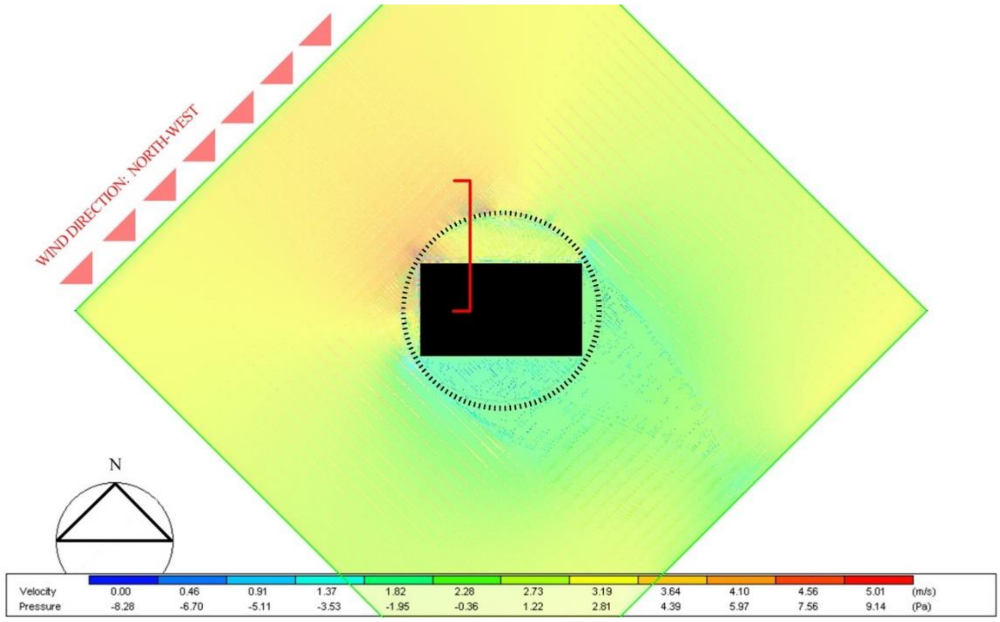


Figure 4. CFD analysis output. Horizontal section of the model within the boundary box. The colored contour lines represent wind pressure, while the colored vectors represent wind velocity and direction. The section line marked in red is a reference for Figure 5.

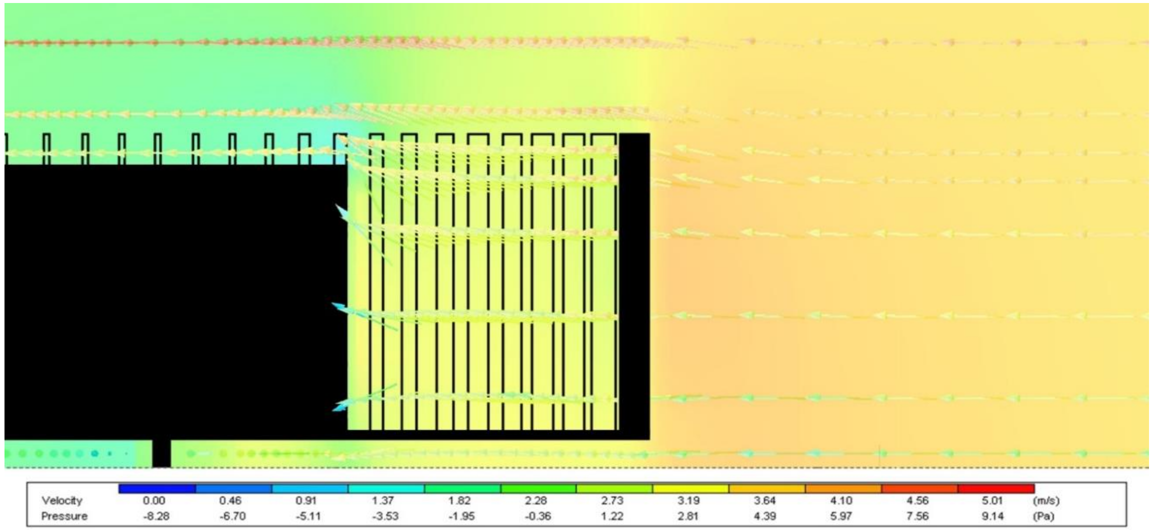


Figure 5. CFD analysis output. Partial vertical section (reference section line in Figure 4). The colored contour lines represent wind pressure. The colored vectors clearly show the change in wind velocity and direction as the airflow crosses the external louvered fence and as it hits the façade.

3.2. Phase One

The simulation process explained in Section 3.1 was then applied to the remaining alternatives. Table 2 shows the results of velocity and pressure monitored in the observation points in the North and South courtyards and facades. For ease of reading, the irrelevant data have been omitted.

For both North-West and South wind, in the courtyards points the general trend shows that the flow velocity is higher when the fence is 'open' and slower when it is 'close'. On the other hand, velocity slows down almost evenly as it reaches the façade points (obstacle), while pressure increases; moreover, while wind velocity measured at the façade's points is quite steady whether the fence is open or close, the pressure is sensibly higher with the open louvers. North-West and South conditions differ due to the different inputted wind velocity and direction; overall the latter causes a more even distribution of wind on the southern façade, which receives the wind perpendicularly, and more unbalanced on the northern one, where the stronger North-West air vectors generate more pressure in the western region of the facade.

The three fencing options do not vary significantly in terms of wind velocity at any observation point, with the option 1.2.1 (open vertical louvers) showing slightly higher results for both North and South courtyards, with respectively North-West and South wind. It is surprising to see that the wind velocity in the courtyard points NC and SC in option 1.2.1 is even higher than in the case of no fence at all. This is probably due to the 'funnel effect' that increases the airflow speed when it passes through the gaps between the louvers. This is also the case for the other two options (1.1 perforated cladding and 1.3.1 open horizontal louvers), with the only exception of the perforated cladding, which shows lower velocity in the South courtyard (SC). It is plausible that the perforated metal plate is more difficultly crossed by the slower perpendicular wind.

With regards to studying the two courtyards, the pressure is not indicative because the relative observation points (NC and SC) are suspended in space, and not on a surface; in this case, wind velocity is enough to indicate whether sweat evaporation by convection (giving humans the sense of cooling) occurs and at what rate. For this reason, option 1.2 (vertical louvers) seems preferable.

The results for the three options are also very similar with regard to the velocity measured in the points on the facades, with slightly higher values again for option 1.2.1.

With regards to the final scope of using external air to increase the facade back-ventilation and contribute to indoor passive cooling, the higher the pressure on the façade, the more significant the effect. The next steps of the research intend (i) to breach the façade in specific points to channel the air through the façade air-gap (perforations to be made on the cladding) and (ii) to design appropriate opening/windows to let the air in the indoor environment. As clarified at the beginning of the paper, this study merely assesses the external conditions to demonstrate the suitability of the following steps, which are currently at the phase of study.

Given the above, the pressure values measured for the three fencing options highlight option 1.2.1 (open vertical louvers) as preferable for the North façade and option 1.3.1 (open horizontal louvers) as preferable for the South façade, even if the difference is marginal.

Given the result of the analysis on the courtyard observation points; given the least significant differences measured in the southern area; and given the preference to grant comfort conditions to the North courtyard (naturally shaded extension of the indoor living quarters), option 1.2 was finally selected.

Table 2. Phase 1 results, detailing the values of velocity and pressure monitored at the observation points.

Fencing options		Simulation	Observation points					
			Courtyards		Facades			
			NC	SC	Nfe	NFw	Sfe	SFw
			[m/s / Pa]	[m/s / Pa]	[m/s / Pa]	[m/s / Pa]	[m/s / Pa]	[m/s / Pa]
No fence		1. North	1.37/2.81	-	1.37/6.20	1.37/3.19	-	-
		2. South	-	1.85/2.90	-	-	0.93/2.90	0.93/2.90
1.1 Perforated cladding		1. North	3.14/3.10	-	1.35/6.10	1.35/4.30		
		2. South	-	1.30/2.50	-	-	1.02/2.60	1.02/2.60
1.2 Vertical louvers	1. Open	1. North	3.19 /2.81	-	1.37/2.75	1.37/6.30	-	-
		2. South	-	1.93 /2.74	-	-	0.97/2.74	0.97/2.74
	2. Close	1. North	1.36/1.70	-	1.40/1.33	1.40/1.20	-	-
		2. South	-	0.92 /1.70	-	-	0.92/2.10	0.92/2.10
1.3 Horizontal Louvers	1. Open	1. North	3.12 /2.50	-	1.34/2.10	1.34/7.06	-	-
		2. South	-	1.54 /3.09	-	-	0.93/3.45	0.93/3.45
	2. Close	1. North	1.80 /3.50	-	1.36/3.50	1.34/1.20	-	-
		2. South	-	0.92/-2.11	-	-	0.91/3.10	

3.3. Phase Two

As anticipated, phase 2 of the study aims at analyzing further developments of the selected option to account and plan for design developments. For the reasons mentioned in the previous section, the CFD analyses have only been run for the northern area, under North-West wind conditions. Table 3 shows the results of velocity and pressure monitored in the observation points.

The simulation results have been compared with the previous data from option 1.2.1. Only option 2.3 (open louvers in V" position) showed some marginal improvement, reaching 3.50 m/s (0.31 m/s increase); this is probably due to the increased 'funnel effect' achieved thanks to the "V" morphology, which tends to squeeze the air mass through the smaller opening, conferring it more velocity. This solution can be considered in the construction of the specific frame supporting the louvers, either in a fixed installation of in a operable one (folding opening system to move the louvers in "V" position). Options 2.1 and 2.2 do not seem to affect (neither positively nor negatively) the previous results.

Table 3. Phase 2 results, detailing the values of velocity and pressure monitored at the observation points

Fencing options	Simulation	Observation points		
		Courtyards	Facades	
		NC	Nfe	NFw
		[m/s / Pa]	[m/s / Pa]	[m/s / Pa]
2.1 Increase depth of louvers to 60 cm	1. North	3.16/ 2.78	1.36/1.90	1.36/4.40
2.2 Louvers tilted in North-West direction	1. North	3.17/2.39	1.36/3.20	1.36/6.50
2.3 Louvers coupled and opened in "V" position	1. North	3.5/3.20	1.37/3.65	1.36/6.50

5. Conclusions

With the aim of adjusting the architectural design of a prototype house in order to activate passive cooling by natural ventilation, this study performed CFD simulations to assess the quality of airflow in the proximity and on the facades of the building: the wind crosses the building's surrounding fence, an incoherent surface (partially fluid-permeable) that constitutes an obstacle to the wind, deflecting and slowing it down unpredictably.

The CFD module in the software Design Builder allowed loading detailed weather data and accurately studying several options of fence finishing, including perforated panels and louvers with various orientation and tilt. CFD analysis for different moments of the day/year, characterized by diverse wind conditions (direction and velocity) allowed collecting precise information at multiple observation points, strategically located in the spaces within the house and the fence (outdoor courtyards) and on the house's North and South façade.

Beside acknowledging that all solutions increase the wind velocity due to the 'funnel effect' (shrinkage of the fluid channel that compresses the air, increasing its speed), no outstanding difference in the airflow quality was found for the different fence types, and nothing very far from the pre-simulation predictions was measured. Nevertheless, the layout with vertical louvers, open to let in maximum flow, showed a small increase in air pressure and velocity at the selected observation points and was therefore considered preferrable (phase 1). Moreover, the possibility of coupling vertical louvers in a "V-shape" position seems to enhance the 'funnel effect' and further increase the air velocity (phase 2).

Finally, the results of the quality of airflow measured in this preliminary study will assist the future steps of the research toward achieving the following final scopes:

A. Enhance wind flow in the courtyards (the North and South spaces contained between the house thermal envelope and the outer louvers fence).

B. Increase the back-ventilation efficiency in the building's ventilated façades, with the aim of maximizing hot-air removal by stack-effect and consequently reduce heat transfer toward indoor spaces.
C. Directly channel wind-driven airflow inside the building to assist passive cooling strategies.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "conceptualization, V.B.; methodology, V.B.; software, H.A.; validation, H.A.; formal analysis, V.B.; investigation, H.A.; resources, V.B. and H.A.; data curation, H.A.; writing—original draft preparation, V.B. and H.A.; writing—review and editing, V.B.; visualization, V.B. and H.A.; supervision, V.B.; project administration, V.B.; funding acquisition, V.B.".

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Embedding Passive Intelligence in Educational Buildings in Warm Summer Humid Continental Climates: A case study in Minneapolis

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Abstract: The application of passive intelligence in buildings has been gaining attention widely the past decade; however, it becomes more significant in challenging environments. In warm summer humid continental climates, it can be challenging to maintain a cool indoor environment in a hot summer, and at the same time have a warm environment indoors during the extremely cold winter. In this paper, an emphasis will be done on applying passive intelligence in extreme climates; the focus will be kept on the buildings' envelope. A representative case study of an educational building in Minneapolis was selected. The main part of the school building stock in Minneapolis was built before the energy regulations, so most of the buildings need comprehensive refurbishment to achieve the performance required by laws that are in force. This study aimed at identifying passive design features through extensive virtual studies done on an energy modelling program that can be incorporated in warm summer humid continental climates to make them energy efficient. The strategies targeted had the goal of reducing the large heating loads in winter and the cooling loads in summer. To accomplish the reduction in heating loads, an analysis was performed comparing between the existing building envelope and an improved one conforming to the recent building energy codes in Minnesota. The total effect of insulating the building envelope can be seen in a reduction of the energy use intensity of about 51%. Moreover, improving the building's air tightness resulted in a further improvement of nearly 19%. To tackle the cooling loads, an emphasis was held on the use of high thermal mass and natural ventilation strategies in summer. Applying high thermal mass and night flushing resulted in a 9.5% decrease in the EUI, all through the reduction of cooling loads. Finally, it can be concluded that an accurate climatic and case study analysis to select the appropriate union of the different passive strategies, can have a significant effect on the reduction of energy consumption.

Keywords: Passive design; Insulation; Natural Ventilation; Energy; Sustainability; Warm Climates; Cold Climates; Heating Loads; Cooling Loads; Energy Use Intensity

1. Introduction

Building envelopes represent both a physical barrier between inside and out, and a great means to showcase architecture in terms of character, impression, and sustainability. With latest development in technology, buildings are presenting themselves more and more as a canvas to put the idea of passive sustainable design into practice [1]. Passive intelligent buildings date back to as early as 1980s [2] if not before, almost certainly one of the most widespread definitions of intelligence in building can be that of Clements-Croome's [3] where he suggests: 'An intelligent building is a dynamic and responsive architecture that provides every occupant with productive, cost-effective and environmentally approved conditions through a continuous interaction among its basic elements: places (fabric; structure; facilities); process (automation; control; systems); people (services; users) and management (maintenance; performance) and the interrelation between them'.

However, the application of passive intelligence becomes more significant in challenging environments. In warm summer humid continental climates, it can be challenging to maintain a cool indoor environment in a very hot summer, and at the same time have a warm environment indoors during the extremely cold winter. In this paper, an emphasis will be done on applying passive intelligence in extreme climates; the focus will be kept on the buildings' envelope, understanding the effect of insulation and air tightness on the construction elements, and natural ventilation strategies the on reducing the cooling and heating loads.

It can be argued that, across the globe, warm days are becoming warmer and more frequent, while we are experiencing fewer cold days. Over the past decade, daily record temperatures have struck twice as often as record lows across the continental United States, up from a near 1:1 ratio in the 1950s. Heat waves are becoming more widespread, and extreme heatwaves are more frequent in the U.S [4]. Although warmer winters will reduce the need for heating, modeling suggests that total U.S. energy use will increase in a warmer future due to cooling needs [4]. Therefore, will this change the focus of designers trying to heat the buildings, to a more focus on trying to cool the building? In this research, a focus was casted on educational buildings in Minneapolis, to study applying passive strategies to reduce cooling and heating needs in a warm summer humid continental climate.

In the largest school district in Minnesota, Minneapolis 58 schools are found with 72 buildings that all need major renovations because their function has changed so significantly since they were built[5]. The University of Minnesota has more than 850 buildings, and nearly 25 percent of them are more than 70 years old. Similarly, many of Minnesota's private colleges are old, some are over 150 years old [6]. Many of those older facilities are struggling to serve the technological and thermal comfort needs of the students and teachers. Multiple renovation projects are part of a $77 million 2015 capital request to the state, which also includes a $55 million request for Higher Education Asset Preservation and Renovation funds [7]. Building new schools in Minneapolis would cost a combined $41.1 million, $22.1 million to replace Northport and $19 million for Lakeview. The renovation cost for Northport, which opened in 1956, will be $21.8 million; for Lakeview, dating to 1964, it will be $10.9 million [8]. Consequently, needless to say, finding uncostly passive intelligent solutions to renovate the buildings becomes an urgent issue in Minneapolis's educational sector.

2. Methodology

2.1. Climate and design data analysis

In the first step, a study of the climate analysis of Minneapolis, Minnesota was done using the EPW (Energy Plus Weather) data file of a typical meteorological year (TMY) in excel. Excel was used to analyze the EPW data in terms of average daily and monthly dry bulb temperatures, relative humidity, cooling and heating degree hours, and wind speed and direction.

Then, an analysis of the design data and internal gains considered was done taking into account the CIBSE guides[9], and a typical school calendar in Minnesota. The usage schedules and diversity factors throughout the days were inferred. Following that, ASHRAE's psychometric chart was used to determine the passive strategies required in Minneapolis to reach the thermal comfort, the two most significant strategies for summer and winter where analyzed.

2.2. Case study selection and construction detailing

The school building selected is characterized by a U shape, with an internal courtyard, typical of the school building built at that time, shown in Figure 1. It is composed of four floors in which classrooms, playrooms and laboratories are located. For the energetic analysis, we have considered just half of the building, so an L shaped structure, since both sides are symmetrical. In the years when the school building was built, in the 80's, the implementation of energy codes was not as widespread as today. The main entrance is facing west, however most of the classrooms are facing south and north.

The case study model was modeled using Revit software. A scenario of a typical construction used in school buildings in the 80's in Minneapolis, was used as the base case to compare the improved scenario with. Description of Analyzed building scenarios as follows:

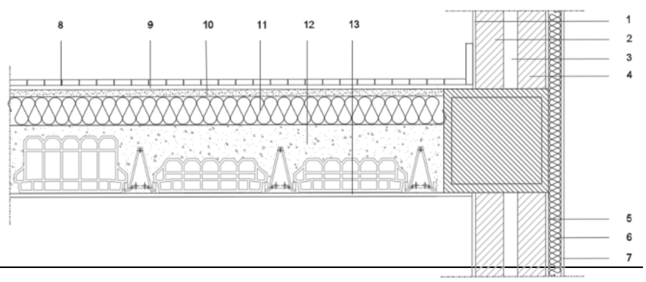
1. The existing case scenario, where the building has inappropriate insulation and is considered loose, since it has been built before any energy standards were applied in building regulations. In1 terms of natural ventilation, it highly depends on the occupants' usage of the building and it does not seem to be regulated mechanically or in a strategic manner.

2. The improved case scenario was analyzed based on the recent construction methods and energy codes and can be considered airtight [10]. The strategies include insulation of the existing building, air tightness of openings, and incorporating natural ventilation strategies. Table 1 shows improved case construction detail of a wall.

Figure 1. a) Case study of a typical school building in Minneapolis b) West facing main entrance

Table 1. Improved case construction detail of a wall

	Wall	
	Inside	Thickness (m)
1	10 mm polymer render	0.010
2	bedding component	0.010
3	light weight block	0.100
4	air cavity	0.050
5	light weight block	0.100
6	Kingspan thermal insulation	0.045
7	plaster	0.013
	Outside	



2.3. Energy analysis

In the following steps, the Integrated Environmental Solutions Virtual Environment (IESVE) software was used for the energy analysis of the case study model of a school building in Minneapolis.

The energy analysis was done focusing first on the effect of two passive strategies within the envelope, the first one includes applying insulation to construction elements within the building envelope to attempt to reach the optimum indoor comfort temperature during winter and summer. The insulation specifications were improved according to the recent Minnesota Building Energy Codes, effective since 2018 until now[10]. Specifically, chapter 1323.0402 of the commercial energy code section C402, building envelope requirements [11]. The second strategy focuses on achieving comfort during summer, by applying different strategies of ventilation and studying which one allows the building to reach the highest number of comfort hours. As shown in Table 2.

Table 2. Existing and improved case scenario of thermal resistances

Building envelope element	Existing	Improved
Wall U -value (W/m².C)	0.60	0.17
Roof U -value (W/m².C)	0.35	0.13
Glazing U -value (W/m².C)	5.52	1.25
Air tightness (ACH)	1.3	0.25

3. Results and Discussions

3.1. Climate Minneapolis

The climate of Minneapolis is classified as hot-summer humid continental without dry season, has a hotter all-time record high temperature of 42 °C. Humid continental climate is a major climate type of the Köppen classification that exhibits large seasonal temperature contrasts with hot summers and cold winters. It is found between 30° and 60° N in central and eastern North America and Asia in the major zone of conflict between polar and tropical air masses [12].

Figure 2 depicts the hourly dry bulb temperatures throughout the year in Minneapolis. It can be noted that most of the months are considered cold and fall below the comfort level (20- 26 C). January, February, March, November and December have freezing temperatures falling below 0 C. Maximum temperatures can be spotted during summer months, June, July and August. The maximum temperature reached is around 38 C during July, while the minimum is around -28 C in December.

Rain is the most common form of precipitation during the summer months, while snow, sleet, freezing rain, and occasionally rain occur during the winter [13]. The average of the humidity is ranging between 60% and 70% along the years, with a high fluctuation of the temperature in the months. In Minnesota, the relative humidity is highest during August and January, while a steep decrease in the relative humidity can be seen in May.

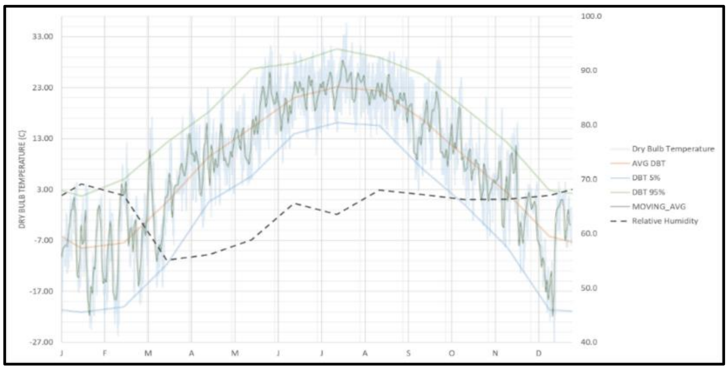


Figure 2. Dry bulb temperature average daily and monthly and relative humidity

The maximum average temperature can be seen during the month of July, while the minimum average can be seen during January and December. Furthermore, Figure 3 compares between the heating and cooling degree hours, it can be noted that the number of heating degree hours is much larger than the cooling degree hours. Therefore, in the analyzed climate the heating needs are much higher than the cooling needs, a focus on reducing heating and cooling needs will be done, by utilizing passive strategies.

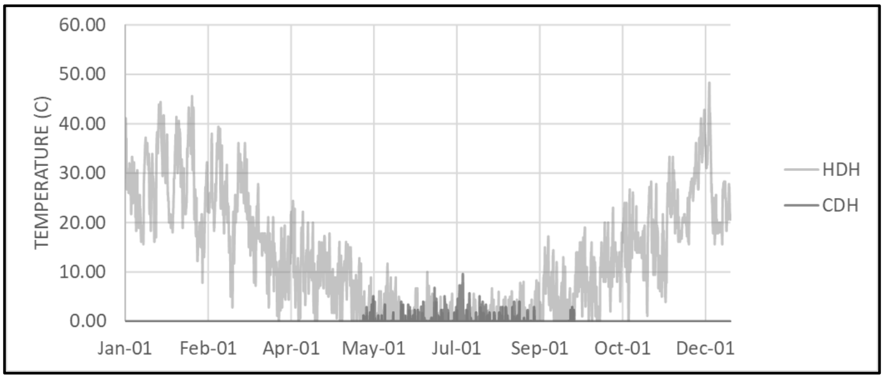


Figure 3. Cooling and Heating degree hours

In order to examine the applicability of utilizing natural ventilation as a passive strategy, a study of the available wind source speed and direction was done. First, analyzing the wind direction from the EPW wind data. In Figure 4, the concentric circles represent the percentage of the wind that blows in each direction. As it is possible to notice, the wind blows in all the direction with an irregular trend. The peak is august with the 24% of the time the wind being oriented towards the south. The average wind direction along the year is prominent in the northwest and southeast directions. In the following figure and table, the cumulative frequency is represented as a function of the wind speed. It can be seen that for most of the months the greatest frequency lies between an interval between 3.5 and 6.5 m/s. Higher velocities can be spotted in December, while lower velocities can be spotted in mid-summer months. A study of the climate surrounding the building under investigation is necessary to determine appropriate passive strategies.

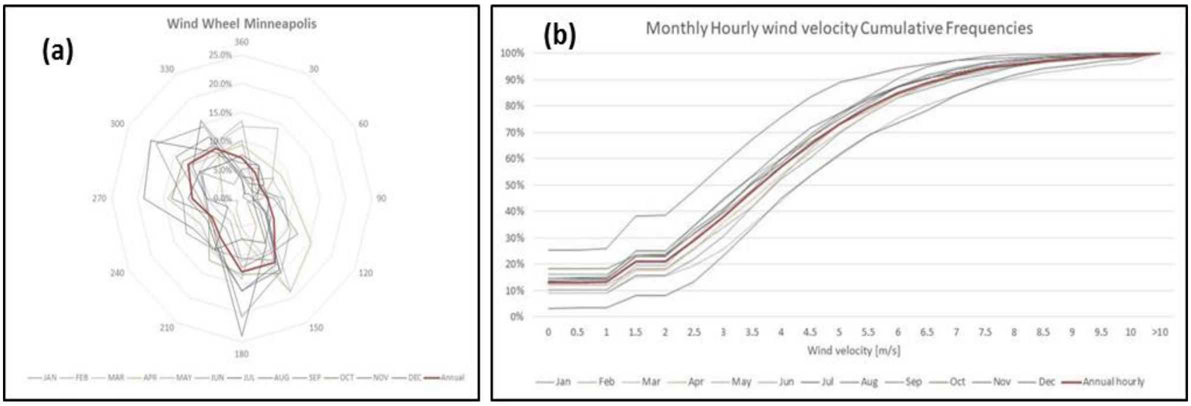


Figure 4. a) Wind direction b) Cumulative frequency of the wind speed along the year

3.2. Design data internal gains analysis

Studying the internal gains depends highly on the building's use. In the following tables, 3 and 4, the thermal templates data assumed for the building is presented. The sensible and latent gains coming from each different source has been decided according to the CIBSE guides, in particular: CIBSE Guide A: Table 6.2 'Benchmark allowances for internal heat gains in typical buildings and Table 6.3, and ASHRAE Fundamentals handbook (2001)[14]. The users' schedules in a 24-hour working day can be seen in Figure 5 for both a classroom and a laboratory, in addition to the diversity factors in terms of the different heat gains during the day. The main difference between the two rooms lies in the laboratory equipment increased heat gains which will require higher cooling loads during summer. The study of the internal gains allowed a more accurate understanding of the space's requirements in terms of heating and cooling along the different seasons.

Table 3. Internal heat gains

Room Types	Internal Heat Gains				
	m²/person	People Peak (W/person)		Lighting Peak (W/m²)	Equipment (W/m²)
		Latent	**Sensible**	**Sensible**	**Sensible**
Classroom[1]	1.5	60	80	12	10
Lab	1.5	60	80	8	43.3[2]

[1]The sensible and latent heat emission were taken from Table 6.2 in CIBSE Guide A, as 53 and 40 W/m² respectively.

[2] The sensible loads for the computer lab were taken from 2001 ASHRAE Fundamentals Handbook (SI), Table 8 Recommended Heat Gain from Typical Computer Equipment.

Table 4. Room conditions for school working hours

	Room Conditions			
	Heating		Cooling	
	Profile	Setpoint(C)	Profile	Setpoint (C)
All rooms	8:30 am -17:30 pm	20	8:30 am -17:30 pm	26

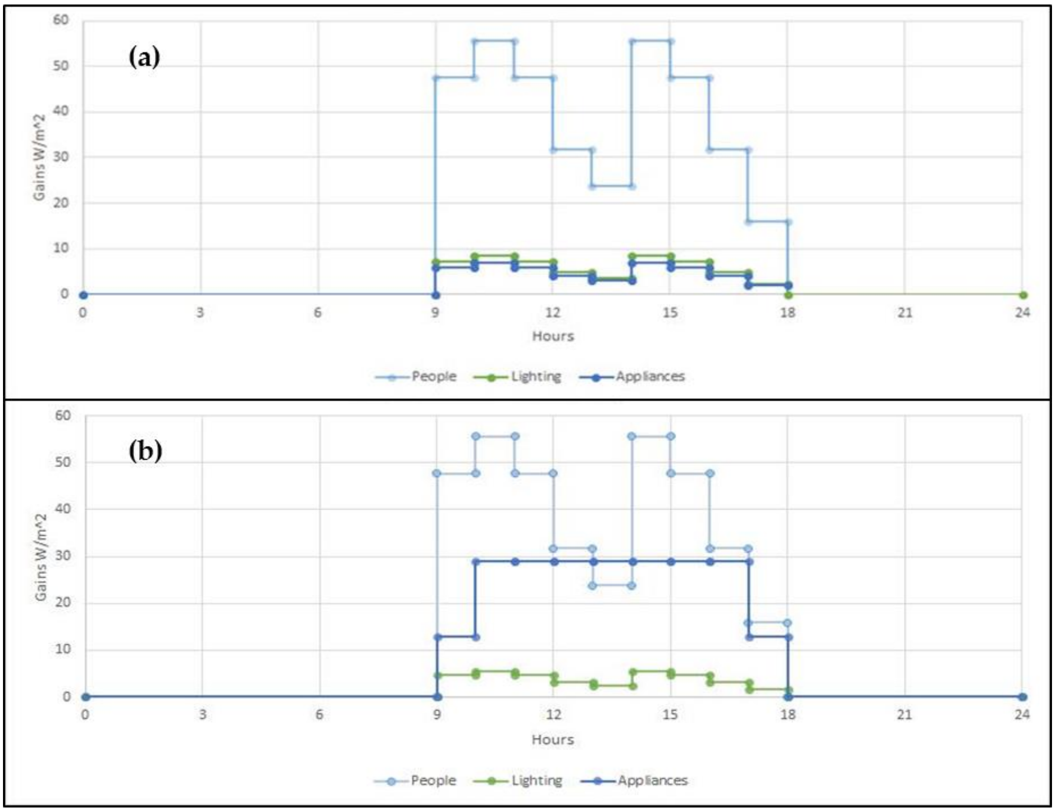


Figure 5. Usage and diversity factors of a) a Classroom and b) a Laboratory

3.3 Analysis of Passive Strategies

3.3.1. Site Context

Minneapolis is the most-populous city in the US state of Minnesota. As of 2019, Minneapolis has an estimated population of 429,606. The school district in Minneapolis is located in a suburban area not too far from the city center, the buildings surrounding the district are low rise buildings reaching up to 4 stories. Therefore, the assumed context of the school is semi exposed which is also in line with the real case of the school in Milan.

3.3.2. Analysis of passive strategies based on ASHRAE standards.

Considering the psychrometric chart below the zones highlighted and numbered are explaining the passive strategies to be used according to season, Number 1 shows all the area with temperatures falling below 8 C need direct solar gains to reduce heating. On the other hand, Number 2 shows mostly summer months in Minneapolis which will need sun shading. Points lying in zone 3 require insulation to increase indoor temperatures and reach comfort. Points lying in zone 4, rely on natural ventilation and when combined with high thermal mass, points lying in zone 5 which have high temperatures can use night flushing. In this study a focus is done on the actual effect of insulation and natural ventilation strategies and thermal mass to reduce cooling loads, as shown in Figure 6.

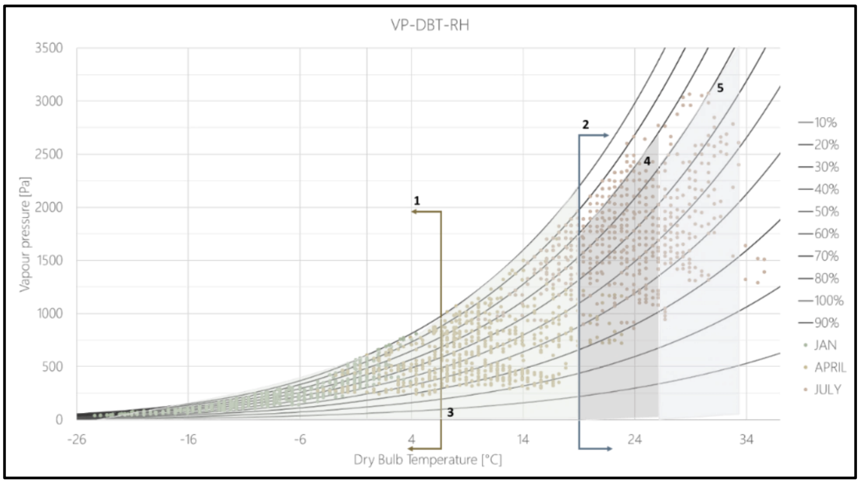


Figure 6. Psychometric chart analysis of hourly temperatures in Minneapolis

3.4. Retrofitting Analysis: Insulation and Air Tightness

The selected classrooms and laboratory, shown in Figure 7a, were analyzed in terms of Gains and losses. This was done to spot the issues within the building envelope and study the suitable passive strategies to be implemented. As it can be seen from the results of the distinct rooms analyzed in Figure 7b, most of the heat losses are due to external conduction, therefore a focus on external building envelope elements should be done to reduce the heating needs, since the heating degree hours are higher than the cooling degree hours in Minneapolis. In addition, the building's infiltration rate was reduced to simulate an airtight building compared to the existing loose one, the effect of air tightness on reducing heating loads was analyzed.

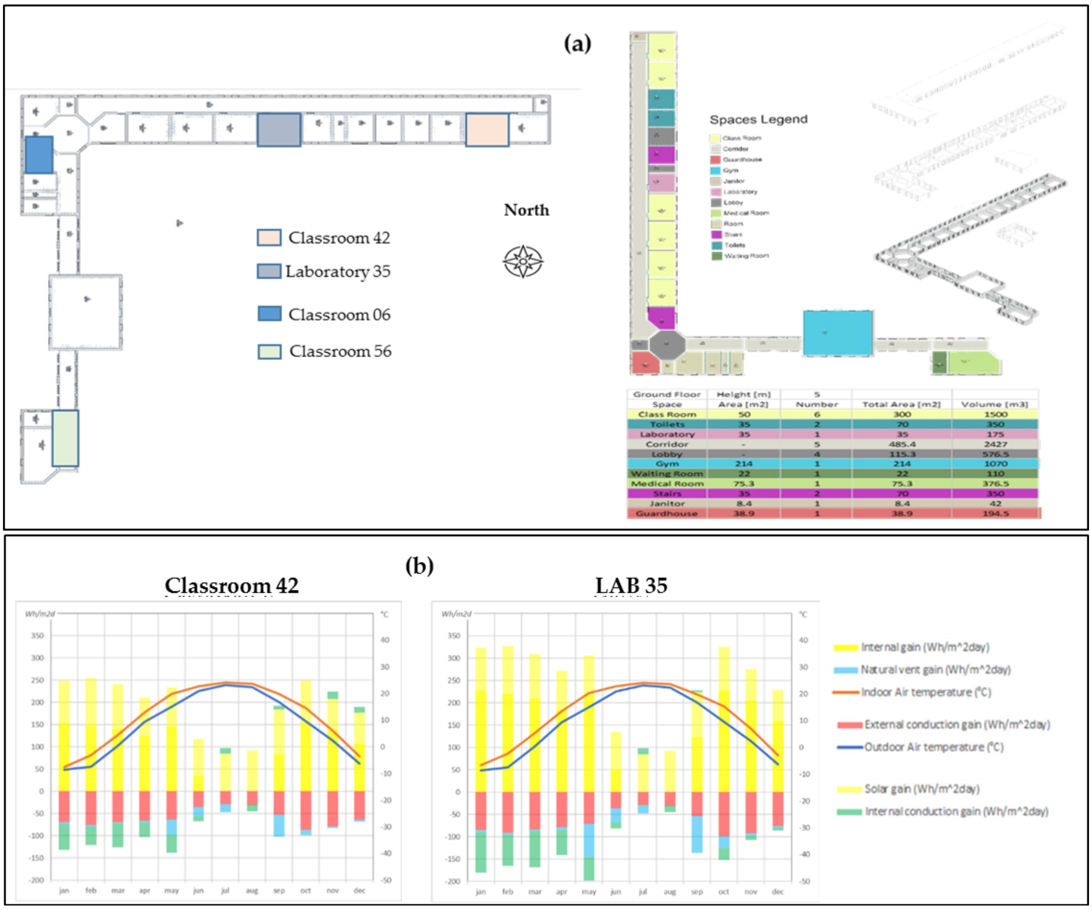


Figure 7. a) Floor plan and selected rooms to be analyzed, b) Analysis of heat gains and losses within the rooms located on the south for room 42 and lab 35.

As depicted in Figure 8 in the improved case, the conduction gains were reduced significantly compared to the existing case in all classrooms and the lab. The reduction in conduction gains was highest in room 56 facing east, because it has the highest surface area of glazing. From the analysis below, a priority should be given to insulating windows due to their high effect on the conduction losses in winter. Classrooms 42 and 35 are both south facing therefore, they have high conduction losses in winter due to the high solar transmittance.

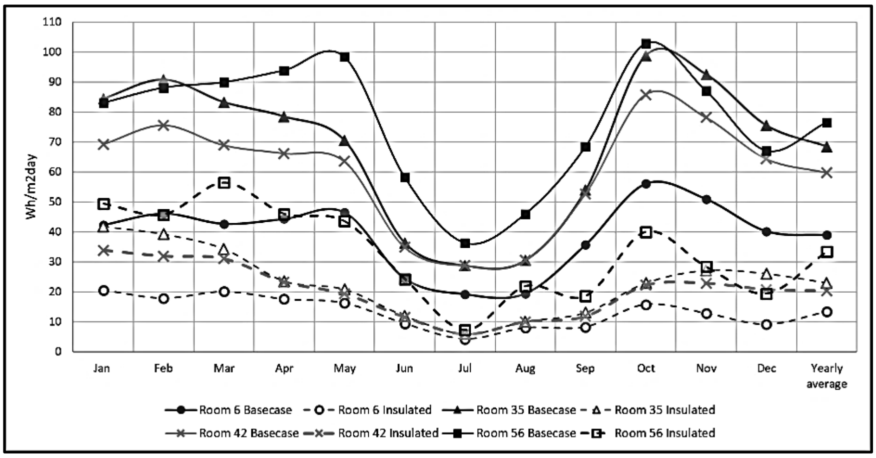


Figure 8. Reduction of conduction losses in the improved case scenario when insulating the building.

The improved case was analyzed per building element, the contribution of the building envelope elements was studied in order to prioritize the retrofitting options. The contribution can be critically analyzed in terms of its effect on the heating and cooling loads and the energy use intensity (EUI). The effect can be explained by the existing case envelope's heat transmission properties and the surface area of each of the building envelope elements. An Ideal heating and cooling system was inserted to maintain an inside air temperature between 20 C and 26 C for heating and cooling respectively, and the heating and cooling loads were studied for each change.

The results in Figure 9 have shown the most significant effect by retrofitting the Windows, first by replacing the single glazed windows by a double-glazed window with a U-value of 1.2 W/m^2C. Furthermore, Improving the airtightness of windows lead to a reduction in the infiltration and an improvement in the heating loads specifically. The contribution of insulating windows was around 30% reduction of energy use intensity, this can be explained by the very high transmittance of the existing case in comparison to the improved case and the high surface area of windows. Improving the air tightness contributed to around 38% reduction in energy use intensity, specifically heating loads, since the warm air will be maintained inside the room with an increased tightness of the envelope.

Retrofitting the roof had the second most significant contribution resulting in a decrease of 17% of energy use intensity. Which leads to the conclusion that improving old attics in educational buildings can have a great impact on the energy savings of the building. Although walls have a big surface area, the contribution was 15% savings, a little less than that of the roof's, mainly due to the fact that the roof's sloped surface is highly exposed to the sun most of the day, while the walls surface area is partially shaded by the courtyard and has a large surface area of the walls along the north direction. The total EUI reduction due to insulation accounted for around 51%, and improving the infiltration reduced the EUI by 19%. The analysis of heat gains and losses was beneficial to determine the main deficiencies which need to be focused on and treated to reduce the EUI as much as possible, particularly during winter.

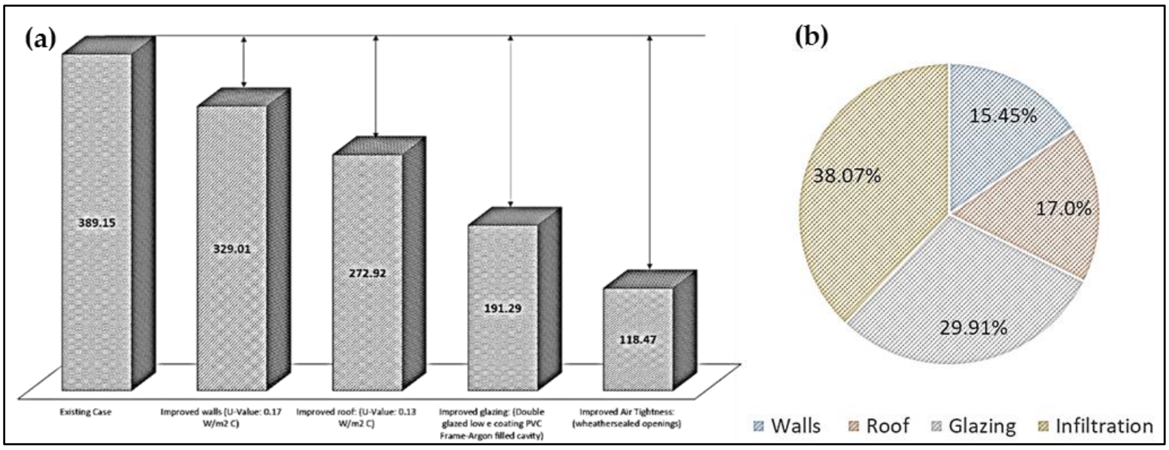


Figure 9. a) Cumulative energy use intensity savings ($kWh/m^2/year$) b) the contribution of each of the improvements of building elements on the total savings

3.5. Thermal Mass and Ventilation

To reduce the cooling needs in summer and reach the indoor thermal comfort, a study was done comparing medium thermal mass and high thermal mass effect on storing heat. Moreover, the analysis extended to compare the effect of having natural ventilation during the day, or at night, and weather cross ventilation will help in reducing the cooling loads.

The effect of applying high thermal mass can be seen in Figure 10a in terms of dampening of temperatures, delays in peak temperatures during summer, and adjustment of temperatures within the comfort range. In terms of cooling hours and indoor temperatures, switching from a medium thermal mass to a high thermal mass did not have a big effect; a reduction of around 1% of cooling hours in mid-summer months can be observed in Figure 10b.

High thermal mass has been combined and compared with natural ventilation during the day, night flushing, and cross ventilation. Results in Figure 10a, have shown that opening windows during the night at 50% angle and a threshold of 24 C, to provide free cooling during the summer, reduced the temperatures during the night releasing the heat, which was stored during the day, towards the outside of the building.

The percentage of cooling hours utilizing the different passive ventilation techniques and thermal mass has shown similar results. The analysis was done on all summer months to investigate the suitable strategies for each month and evaluate the most efficient strategy. The results in Figure 10b have shown, that during mid-summer months, where the focus is mainly on reducing cooling loads, a decrease in cooling needs is observed when using high thermal mass and night flushing, providing free cooling for the building during the day when releasing the accumulated heat and allowing the cool night air to ventilate through the building. On the other hand, in May and September, when it was noticed that sometimes temperatures at night are higher than temperatures during the day, and cooling loads are not that high, night flushing was not the most efficient. Instead opening windows during the day was more beneficial to reduce the cooling hours. The cooling hours shown in Figure 10b was between 9% and 7% for mid-summer months when using night flushing, while in May and September, utilizing natural ventilation had the best effect on reducing cooling hours achieving only 6% and 3% respectively.

The effect of natural ventilation and night flushing can also be seen in terms of indoor temperatures in Figure 10c, where the indoor temperatures decreased in mid-summer months but increased in May and September when incorporating night flushing.

Finally, as depicted in Figure 11a, the strategy that achieved the highest number of neutral hours in Minneapolis during the year, achieving temperatures lying between 20 and 26 C, is the High thermal mass with Night flushing Ventilation scenario. During months where lower cooling loads are experienced such as May and September, Natural Ventilation during the day works best. When we have higher cooling loads, in June, July, and August, night flushing is more effective with high thermal mass to remove the heat acquired during the day and cool the building. Utilizing the high thermal mass and night flushing passive technique resulted in a large decrease in the cooling hours across all months. The savings were mainly in terms of cooling loads, shown in Figure 11b, allowing passive cooling during night resulted in a decrease of the total energy use intensity by about 9.5%, while the cooling loads were reduced by almost 50%. Key benefits in terms of passive cooling efficiency were realized when analyzing and comparing multiple natural ventilation techniques.

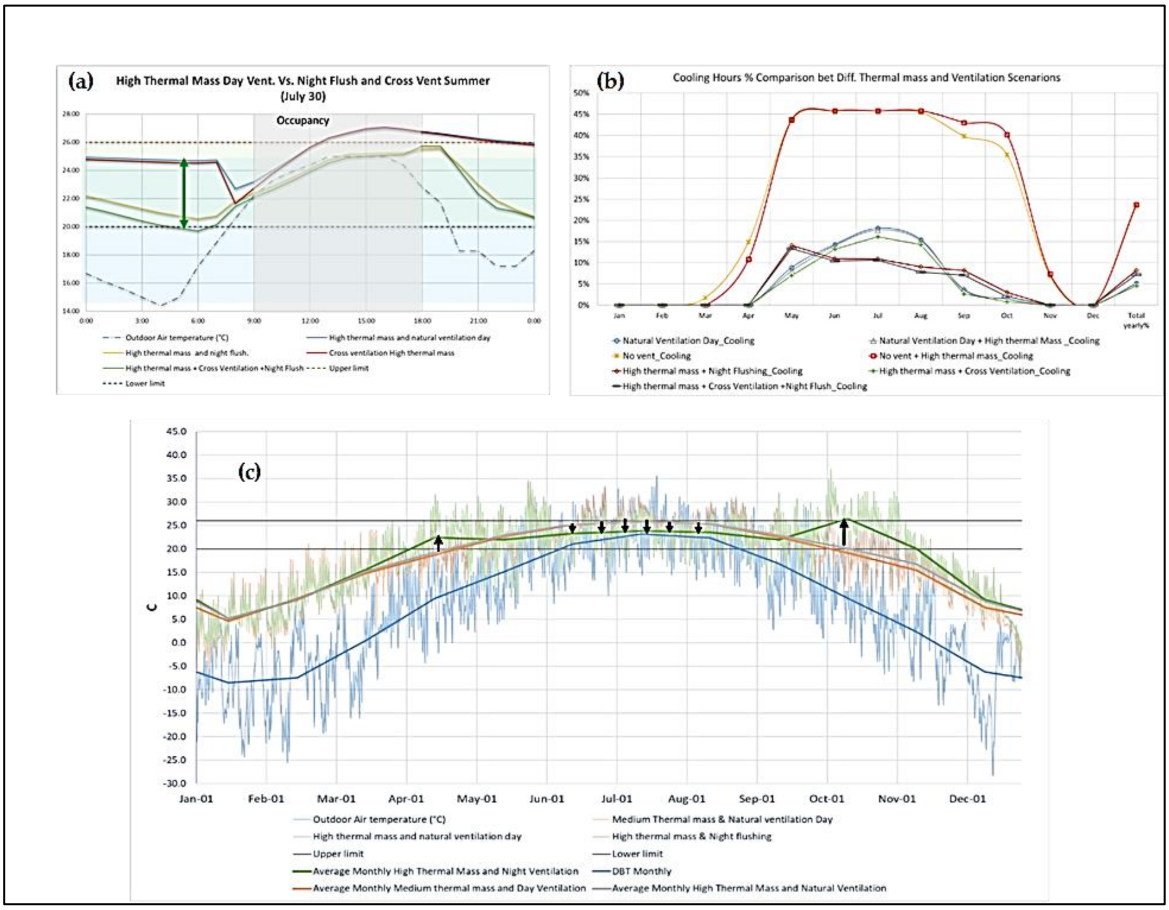


Figure 10. a) effect of high thermal mass and the different ventilation strategies on indoor temperatures. b) Comparison between cooling hours using different thermal mass and ventilation scenarios c) The effect of using different thermal mass and ventilation scenarios on indoor temperatures.

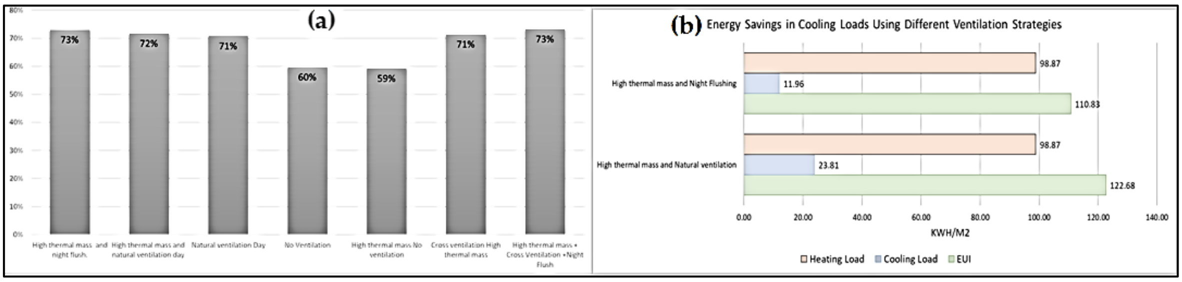


Figure 11. a) Percentage of neutral hours achieved when utilizing the different ventilation strategies. b) Cooling Load saving after applying night flushing in mid-summer months

4. Conclusion

To conclude, a study was done on an educational building in Minnesota, Minneapolis embedding passive intelligent strategies. An emphasis was kept on the buildings' envelope, understanding the effect of insulation, air tightness, and natural ventilation strategies on reducing the cooling and heating loads. A representative case study of a school building in Minneapolis was selected. The main part of the school building stock in Minneapolis was built before the energy regulations, so most of the buildings require comprehensive refurbishment to achieve the performance required by laws that are in force. This study identified passive design features through extensive virtual studies done on IESVE, that can be incorporated in warm summer humid continental climates to make them energy efficient. The strategies targeted accomplished a reduction in heating loads, by improving the building envelope, so it conforms to the recent building energy codes in Minnesota. The total effect of insulating the building envelope can be seen in a reduction of the energy use intensity of about 51%. The largest effect was achieved by insulating the glazing elements, having a 38% contribution to the total reduction of the EUI. Moreover, improving the building's air tightness resulted in a further improvement of nearly 19%. Moreover, the cooling loads can be tackled by utilizing high thermal mass and natural ventilation strategies in summer. The analysis results have shown that applying high thermal mass and night flushing resulted in a 9.5% decrease in the EUI, all through the reduction of cooling loads. Finally, it can be concluded that if passive intelligence was embedded within the envelope at an early stage through applying the latest construction methods, conforming to most recent energy standards, and utilizing climatic resources strategically, a significant reduction of energy consumption can be achieved.

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Improving Energy Performance of the UK Housing through the Implementation of Passive House Standards

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Abstract: The UK government has committed itself to achieve net-zero on Greenhouse Gas (GHG) emissions by 2050. The UK housing sector is one of the major contributors to GHGs and over 60% of the energy used in the UK residential sector relates to heating. Thanks to their extremely high fabric standards, Passive House strategies and standards can significantly reduce the heating energy demand by 80%. Yet, these strategies are not widely implemented in the UK compared to other European countries such as Germany. This paper aims to explain such strategies and assess the effects of upgrading a typical UK house to both Part L of the UK Building Regulations and Passive House standards to compare the energy performances before and after upgrading. The case study building is modelled in EnergyPlus and the energy performances are compared. The results reveal that the heating energy consumptions reduced significantly by over 78% when the Passive House standards were implemented.

Keywords: Energy Performance; Energy Efficiency; Heating, Passive House; Housing.

1. Introduction

More than half of the billed energy in the housing sector in the UK and EU is related to heating [1]. This high energy bill is associated with poor building energy performance, caused by factors such as poor construction detailing, occupants' behaviours, and building fabrics [2]. Energy performance is defined as measuring the relative energy efficiency of a building, including its equipment or building components, measuring the total amount of energy required to power all the building services and equipment [6]. These have a direct impact at the same time on the home's energy bill, CO_2 emissions and the wellbeing of the building occupants. A passive house requires 10% of the energy for heating compare to a typical one [3]. In countries such as Germany, a pioneer in passive design strategies, cities such as Heidelberg have adopted the passive design concept as the building standards [4]. The passive house design can potentially improve energy performance of the UK housing, providing indoor thermal comfort and reduce the energy bill as well as reduce Greenhouse Gas emissions gases emissions.

According to passipedia [5], a passive house is an integrated concept to ensure the highest indoor level of comfort, rather than an energy standard. The achievement of this thermal comfort is gained through extensive passive measures such as adequate insulation, heat recovery system, passive use of solar energy and internal heat sources. At the same time, a passive house should be energy-efficient, affordable, comfortable and ecological [6,7]. A large part of the heating demand of a Passive house is sourced by the sun, household appliances, human occupants as well as the heat from the air extractor [8], . Fresh air is provided by a heat recovery system that efficiently allows for the heat contained in the exhaust air to be re-used [9]. "Passivhaus buildings provide a high level of occupant comfort while using very little energy for heating and cooling" [7].

The passive house concept was developed for the first time in 1988 by Dr Wolfgang Feist, a German physicist, and Dr Bo Adamson, a Swedish scientist driven by the effort to refine the principal to design techniques for the Passive house performance metric, which lead to the design and construction of the first passive house in Darmstadt, Germany in 1991. Demonstrating and showing a vision for the construction's future, that combines energy efficiency, optimal comfort, affordability, sustainability as well as good indoor air quality. More than 2 decades later the Darmstadt terrace first passive house was built, is giving a consistent amount of fewer than 15 kWh per square metre of living space, remaining the same exactly as planned when it was built [4,10]. This house is occupied by four families, and year after year, its energy consumption is monitored.

A passive house is a high energy efficient building, consuming over 75% or less energy for cooling or heating in comparison to a new average building and 90% compared to a typical building [6]. According to Ovoenergy, n.d., the energy needed for heating for a leaky house in the UK is around 300 kWh/m^2 and 15 kWh/m^2 for a passive house that is 5% of the energy used for a leaky house. The energy savings are similar in warm climates where energy is required for cooling [5]. For a building to be called a passive house, it must meet certain requirements from the design to the completion. Also, the low amount of energy needed for the daily building operation needs to be covered by renewable resources such as biogas or solar [12]. A passive house must be fitted with adequate insulation, demanding a minimum amount of heating. The energy demanded either for heating or cooling should not exceed 10 w/m2 and 15kwh/m2a. The primary energy used in a passive house must not be greater than 120 kWh/m2a. However, it is advisable to keep this demand lower than 60 kWh/m2a [3].

The cost of building a passive house is higher compared to a traditional building. However, this cost difference has reduced considerably by the time; the extra additional capital cost is directly related to the thermal insulation for the walls, slab, roof, triple glazing windows, and heat recovery system [7]. The production of a passive house varies depending on the country where the project is developed; in Germany, the cost of building a passive house is 5%-8% higher than a typical building, in the USA 5%-10%, meanwhile in the UK is from 8%-10% [13,14]. Passivhaustrust, 2019 , in a report from a case study from the Exeter council which has been building passive houses since 2010, has found that cost price production has reduced by 25% over the last 5 years. This cost reduction is believed associated with the widely adopted technology to build passive houses.

1.1. Passive house building design

To design a Passive house, many factors must be considered, such as the orientation of the building, its form, materials u-values as well as choosing the right design approach. According to BRE, n.d, the building should be orientated along east/west facing 30 degrees to the south to allow the building to gain the maximum benefit of the direct solar. If this orientation is not possible, the result could be an extra annual heating demand of 30%-40%. However, the overheating in hot seasons must be considered as this is being more intense through the years, and it is expected to be increased by 1.2-8.1 degrees in England by 2080, due to the global warming that could cause the premature death of an estimated of 7, 000 people [15,16].

The ratio area/volume (A/V) between the internal volume and the external surface of a building has an important impact on the overall energy demand. It is advisable to design small compact buildings rather than a large in order to reach the desirable A/V ratio ≤ 0.7 m^2/ m3 [17]. The passive house standards demand that all the elements that made up the building have a very good U-value and airtightness. These U-values vary depending on the building context; location, building form and so on, being the recommended values limit for the walls, floors and roofs ≤ 0.15 W/m^{2}K complete window installation ≤ 0.85 W/m^{2}K; meanwhile, the airtightness should not be greater than 0.6 air change per hour at 50 Pascals pressure (ACH50) [17].

The airtightness causes an important impact on the energy performance of the building. Up to one-third of the heat losses is associated with the air infiltration through the building envelopment in older buildings in the UK [18]. In a comparison of UK existing buildings to European countries and America, the UK dwellings tend to be leakier [19] and the reason could be associate with the way that buildings are constructed in the UK This leakiness can lead to an increase of the annual energy consumption, moisture accumulation and risk of condensation [20], as well as degradation of the structure and reduction of the effectiveness of the insulation [21].

The importance of the airtightness was addressed in a consultation in the UK in 2000 [22] leading to the implementation of a minimum airtightness requirement of 10m3/(h.m2) @ 50Pa for new dwellings within the Building Regulations Part "L" [16]. The airtightness in new dwellings has improved in the last years; however, a study by the Energy Efficiency Partnership for Homes (EEPfH), in England and Wales, where 100 new dwellings were assessed, it was found that 20 per cent did not achieve the minimum air permeability required [21]. Johnston et al., 2011, concludes that the airtightness could be improved by paying more attention to detail on-site and ensure the maintenance of the primary barrier is maintained [19].

All the designing team members must understand the principal and standards of a passive house design to integrate passive design strategies from the beginning, as in many cases, some wrong early decisions can be difficult or impossible to change later, such as the orientation or building form. To check if the targets are being achieved, it is suggested to use the Passive House Planning Package (PHPP). This is a tool developed by the Passive House Institute to help the designer to achieve passive house standards [15].

1.2. The current situation in the U.K and the world.

Since the first passive house was built in Germany, 65,000 more have been built around the world, and from that amount, 1,000 are in the UK The first passive house built in the UK was a detached rural self-build in Wales in 2009 [4]. Countries such as Austria, Germany and Canada have implemented either the passive house concept as building standards or applied loan discounts to encourage a wide implementation of passive houses.

The total number of homes in the UK is 29 million, from that 1,000 are passive houses [23]. The remaining 28,999,000 homes in the UK are relatively consuming extra energy to achieve indoor comfort conditions. This extra consumed energy not only increases the household energy bills but also emits green gases contributing to global warming. The wide implementation of passive design strategies in new and existing homes would reduce the energy bills as well as cut CO_2 emission to the atmosphere. Building passive houses is a long-term investment that has an important impact on the energy performance and the human's wellbeing providing a healthy indoor environment.

1.3. Barriers and solutions

For the implementation of new energy efficient design is often required new techniques and technology, creating technical barriers and risks, as well as no technical barriers such as cultural, social and economic [24]. Government incentives for the implementation of this system can react against schemes affecting the industry if there is not enough personnel qualified to cope with the crescent demand [25]. This is the case of Japan, where the industry suffered a backlash after a premature fast growing of solar installation due to a government grant scheme. [26]. In the UK most developers are not motivated to produce zero carbon homes, and they are not interested in delivering a quantity of these building until strict legislation is in place [27]. Housebuilders pay an extra cost to build Zero Carbon homes that benefit the future occupants reducing the operational cost; however, housebuilders are unable to attract clients for such premium. Also, another barrier is that the local authorities, QUANGO, developers and architectural consultants do not have a strong social responsibility as a driver [27]. This issue is probably one of the most important as they are the motor of the construction development

The delivery of a passive house is 8-10% more expensive compared to a typical house [28]. However, a study by Newham and Whidborne 2012, demonstrate the advantages of implementing passive design strategies. The study compares a typical house that complies with the UK building Regulation, Part L 2010 and a passive house. The construction cost for a Part L 2010 house is £99,957 with 25 years at 3.9% APR mortgage and the price for a passive house at £115,623 with the same mortgage characteristics as the previous one. The passive house is £16,665 (15%) more expensive than a typical house; however, in the long term (25 years), the passive house owner is £1,293 richer than the other, a product of the energy bill savings. In this scenario, the passive house is 15% more expensive; however, studies have demonstrated that the actual difference price is from 8%-10%, as discussed previously [28].

A solution may be to increase gradually the level of standards within the building regulations emphasising both the embodied energy of the building material and the energy use of the buildings. Another effective solution would be to apply loan discounts when buying a passive house, as in Australia, or offering monetary grants, as encouragement as in Heidelberg, Germany [4].

1.4. Domestic energy consumption

Most of the energy utilised in the housing sector in the EU countries is related to heating. Over 64.1% of the energy used in the residential sector is for space heating (Figure 1), [1]in the case of the UK was about 70% in 2016 [1]. Rogers et al. [29] discusses that around 27 million houses in the UK used gas natural for heating that accounts the 66% of the bill. Understanding the main usage of energy in the domestic sector as well as where the most efficacy gains could be made is vital to improving energy efficiency [25].

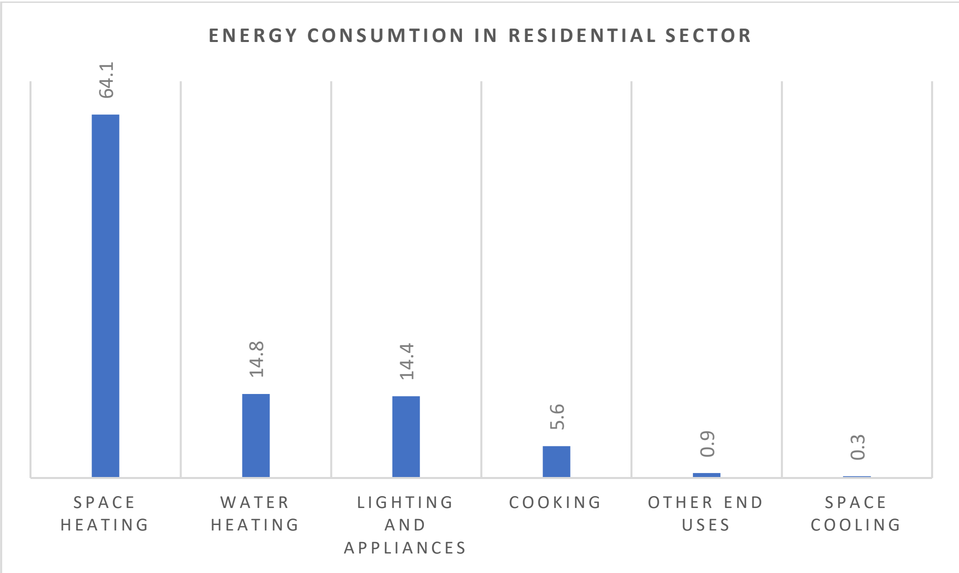

Figure 1. Final energy consumption in the residential sector by use, (Source of table EU-28, 2017 [1]).

The DECC, 2013 report classifies domestic energy consumption into 5 categories: heating, hot water, appliances, cooking and lighting. From the list, heating is the most predominant, with 10,494kwh from the 19,800kwh between gas and electricity needed to cover the energy demand for a dwelling (Table 2)[31]. Also, microclimates should be considered; for instance, in the north of Scotland, the use of heating tends to be higher in comparison to the South of England [30]. The estimated yearly energy bill in term of gas is around £608 based on 16,500kwh and £424 in electricity based on 3,300kwh for a dwelling emitting around 5.5 t CO_2 to the atmosphere [25].

Installation of central heating systems has significantly increased in the domestic sector in the last 40 years, leaving less than the 3% of houses without a central heating systems. According to Palmer & Cooper, 2012 , this is due to the aspirations of warmth and how this thermal comfort can be achieved [30]. Another report shows the central gas heating continues to increase steadily; from 1996 it increased from 73% to 85% in 2014, from 14.8 million dwellings to 19.9 million respectively [32].

In an attempt to reduce greenhouse emission (GHE) and to improve the energy performance, the European Union (UE) as well the UK have created many schemes and set many targets. The EU has committed to reduce GHE from primary energy use by 20% as a minimum, compared to 1990 levels, as well as 20% improvement in energy efficiency and 20% production of renewable energy by 2020 [33], which is being reached for most of the members in some areas [34]. Also by 2050 the climate change act commits the UK to reduce GHG by 80% as minimum compared to 1990 levels [23,35].

To reach such targets, the UK settled schemes such as the Low Carbon Building Programme launched in 2006 that grants the installation of heat pumps, solar power panel and other systems to generate energy on-site, but only 444 from 2006 to 2008 were granted for ground source heat pumps [25]. By 2016 all new homes were planned to be Zero-Carbon Emissions within the UK; however, this was abolished in 2015 [36]. These measurements resulted in a wave of pioneers and innovations with the aim to reduce heat loss through the building envelop, increasing the insulation levels and airtightness [37]. Installation of renewable system required skills and the UK may not have enough skilled personal to cover the crescent demand consequence of the incentives, that could make the government react against the scheme affecting the industry [25], that is the case of the backlash against the industry suffered Japan after a premature fast growing of solar installation due to a government grant scheme[26]. This was also evident in the recent rushed through Green Home Grants offered by the UK government in 2020 before a premature end to the scheme in 2021 due to various logistics and lack of enough installers to answer to the demand. Similarly, the Green Deal Scheme was introduced in 2013 to address the fuel poverty in England that accounted for 18% of the households; aiming to reduce fuel poverty from 250,000 to 125,000 by 2023 [38]. However, the scheme was scrapped in 2015 [39]. According to House of Commons Business Energy and Industrial Strategy Committee, 2019 [40]the scheme failed because of an uncompetitive interest rate (7%); while the scheme was operating, only 14,000 households took the loan from the 14 million expected. Since 2014/15, the number of households living in fuel poverty has increased by 210,000 to reach 2.55 million people [41], in the "Zero carbon homes: Perceptions from the UK construction industry", found that the developers are not motivated to produce zero carbon homes, and they are not interested in delivering a quantity of these building until strict legislation is in place. They also noticed the local authorities, QUANGO, developers, design consultants and architectural consultant, and contractor interviewed do not have a strong social responsibility as a driver [27].

1.5. Energy efficiency

Different tools have been developed to measure and assess the building energy performance. In the UK, to assess and compare the environmental impact as well as the energy performance within domestic dwellings. The Standard Assessment Procedure (SAP), developed in 1992, was adopted by 1995. Lately, the Reduce Data SAP (RDSAP) was introduced to cut the cost of the performance procedure [42].

Innovate UK (IUK) launched in 2010 the Building Performance Evaluation (BPE) programme to assess the buildings' performance. The programme four years monitored postconstruction buildings for at least one year after being occupied to determine the occupants comfort satisfaction, behaviour, heating affordability and to see how buildings affect the occupants [37,43][43]. The BPE found that the majority of the monitored buildings consume 3.6 times more energy than predicted, emitting carbon 2.6 times more than the design intent to [44]Among these tools is the Passive House Plan Package (PHPP) used to evaluate a P.H. performance. In the Camden Town P.H., in London, using the PHPP tool in the design process 65kwh/m^2 energy consumption demand was achieved [45], 55kwh/m2 less than the P.H. standard requires, which makes this tool quite efficient.

In the case study "Comparison of building performance between Conventional House and Passive House in the UK" by Liang et al. 2007 [46]in Newcastle North East of England, that monitored the energy performance of a traditional house built in 1978 and a P.H. in 2014, it was found the primary energy demand was 169.85kwh/m^2/year and 64.11kwh/m^2/year, respectively [46]. Also, a simulation using DesignBuilder software was run for the conventional house after improving the building elements were suggested the heat loss happened (Table 1), the results were a significant reduction from 169.85kwh/m^2/year to 110.85kwh/m2 year at indoor temperature of 16°C, with an important reduction in heath energy of 77.7% [46].

Table 1. Comparison of U-Values for different envelop elements [46].

Item	Passive House U-Value (W/m2.k)	Typical House current U-Value (W/m2.k)	Typical House retrofit U-Value (W/m2.k)
Walls	0.15	0.54	0.12
Floors	0.15	0.25	0.10
Roofs	0.15	2.93	0.13
Windows (Glazing)	0.85	1.96	0.78

The energy performance of a building depends on many factors such as the quality of the building material, building design strategies, and the occupant's behaviour [2]. Failure in detailing the construction, building material fabrics and installation can end up in a significant gap between the energy performance prediction and the actual performance [47,48]. An example of accurate design and execution of a building is the Caning Town P.H., where the heat loss through the fabric was expected to be 66w/k, and the actual measure was 56w/k +/- 5w/k, which suggest the building envelopment was built as planned, with no significant defects [2]. Around 53% of the energy used in a whole dwelling comes from heating; passive house design strategies have the potential to minimise in an 80%.

2. Materials and Methods

The strategy used for this research is a concurrent mixed method to form analysis for the research problem with qualitative and quantitative data. This combination of methods has been chosen as they can be carried out independently, allowing the draw of reliable and accurate conclusions about the research. To compare energy performance of a typical semi-detached house (Figure 2) [50] and a passive house, a case study is selected, and simulations are conducted in EnergyPlus. Two models were developed, one to comply with Part L, UK building regulation and the other to comply with the Passive Housed standards.


Figure 2. Pair houses viewed from the front (left); Pair houses viewed from the rear (right) [50]

The houses are located in Loughborough, Nottingham, UK (52.771071° N, 1.224264° W), in a suburban residential area. These are unoccupied semi-detached two-storey houses (fig 9&10), with a mirrored floor plan (Figure 3). The houses are naturally ventilated and both houses are designed with identical window sizes and openings with an 85m2 floor area, 209.2 m^3 volume and three bedrooms.

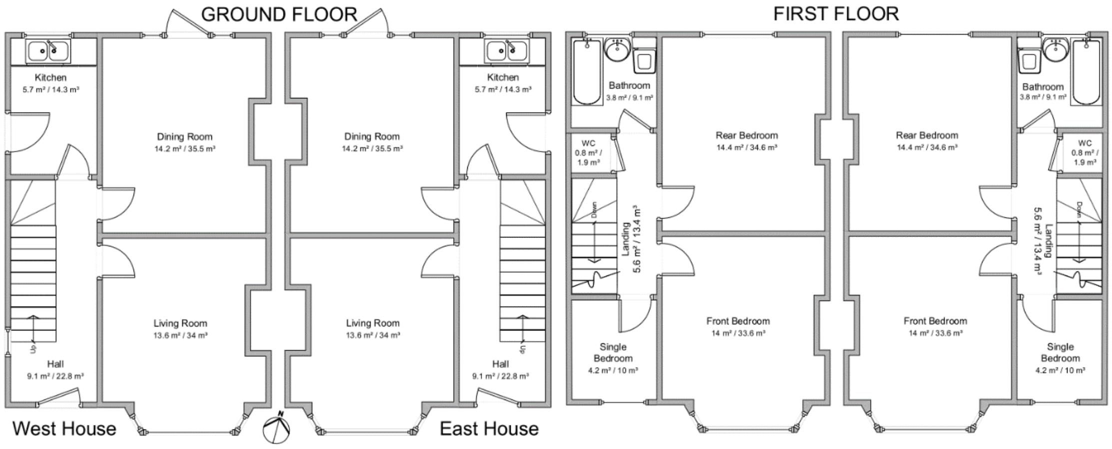

Figure 3. Dwellings floor plans [50].

The front of the dwelling is orientated south-southwest (160°). The access for each house is gained through the south side into an entrance hallway with stairs that leads to the first floor; the kitchen is on the north, with separate dining and living rooms. The living rooms have bay windows facing south, and the dining rooms with glazing doors facing north. There are 3 bedrooms, a landing, a small W.C. and a separated bathroom facing north on the first floor. The three bedrooms include a small room on the south side and two large bedrooms over the living and dining rooms facing north and south.

The houses are adjoining side-by-side therefore will influence each other. One house shades the other during the morning and the other in the afternoon. Also, through the party wall between houses will be inevitable heat transferrer.

The building materials' density (kg/m^3), thermal conductivity (W/mk) and specific heat capacity (J/kgK), for both passive and part "L" building standards houses, are settled based on the CIBSE Guide A [51] the Chartered Institution of Building Services Engineers., 2019. To reach the passive and part L houses building elements U-values requirement, the insulation thickness is increased as this is the element that makes the biggest impact in terms of insulation among the building elements (Table 4).

An air changes rate of 0.05 (ac/h) and 0.5 (ac/h) were considered for the passive house and the Part "L", respectively. The heating setpoint for both houses is; 21°C bathroom, 18°C bedrooms/kitchen, 21.5°C halls/stairs/landings, 22.5°C living/dining rooms and 20°C W.C. [51]. The occupancy was considered as 24/7 without any cooling system.

3. Results

The total yearly energy consumption for heating for the Part L 209 house (west house) is 3,537.85 Kw/h and 3,623.93 for its pair 207 house (east house) and the Passive houses 754.95 Kw/h, and 829.47 Kw/h, respectively (Table 4 & 5). The results suggest significant reduction in energy consumption in both houses 207 and 209. The energy consumption difference after the upgrade is 2794.47 Kw/h (77.11%) and 2782.90 (78.66%). This annual energy consumption reduction is close to the expected, which is 80%. This 2-3% extra energy consumption could be associated with Passive House's use of a heat recovery system to supply good indoor air quality but retain the heat that is generally wasted. The minor difference between houses (209-207) could be associated with higher exposure to the solar radiation of house 209 located on the south-west side. The optimal orientation of a house (30% facing south-west/east) could end up in a 30% to 40% in heating energy saving, as a product of the solar gains.

Most energy reduction has occurred in the 209 Passive House in the hall and landing in this order; a reduction of 729.45 kw/h year and 605.09 kw/h years in the hall and the landing, respectively. The dining and living rooms also show significant energy reduction for heating. In the part L scenario, the house 209 dining room energy consumption is 654 kwh and 662.87 for the 207. The energy consumption difference between both houses is minimal, the reason could be because both are facing the north with no solar heat gains. Upgrading to the PH, the energy performance of the spaces improves on 400.38 kwh (209) and 413.38 kwh (207). In the living rooms located on the front of the houses (facing south) the energy consumption is 503.09 (209) and 521.95 (207) for the part L houses. This rooms are around $1m^2$ smaller than the dining room and consume around 130 kwh less. When upgraded to PH the energy reduction for heating is 400.38kwh for the 209 house and 413.04 for the 207.

The only spaces that do not consume energy for heating in both Part L and Passive house are the kitchen. This could be due to the high internal heat gains due to cooking. The energy consumption for the single bedroom 209-part L house is negligible (0.02 kwh and 0.36 for its pair) thanks to the high solar gains and high ratio of glazing to the floor area. Once both are upgraded to the passive house standards, their energy consumption is reduced to 0 kwh.

Table 2. Passive and part "L" houses components thickness and U-values.

Part "L" house			
Building element	**Description**	**Thicness (metres)**	**U-Value (W/m2k)**
External walls	Brick Insulation (polyurethane foam, 80mm) Concrete block Plasterboard	0.28	0.30
Party walls	Plasterboard Insulation (polyurethane foam, 125mm) Plasterboard	0.15	0.20
Half party walls	Plasterboard Insulation (polyurethane foam, 0.60mm) Plasterboard	0.08	0.40
Ground floor	Concrete slab Insulation (polystyrene foam, 0.96) Floor screed	0.32	0.25
Roof	Tiles Insulation (polyurethane foam, 125mm) Plasterboard	0.16	0.19
Window	Planilux 4mm Argon gass Planilux 6mm	0.02	1.96
Internal floor	Carpet Concrete slab	0.22	6.19

Passive House Standards			
Building element	**Description**	**Thicness (metres)**	**U-Value (W/m2k)**
External walls	Brick Insulation (polyurethane foam, 165mm) Concrete block Plasterboard	0.37	0.15
Party walls	Plasterboard Insulation (polyurethane foam, 165mm) Plasterboard	0.19	0.15
Half party walls	Plasterboard Insulation (polyurethane foam, 79mm) Plasterboard	0.10	0.31
Ground floor	Floor screed Insulation (polystyrene foam, 162mm) Concrete slab	0.39	0.15
Roof	Tiles Insulation (polyurethane foam, 165mm) Plasterboard	0.20	0.15
Window	Planilux 4mm Argon gass Planilux 6mm	0.03	0.79
Internal floor	Carpet Concrete slab	0.22	6.19

Table 3. Passive and part "L" houses settings.

Settings House 209										
Items	**Living Room**	**Dining Room**	**Kitchen**	**Hall**	**Front Bedroom**	**Rear Bedroom**	**Single Bedroom**	**WC**	**Bathroom**	**Landing**
Lighting load (Wm2)	2	2	2	2	2	2	2	2	2	2
Electric equipment load w/m2	22.09		71.45		14.73	16.2	30.61			
Temperature set point©	22	18	18	22	18	18	18	20	21	22

Settings House 207										
Items	**Living Room**	**Dining Room**	**Kitchen**	**Hall**	**Front Bedroom**	**Rear Bedroom**	**Single Bedroom**	**WC**	**Bathroom**	**Landing**
Lighting load (Wm2)	2	2	2	2	2	2	2	2	2	2
Electric equipment load w/m2	23.06		72.86		15.1	17.99	23.85			
Temperature set point©	22	18	18	22	18	18	18	20	21	22

Table 4. Part "L" house annual Kw/h energy consumption.

Part "L" House 209 (West house)		
ZONE AIR SYSTEM SENSIBLE HEATING ENERGY [J]		
	Area	Joules/Year
1	209_ HALL	3172040000
2	209_ KITCHEN	0
3	209_ LIVING_LR	1811130000
4	209_ DINING_LR	2354390000
5	209_ SINGLEBEDROOM_BR	57334.81
6	209_ FRONTBEADROOM_BR	61993363.77
7	209_ REARBEADROOM_BR	443228000
8	209_ WC	319365000
9	209_ LANDING	2796020000
10	209_ BATHROOM	1778050000
11	209_ ROOF	0
	TOTAL Kw/h	3537.85

Part "L" House 207 (East House)		
ZONE AIR SYSTEM SENSIBLE HEATING ENERGY [J]		
	Area	Joules/Year
1	207_ HALL	3350820000
2	207_ KITCHEN	0
3	207_ LIVING_LR	1879020000
4	207_ DINING_LR	2386320000
5	207_ SINGLEBEDROOM_BR	1313808.52
6	207_ FRONTBEADROOM_BR	0
7	207_ REARBEADROOM_BR	0
8	207_ WC	339849000
9	207_ LANDING	3267070000
10	207_ BATHROOM	1821790000
11	207_ ROOF	0
	TOTAL Kw/h	3623.94

Table 5. Passive House annual Kw/h energy consumption.

Passive House 209 (West house)		
ZONE AIR SYSTEM SENSIBLE HEATING ENERGY [J]		
	Area	Joules/Year
1	209_ HALL	546038000
2	209_ KITCHEN	0
3	209_ LIVING_LR	369746000
4	209_ DINING_LR	435664000
5	209_ SINGLEBEDROOM_BR	0
6	209_ FRONTBEADROOM_BR	0
7	209_ REARBEADROOM_BR	67364.55
8	209_ WC	111617000
9	209_ LANDING	617702000
10	209_ BATHROOM	636976000
11	209_ ROOF	0
	TOTAL Kw/h	754.95

Passive House 207 (East House)		
ZONE AIR SYSTEM SENSIBLE HEATING ENERGY [J]		
	Area	Joules/Year
1	207_ HALL	592867000
2	207_ KITCHEN	0
3	207_ LIVING_LR	392075000
4	207_ DINING_LR	397960000
5	207_ SINGLEBEDROOM_BR	0
6	207_ FRONTBEADROOM_BR	0
7	207_ REARBEADROOM_BR	0
8	207_ WC	120407000
9	207_ LANDING	817909000
10	207_ BATHROOM	664856000
11	207_ ROOF	0
	TOTAL Kw/h	829.47

According to the results of simulation, upgrading a Part L Building Regulations house to a Passive House Standards could reduce energy consumption by up to 78.66%. Accordingly, the energy bill would have an important reduction of £223.55 per year taking as a reference the actual average gas cost of a kwh is 3.80p [52] . The energy consumed by the heating system make up around the 70% of the total energy bill which would have an important improvement in this scenario, additionally around 0.23 tons of CO_2 emissions would be saved.

5. Conclusions

A good technical understanding of the energy usage in the domestic sector and the building occupants' behaviours and culture is vital to draw accurate and effective paths to reach energy efficiency targets. The EU and the UK have settled objectives and created various schemes to encourage the implementation of building passive design strategies, improve the domestic building performance, as well as to decrease the GHG emissions as well as improve the wellbeing of their inhabitants. Yet, at least in the case of the UK, many of these strategies have been doomed to failure due to various shortcomings. For a successful implementation of sustainable and passive design strategies in the housing industry, all the sectors such as authorities, QUANGO, developers, design consultants and architectural consultant, and contractor must have a strong commitment to these strategies. Heating (space and water) is the biggest contributor to energy consumptions in the housing sector in the UK, accounting for more than 60% of the energy consumed. Adopting Passive

House standards in the UK could have a big impact contributing to the Government's targets to achieve net zero emissions by 2050. Passive design strategies can potentially reduce heating energy consumption by nearly 80% providing indoor thermal comfort, while reducing emissions and energy bills for the occupants. More research is required to assess effects of building technology, materials and occupants' behaviours on the energy performance.

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Reducing the Total Energy Consumption of an Existing Office Building Through Alternative Construction Parameters

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Abstract: The sudden increase in the energy consumption trends attracted the attention of many aspects, depletion of energy resources, and multiple environmental issues such as CO2 emissions, global warming, and climate change. One of the most important challenge of future buildings is the reduction of energy consumptions in all their life phases, from construction to demolition. The building sector consumes from 30 to 40 % of the world global energy, 40 % of total resources, 25 % of the worldwide water, and around 30 % of the Carbon dioxide emission. To reduce energy consumption in the new designed buildings, the application of an energy efficiency concept is required. This paper aims to characterize a real case study of an office building in the United Arab Emirates (UAE) using energy simulation software representing the alternative parameters in terms of wall, roof, window to wall ratio, and HVAC system to find the best-optimized case achieving low energy consumption. The energy performance of the office building was calculated using the e-Quest simulation tool recording the impact of each parameter on the overall energy consumed by the building. The component that contributes more to decreasing the energy was the window to wall ratio with 43%, followed by a new wall structure with 23%, then a modified HVAC system with 18 SEER value with 22%. The results showed that the optimized value of the above parameters decreased the energy consumption from 167.380*1000 kWh to 97.57*1000 kWh which is 41% lower than the base case, with energy savings of ~70.00*1000 kWh per year.

Keywords: Energy efficiency; Retrofitting; Wall structure; SEER value

1. Introduction

To reduce energy consumption in the new designed buildings, the application of an energy efficiency concept is required. This principle aims at designing buildings with high performance using low energy-consuming systems. Energy efficiency is a general term with multiple quantitative measures that have several indicators to measure the changes in energy consumption. In a simplified way, energy efficiency refers to using much less energy compared with the current situation of the same service [1]. Among the various sectors, buildings are the largest consumers of energy, consuming up to 45% of the energy in the US [2]. According to the International Energy Agency (IEA), the energy consumption will exceed 50% by 2025 [3].

In the UAE, buildings consume a major portion of the produced electric energy where the average consumption of some buildings is about 220-360 kWh/m2/year [4]. Almost 80 % of this energy is used by building air-conditioning and ventilation systems due to the prevailing extremely hot climatic conditions. Estidama building code had been released in 2009 which is determine the use of appropriate building parameters such as building materials and energy efficiency systems [5]. To achieve an accurate cooling/heating load calculation, a better analysis of heat transfer through the material is very important in an energy-efficient building design. Thus, the knowledge of thermal properties and the precise evaluation of the heat transfer through the envelope components. Therefore, it is essential to search for solutions to reduce the energy consumption of buildings [6].

Several factors affect the building's energy consumption. The most affecting parameters are walls and roof U-value, and the HVAC system [7,8].

With a large number of existing old, designed buildings, the concept of retrofitting becomes a direct aspect to achieve the goal of green buildings [9]. Retrofitting is the process of modifying with new or improved parts or equipment not available or considered not necessary at the time of initial design. The office building represents a major share in energy consumption compared to others building types with an annual energy consumption around 1000 kWh/m2. In this study, a real case of an office building in the UAE has been assessed using energy simulation software representing the alternative parameters in terms of wall, roof, windows type, window-to-wall ratio, window frame, and HVAC system to find the best-optimized case achieving low energy consumption.

2. Materials and Methods

2.1. Buding descreptions

The chosen case study is an office building located in Al Hamriya, Sharjah-UAE, with 2000 m2 and 40 employees. The climate in the UAE is hot-humid with an average of 36 °C in Summer and 19.5 ° C in Winter. A numerical model had been designed using HEED energy analysis software and the availability of the architectural, mechanical, and electrical drawings helped in the design accuracy. To test the model performance, yearly electrical bills provided by the owner served as a validation tool. Table 1 shows the base case detailed description.

Table 1. Base case detailed descriptions

Building type	**Office building**
Dimensions	20*100 m
Number of Floors	1 2000 m2
Location	Sharjah
Cooling Equipment	packaged DX series fan powered VAV
Heating Equipment	No heating equipment
Building orientation	North East
Shape	Rectangular
Floor height	3.5 m floor to floor 3.2 m floor to ceiling
Roof structure	U-Value = 1 W/m2k
Wall structure	U-Value = 2.49 W/m2k
Doors	2 doors wood 3.00*2.5 m
Windows	Double reflective NW:100*3.5 m2 SE: 100*3.5 m2 NE: 20*3.5 m2
Frame type	Aluminum fixed
Overhang	SE: 4*100 m2 NW: 4*100 m2 NE:7*20 m2
Operation schedule	From 6 am to 12 am

2.2 Base Case Geometric Model

The energy consumption for the selected building was numerically simulated using e-Quest energy analysis software, the model was used to evaluate the energy-saving potential. Take into consideration all the above-mentioned parameters, the building envelopes, the HVAC system, internal loads (40 employers), types of equipment, and lighting using UAE weather conditions. The comfortable indoor temperature was determined with an average of 21-25°C [10]. Figure 1 illustrates the actual and simulated consumption of the selected base case on July depending on the space cooling, ventilation, lighting, and appliances with an acceptable error of 3.3%.

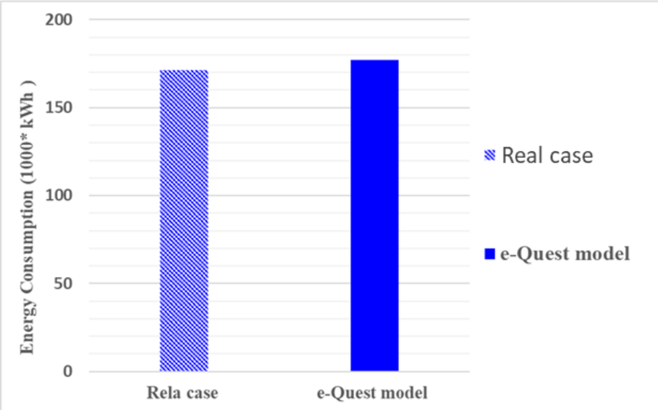
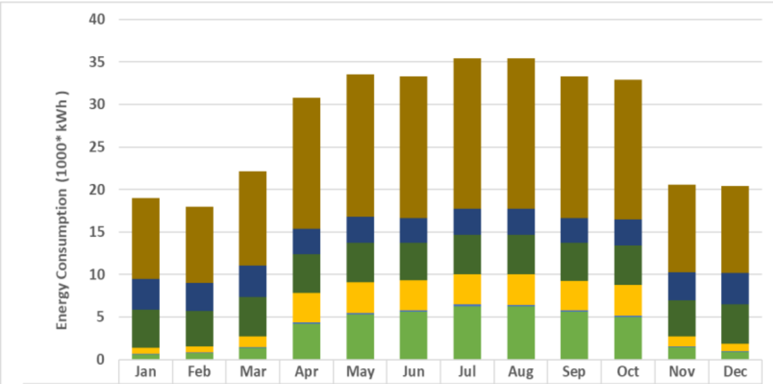


Figure 1. The actual and simulated July month consumption of the selected office building.

The total energy consumption of the base case for space cooling, heat rejection, ventilation fans, mechanical equipment, and area lights was 167.380*1000 KWh. Figure 2 shows the detailed and total energy consumption for each month throughout the year.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	9.48	8.99	11.08	15.4	16.76	16.67	17.72	17.7	16.64	16.44	10.28	10.21
Area Lights	3.59	3.3	3.72	3.02	3.03	2.91	3.03	3.03	2.91	3.03	3.32	3.72
Misc. Equip	4.52	4.13	4.63	4.57	4.63	4.46	4.63	4.63	4.46	4.63	4.24	4.63
Vent. Fans	0.72	0.76	1.23	3.42	3.61	3.47	3.61	3.61	3.47	3.6	1.17	0.87
Heat Reject	0.06	0.06	0.08	0.2	0.2	0.19	0.2	0.2	0.19	0.2	0.08	0.08
Space Cool	0.59	0.75	1.42	4.2	5.29	5.63	6.26	6.23	5.6	4.98	1.46	0.91

Figure 2. Real case simulation results: The energy consumption of the base case during the year (1000*kWh).

3. Results and Discussion

3.1 Retrofitting Alternative

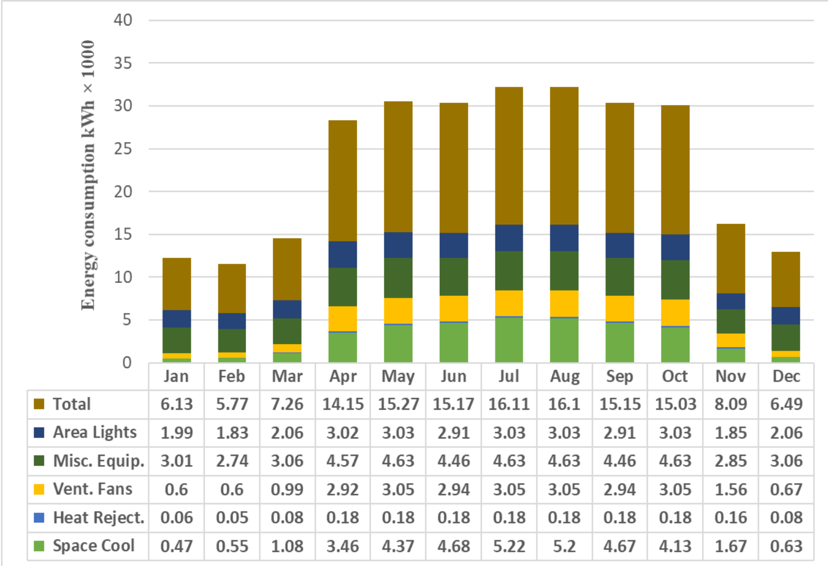
To define the best alternative parameters several building components should be take into consideration, which include walls and roof structure, window to wall ration WWR, glazing type, and HVAC system as shown below:

- WWR: according to ASHRAE 90.1-2007, the ideal WWR is 24% of the wall.
- Walls overall U-value: reaching the current standard condition from Estidama code 0.32 W/ W/m²K and lower values if applicable.

- Roof overall U-value: reaching the current standard condition from Estidama code 0.14 W/ W/m²K and lower values if applicable.
- HVAC system: the higher the SEER, the greater the air conditioner's efficiency (Alves, 2016)

3.1.1 WWR

The case study's WWR is 91.3% which is much higher than the recommended value. The overall WWR for all façades had been changed as recommended to 24%. The total energy consumption for the modified windows shows a massive decrease in energy of 16% with 140.71*1000 KWh total energy consumption as shown in Figure 3. The modified building WWR was then considered as a base case for the rest of the alternatives.

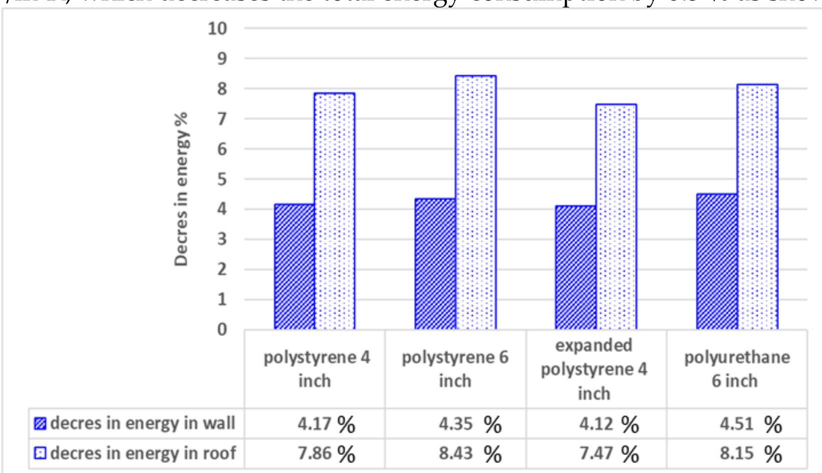


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	6.13	5.77	7.26	14.15	15.27	15.17	16.11	16.1	15.15	15.03	8.09	6.49
Area Lights	1.99	1.83	2.06	3.02	3.03	2.91	3.03	3.03	2.91	3.03	1.85	2.06
Misc. Equip.	3.01	2.74	3.06	4.57	4.63	4.46	4.63	4.63	4.46	4.63	2.85	3.06
Vent. Fans	0.6	0.6	0.99	2.92	3.05	2.94	3.05	3.05	2.94	3.05	1.56	0.67
Heat Reject.	0.06	0.05	0.08	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.16	0.08
Space Cool	0.47	0.55	1.08	3.46	4.37	4.68	5.22	5.2	4.67	4.13	1.67	0.63

Figure 3. Window to wall ratio effect on the total energy consumption.

3.1.2 Walls and Roof alternatives

U-value is a unit that indicates how much heat passes through a specific material. Different types of insulation had been added in the simulations to indicate the best insulation material available in the UAE and common use in the construction sectors, to be used in the retrofitting process for the walls and the roof. Polystyrene and polyurethane were used in different thicknesses. The best overall U-value for the wall was 0.14 W/m2K using 6-inch polyurethane which decreases the total energy consumption by 16%. The same insulation was considered for the roof structure with an overall U-value of 0.15 W/m²K, which decreases the total energy consumption by 8.5 % as shown in Figure 4.



	polystyrene 4 inch	polystyrene 6 inch	expanded polystyrene 4 inch	polyurethane 6 inch
decres in energy in wall	4.17 %	4.35 %	4.12 %	4.51 %
decres in energy in roof	7.86 %	8.43 %	7.47 %	8.15 %

Figure 4. Wall and roof alternatives with total decrees in energy %.

3.1.3 HVAC system

Mechanically, HVAC systems change in regard to energy efficiency and measured by Seasonal Energy Efficiency Ratio (SEER). Figure 5 shows the effects of different SEER values on the energy consumption. The best SEER value was 18 with a total decrease in energy up to 8.3%.

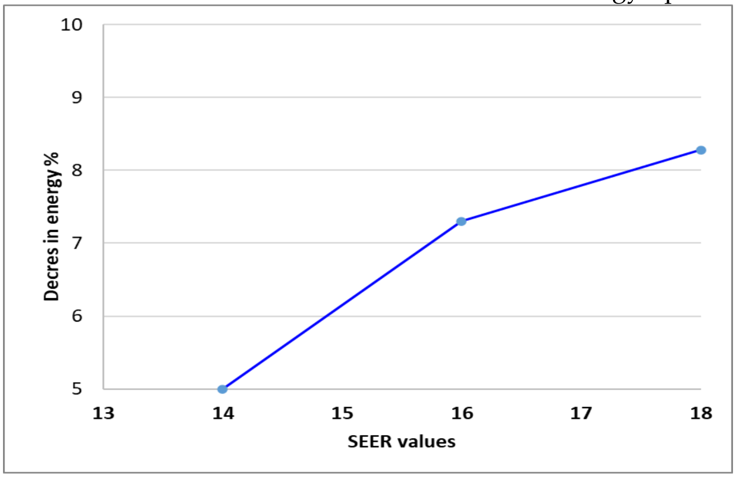


Figure 5. HVAC system (SEER) alternatives with total decease in energy consumption % consumption.

3.1.4 Optimal alternatives

The best alternatives scenarios among the above parameters had been chosen to be tested in the e-Quest software to determine the final decrease in the energy consumption ratio. The total energy consumption of the optimized parameters was 97.57*1000 KWh. Figure 6 shows that among the four selected components, a modified 24% window to wall ratio contributed the most to the decrease the energy consumption with almost 43% followed by a new wall structure with polyurethane 6-inch insulation, HVAC system with 18 SEER value, and roof structure, reducing the energy consumption up to 23%, 22%, and 12% respectively.

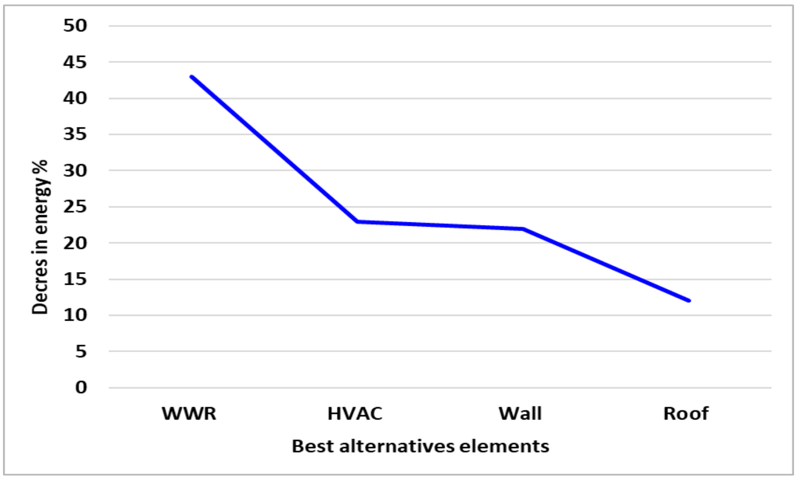


Figure 6. The saved energy in Best-case retrofitting components.

5. Conclusions

Due to the location of the case study, in a harsh hot climate, the external weather puts massive pressure on HVAC systems in buildings and the exposed surfaces of the building like roofs and walls. Thus, the precise evaluation of the heat transfer through the envelope components is mandatory and it is important to design the buildings by the total amount of used energy thus we must select the most critical building parts that contribute to lowering energy consumption and can be replaced and enhanced readily. The best alternative for the wall and roof insulation decreases the total energy consumption by 16% and 8.5% respectively. Whereas changing the SEER value to 18 decreases the energy up to 8.3%. The study showed a total annual decrease in energy by 41%, with energy savings of ~70.00 *1000 kWh per year compared to the base case.

Author Contributions: Maatouk Khoukhi and Abeer dar saleh conceived of the conceptualization, Maatouk Khoukhi and Abeer dar saleh developed the methodology, Abeer Dar saleh run the software, Abeer dar saleh and Shaimaa Abdelbaqi validation of the model, Abeer Dar saleh and Shaimaa Abdelbaqi complete the investigation, resources, data curation and writing—original draft preparation, Maatouk Khoukhi enhanced the first studying the climate, orientation, and different systems that can reduce energy consumption in a long term. This paper presents a real case study of retrofitting of an existing building to achieve lower energy consumption through several alternatives using energy simulation tool. The retrofitting decreases writing—review, editing and supervising the research project.

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Techno-Economic Analysis of Radiant Ceiling Cooling System on Building Energy Consumption under Hot and Humid Weather Conditions

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Abstract: Modeling and simulation performance analysis of radiant cooling systems under UAE weather conditions were performed in this study. The main objectives were to determine the energy saving benefits of radiant cooling compared to conventional air systems, investigate the practical application of radiant cooling in Sharjah in particular and UAE in general, where the climate is hot and humid; and to determine the corresponding cost associated with the retrofitting of existing building with the proposed radiant cooling systems. Modeling and simulation analysis of radiant cooling systems including cooling load calculations and the HVAC system were performed in this study. The comparison of the results obtained for the conventional air-cooling system (100% forced convection) and the proposed radiant cooling system/down-sized forced air system showed: 20% energy savings for the cooling load, 53% energy savings for the fans (ventilation air), 41% energy savings for the pumps (Chiller), and 25% total energy saving for the HVAC system. The normalized metrics for the total energy consumption per floor area (HVAC, Lighting, Equipment) are 162.59 kWh/m² and 140 kWh/m² for conventional and hybrid Radiant Cooling System respectively.

Keywords: Radiant Cooling Technology; Building; Energy Efficiency; Modeling and Simulation; Building Energy; Performance Analysis.

1. Introduction

The radiant cooling system (RCS) works by circulating cooled water through a network of pipes through walls, floor, and ceiling. The cooled surfaces (walls, floor or ceiling) will absorb heat energy from the conditioned space (heat gain or sensible load: solar gains, people, electrical equipment, lighting,) to create a thermal comfort using little energy compared to conventional air systems (100% air forced system). Figure 1 shows an example of RCS using radiant ceiling panels. The RCS is integrated with a downsized forced-air system (DFAS) to meet the fresh air requirements of the building. An effective RCS requires a removal of the sensible load and the latent load (control the humidity of the conditioned space). The RCS uses water as the cooling fluid with high heat transfer properties. The cooled surface absorbs efficiently the heat energy (sensible heat gain) from the conditioned space. The DFAS is used to provide fresh air and for air-based cooling (removes excess humidity for the conditioned space). The use of RCS to remove the sensible heat gain will help to reduce the size of the air handling equipment and ductwork (reduce the energy consumption and the corresponding cost of the cooling system). The RCS will provide cooled ceiling surface and reduce the mean radiant temperature. This will help to achieve thermal comfort will slightly higher set point compared to the one used for the conventional air-cooled system. This will help to reduce the energy consumption of the building and the total cooling load. The development of an efficient and cost-effective radiant cooling system compared to the conventional cooling system is achieved by an optimized design and control of the integrated RCS and downsized forced-air system [1]-[3]. The RCS can be successfully used for various climate conditions and different regions by developing optimized radiant system design and control capabilities. The capacity and performance of the hybrid RCS/DFAS system is affected by several factors such as the climate conditions (temperature and humidity), the building heat gain, the celling/floor/wall surface temperature, the number of pipes, the pipe spacing, the pipe network configuration, the supply water temperature, insulation, and indoor air temperature and humidity. It is very important to note that under hot and humid climate conditions such as the weather conditions in Sharjah and UAE, accurate control of water supply temperature and humidity inside the conditioned space is needed to avoid the condensation of condensation on cooled surface.

Several studies are reported in the literature [4]–[14] on the energy and cost savings of the radiant cooling system (RCS) integrated with the down-sized forced air system (DFAS) compared to the conventional 100% forced convection air system [15]. The comparison includes different type of building (educational, office, airport), purpose (heating or cooling), analysis (simulation, experimental) and climate (cold and humid, hot and humid, dry and hot, very cold). All the results show clearly energy saving (13-80%) of the radiant cooling system (RCS)/DFAS compared to conventional 100% forced air convection system.

The main objective of the proposed study is to develop modeling and simulation performance analysis of radiant cooling systems for Sharjah Buildings: (1) determine the energy saving benefits of radiant cooling compared to conventional air systems, (2) investigate the practical application of radiant cooling in Sharjah in particular and UAE in general, where the climate is hot and humid; and (3) determine the corresponding cost associated with the retrofitting of existing building with the proposed radiant cooling systems.

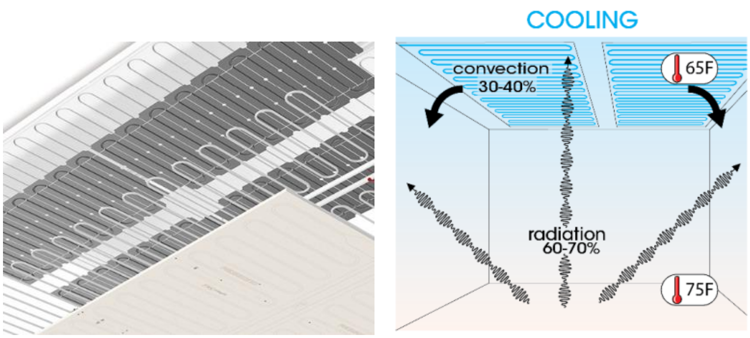


Figure 1. Radiant Cooling System (RCS) – Radiant Celling Panels

2. Methodology

The calculation steps for the hybrid radiant RCS/DFAS system [16]-[17] is summarized as follow: (1) set the weather conditions in Sharjah; (2) set the inside and outside design conditions (temperature and humidity), import the building geometry; enter the building physical properties (roof, walls, floor, windows, doors); Set the radiant panels in the ceiling (pipe size, spacing, and configuration); set the water supply temperature; start the surface temperature, heat gain calculation (convection and radiation); and heat flux calculation calculations; determine the ceiling panel loads (radiant cooling system); determine the fresh air load (down-sized forced air system), and finally the total cooling load.

2.1 Geometry Model

A hall or meeting room as shown in Figure 1 was selected in this study to test the performance of the radiant cooling system in the Emirate of Sharjah. The dimensions of the hall are: Length =20 m; Width =14 m; and Height = 3 m. The hall has eight glass windows (5 windows for the north wall and 3 windows for the west area), each 3.0 m x 1.2 m and two wooden doors of 1.5 m x 2.1 m each (See

Figure 2). Typical overall heat transfer coefficient were used in the calculations: 1.2 W/m².ºC for walls (light color, construction type D); 1.8 W/m².ºC for ceiling (not suspended type 3); 2.1 W/m².ºC for the floor; 6.7 W/m².ºC for the glass windows; and 3.5 W/m².ºC for the wooden doors. The floor area is 280 m². For the occupancy, there are 50 persons in the hall or for the total floor area (5.6 m²/person). The hall lighting per floor area is 13.2 W/m².

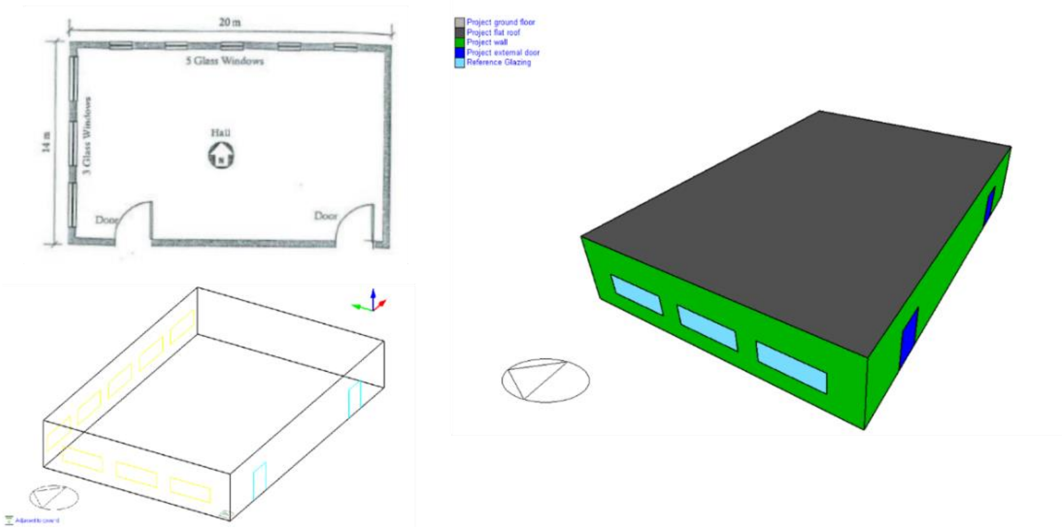


Figure 2. Building Geometry Model.

2.2 Cooling Load Calculation

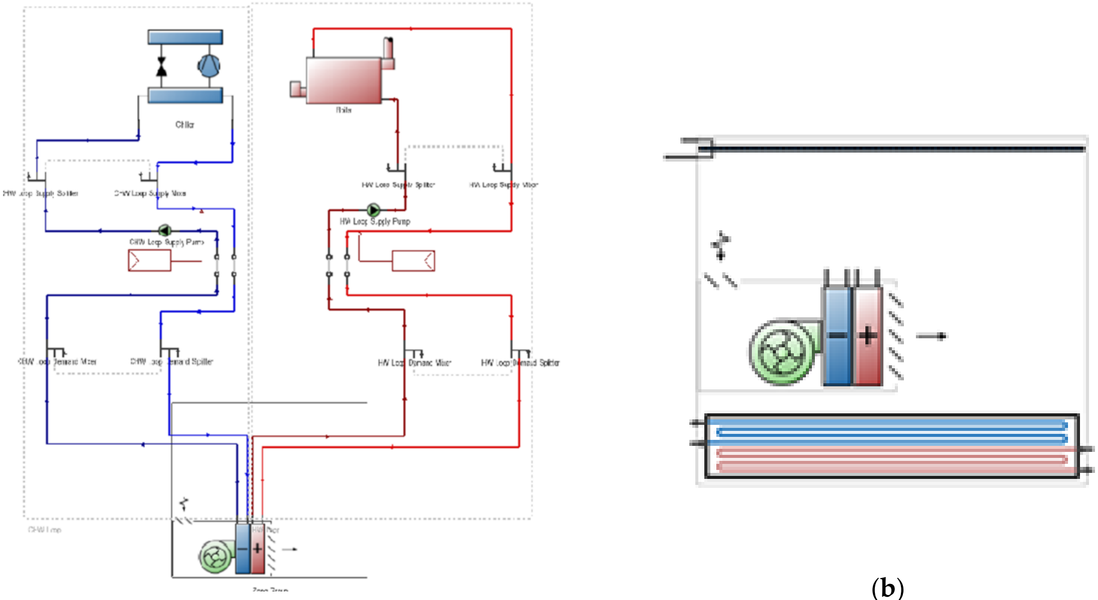
External Load Calculations (Roof, Windows, Walls, Doors, Infiltration): (1) Heat gains through the roof, (2) heat gains through the walls, (3) heat gains through the doors, (4) heat gains through the glass windows, and the heat transmitted due to infiltration.

Internal Load Calculations: Lighting, People, and Equipment: (1) heat gains due to the occupants (sensible and latent), (2) heat gains due to the lighting, and (3) heat gains due to the equipment used in the hall.

Total Load: sensible heat, latent heat, and the total heat gains

2.3 HVAC System Modeling

The HVAC system model using Design Builder is shown in Figure 3.a. The HVAC system components are chiller, cold water loop supply, cold water loop demand side, and fan coil unit as shown in Figure 3.a. The modeling and simulation analysis will help to determine the capacity of mechanical cooling equipment required to meet the hottest summer design conditions likely to be encountered at the site location (July 15 in Sharjah), and to determine the daily, monthly, and annual system cooling load, energy consumption by the water pump and fans.



(a) (b)

Figure 3. HVAC system and radiant cooling system: (a) HVAC System model (chiller, cold water supply, cold water demand side, and fan coil unit); and (b) radiant cooling system RCS (cooling ceiling panels & down-sized forced air system - DFAS).

2.4 Radiant Cooling System Modeling

To model the radiant cooling system, the roof was selected for the chilled water zone. The roof is composed of 5 layers. An insulation layer was added between the first and second inside layers of the ceiling. The pipes were connected between the first inside layer and the new insulation layer added in the ceiling. Water from a chiller was circulated through pipes as shown in Figure 3.b connected in the chilled ceiling zone. The hydronic tubing inside diameter is 1.3 cm and the circuit length was 1000 meter (the number of circuits is about 71 – it is the ratio of the circuit length 1000 m to the width of the building 14 m). The spacing between the pipes is about 27 cm. The zone control temperature is based on the operative temperature. For the condensation control, a simple-off system was used. A down-sized forced air system (DFAS) was also added to provide the fresh air inside the building with dehumidification control supply air.

2.5 Site Data: Sharjah , United Arab Emirates

The performance of the radiant cooling system was tested in the Emirate of Sharjah in the United Arab Emirates. The weather conditions in Sharjah were selected for this analysis: inside and outside design conditions (dry bulb temperature and relative humidity), wind conditions, pressure, and solar irradiance (kWh/m^2) for both the direct normal solar (DNS) and diffuse horizontal solar (DHS).

3. Results and Discussions

This section includes the results of the modeling and simulation of (1) conventional (100% forced convection) HVAC system, (2) modeling and simulation of the Radiant Cooling System RCS integrated with the downsized-forced air system (DFAS), (3) comparison of the conventional and the proposed new radiant cooling system, and (4) cost analysis.

3.1. Results - Conventional (100% forced convection) Air Conditioning Systems

The daily (July 15) and yearly comfort conditions inside the building using conventional air conditioning system were determined: (1) temperature (air temperature inside the building; the radiant temperature - average surface temperature of the roof, walls, and floor; operative temperature - average temperature between the air temperature inside the building and the radiant temperature; and the outside dry bulb temperature), (2) relative humidity (RH%), and (3) the total fresh air needed for the hall. It is notated that the outside dry bulb temperature in Sharjah can reach a value of 45°C between 2-3 pm in July 15. The results show the comfort conditions (air temperature of 22-23°C and RH = 50-55%) are achieved during the hottest day (July 15) in Sharjah. The daily (July 15) and yearly internal heat gains and cooling loads for the hall were determined. This include the heat gains due to the lighting, occupancy (50 persons), equipment, solar gains, the sensible load, latent and total cooling loads (kW). The annual total system loads (sensible cooling load, total cooling load, and chiller load) and the energy consumption breakdown (building equipment, lighting, system pump, system fans, and cooling system load) were calculated. The results show the total cooling load is met by the chiller load and the energy consumption for the cooling load has the highest contribution, followed with the lighting, and then the building equipment. The peaks for the energy consumption and CO_2 emissions for the selected hall in Sharjah in July 15 were respectively 180 kWh and 110 kg. Table 1 summarizes the building electricity consumption (kWh) and the normalized metrics (kWh/m^2 - utility use per conditioned floor area) for the conventional HVAC System. The normalized metric for the lighting, HVAC, equipment is respectively 49.56 kWh/m^2 (30%), 93.49 kWh/m^2 (58%) and 19.54 kWh/m^2 (12%). The total energy consumption per floor area for the conventional (100% forced convection) HVAC system is 162.59 kWh/m^2.

Table 1. Summary of Building Electricity Consumption (kWh) and Normalized Metrics (kWh/m^2 – electricity use per conditioned floor area) for the Conventional HVAC System.

	Cooling	Interior Lighting	Equipment	Total
Electricity (kWh)	22043.63	13710.13	5406.04	44978
Electricity Intensity (kWh/m^2)	49.56	93.49	19.54	162.59

3.2. Results - Radiant Cooling System

The comfort conditions inside the building using the new proposed radiant cooling system integrated with down-sized forced air system were determined (air temperature inside the building; the radiant temperature: average surface temperature of the roof, walls, and floor; the operative temperature: average temperature between the air temperature inside the building and the radiant temperature; and the outside dry bulb temperature). The results show the comfort conditions are achieved with the new cooling system, the air temperature inside the building is about 23°C. The peak energy consumption is about 150 kWh in mid-July. It is noted that the peak energy consumption in mid-July decreases from 180 kWh to 150 kWh when the conventional (100% forced convection) HVAC system is replaced with the hybrid radiant cooling system. The yearly total energy consumption (kWh) for the conventional and the radiant cooling systems are respectively 44978.80 kWh and 38732.69 kWh. The energy use per building floor area decreases from 162.59 kWh/m^2 to 140 kWh/m^2 when the conventional HVAC system is replaced with the hybrid Radiant Cooling System (RCS)/Down-Sized Forced Air System (DFAS). It is also noted that the peak CO_2 emissions related to the building electricity consumption decreases from 110 kg to 90 kg when the conventional cooling system is replaced with the RCS/DFAS radiant system.

3.3. Comparison of the Annual Energy Consumption - Energy Savings

The yearly total energy consumption (kWh) for the conventional and the radiant cooling systems are respectively 44978.80 kWh/year and 38732.69 kWh/year. The yearly energy use per building floor area decreases from 162.59 kWh/m2 to 140 kWh/m2 when the conventional HVAC system is replaced with the Hybrid Radiant Cooling System (RCS)/Down-Sized Forced Air System (DFA S). Table 2 shows the normalized metrics utility use per conditioned floor area for the two systems. The normalized metrics for the lighting, HVAC, equipment for the conventional HVAC system are respectively 49.56 kWh/m2 (30%), 93.49 kWh/m2 (58%) and 19.54 kWh/m2 (12%). The normalized metrics for the lighting, HVAC, equipment for the RCS/DFAS radiant cooling system are respectively 49.56 kWh/m2 (35%), 70.91 kWh/m2 (51%) and 19.54 kWh/m2 (14%). The total energy consumption per floor area for the HVAC system decreases from 93.49 kWh/m2 to 70.91 kWh/m^2 when the conventional (100% forced convection) HVAC system is replaced with the RCS/DFAS radiant cooling system as shown in Figure 4. A comparison of the annual electricity consumption for the cooling load, fans, pumps, and the total between the conventional HVAC system and the RCS/DFAS radiant cooling system is presented in Figure 5. The results presented in Figures 4 and 5 show a total of 25% energy saving for the radiant cooling system compared to the conventional HVAC system. These results are in agreement with previously reported data in the literature. For example, Henze et al. [8] and Armstrong et al.]14] reported energy savings of 20% and 13-18% respectively using radiant cooling panels for building compared to conventional air conditional system. The present study shows energy savings of 20%, 53% and 41% for the cooling load, fans and pumps respectively as shown in Figure 5.

Table 2. Comparison of the Normalized Metrics for Conventional (100% forced air) HVAC system and Hybrid Radiant Cooling System RCS/Down-sized Forced Air System (DFAS) HVAC system.

	Conventional HVAC system	**Hybrid RCS/DFAS HVAC System**
	Electricity Intensity (kWh/m2)	**Electricity Intensity (kWh/m2)**
Lighting	49.56	49.56
HVAC	93.49	70.91
Equipment	19.54	19.54
Total	162.59	140.01

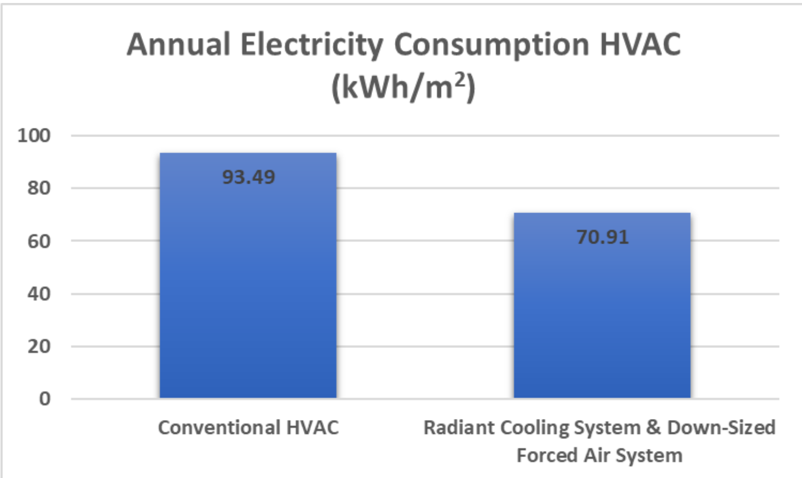


Figure 4. Comparison of the Annual Electricity Consumption (Electricity Intensity kWh/m^2) for the Conventional (100% forced convection) and RCS/DSFA HVAC Systems.

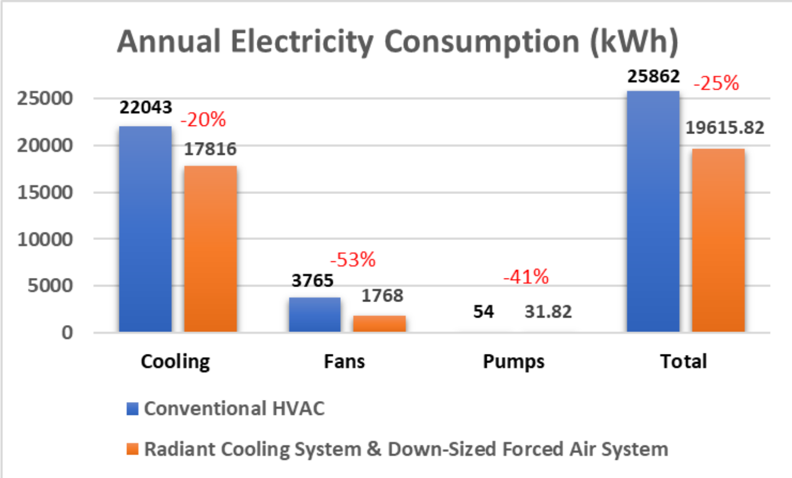


Figure 5. Comparison of the Annual Electricity Consumption (Cooling Load, Fans, Pumps, and Total) for the Conventional (100% forced convection) and RCS/DSFA HVAC Systems.

3.4. Comparison of Cost of Electricity for the HVAC systems - HVAC Cost Savings

The yearly total energy consumption (kWh) per floor area for the conventional and the radiant cooling systems are respectively 93.49 kWh/m^2 and 70.91 kWh/m^2 as shown in Figure 4. The yearly energy savings per floor area is 22.58 kWh/m^2. If the cost of electricity in Sharjah is about 0.44 AED/kWh, the total cost savings using the radiant cooling system is 9.935 AED/m^2 (22.58 kWh/m^2 x 0.44 AED/kWh). The building floor area is about 280 m^2. The annual savings for this building using the radiant cooling system is 2782 AED/year.

3.5. Cost Analysis - Construction Cost for the Building

The estimated building construction cost data shown in Table 3 is based on 'per gross internal floor area' costs of services, sub-structure and frame construction. The cost of constructions and glazing is based on the 'per surface area' cost data from the constructions and glazing database. Surface finish costs are also calculated from actual building surface areas and entered surface finish per area costing data. The results show that by adding the radiant cooling system in the roof of the building (insulation layer in the roof, piping system for the chilled water) will increase the cost of the construction of the building roof by 9306 AED or 33.23 AED/m^2 (capital cost). The cost savings from the HVAC system using the radiant cooling system is 9.94 AED/m^2 per year. The payback period for the radiant cooling system is about 3.34 years. After three years and half the cost of the radiant cooling system will be paid completely from the HVAC cost savings.

Table 3. Cost Analysis - Conventional (100% forced air) HVAC system and Hybrid Radiant Cooling System RCS/Down-sized Forced Air System (DFAS) HVAC system.

Structure Costs	**Floor Area (m^2)**	**Cost (AED) Conventional HVAC**	**Cost (AED) RCS/DFAS Radiant Cooling System**
Sub Total	276.6	279,181.20	279,181.20
HVAC Costs	**Floor Area (m^2)**	**Cost (AED)**	
Sub Total	276.6	199,415.20	199,415.20
Lighting Costs	**Floor Area (m^2)**	**Cost (AED)**	
Sub Total	276.6	79,766.07	79,766.07
Sub-Structure Costs	**Floor Area (m^2)**	**Cost (AED)**	
Sub Total	276.6	146,237.80	146,237.80

Super Structure Cost	Construction Area (m^2)	Cost (AED)	
Project external door	6.5	1250.059	1250.059
Project wall	203.4	127,070.40	127,070.40
Project flat roof	276.6	99,707.56	109,013.60
Project ground floor	276.6	450,678.30	450,678.30
Sub Total	763.2	678,706.40	688,012.40
Glazing Cost	**Surface Area (m2)**	**Cost (AED)**	
Reference Glazing	26.7	20,502.27	20,502.27
Local shading			
Blinds and internal shades			
Sub Total		20,502.27	20,502.27
Surface Finish Costs	**Surface Area (m2)**	**Cost (AED)**	
Walls	203.4	39,098.60	39,098.60
Floors	276.6	59,824.53	59,824.53
Ceiling	276.6	39,883.03	39,883.03
Sub Total		138,806.20	138,806.20
Building Total Cost (AED)		**1,542,615.00**	**1,551,921.00**

4. Conclusions

Modeling and simulation performance analysis of radiant cooling systems for Sharjah buildings was performed in this study. The main objectives were to determine the energy saving benefits of radiant cooling compared to conventional air systems, investigate the practical application of radiant cooling in Sharjah in particular and UAE in general, where the climate is hot and humid; and determine the corresponding cost associated with the retrofitting of existing building with the proposed radiant cooling systems. The comparison of the results obtained for the conventional air-cooling system (100% forced convection) and the proposed radiant cooling system/down-sized forced air system showed:

1. Energy Performance Analysis: 20% energy savings for the cooling load; 53% energy savings for the fans (ventilation air), 41% energy savings for the pumps (Chiller), and 25% total energy saving for the proposed RCS/DFAS system compared to the conventional HVAC system.
2. Energy Performance Analysis - Normalized metrics:
    a. Total energy consumption per floor area (HVAC, Lighting, and Equipment): 162.59 kWh/m^2 for the conventional HVAC system and 140 kWh/m^2 for the Hybrid Radiant Cooling System (RCS)/Down-sized forced air system (DFAS).
    b. Energy consumption for the HVAC system: 93.49 kWh/m^2 for the conventional HVAC system and 70.91kWh/m^2 for the proposed Hybrid Radiant Cooling System (RCS)/Down-sized forced air system (DFAS).
3. Cost Analysis: the cost savings per year and per floor area for the HVAC system: 9.94 AED/m^2.
4. Cost Analysis: the capital cost for the radiant cooling system: 33.23 AED/m^2 and the payback period for the radiant cooling system is 3.34 Years.

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Calibrating Building Thermal Simulation Model Using Indoor Environmental Measurements

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Abstract: Dynamic Building Energy Simulation (DBES) modeling is a useful way to calculate the energy saving through retrofitting of the existing building stock. However, Professionals are concerned about the discrepancy between the calculated and actual energy savings which is known by the performance gap. Calibrating the DBES models is a crucial step before heading towards the optimization step. The existing standardized statistical indices depend on energy bills to perform the calibration. These indices are not easily applied in developing countries where a combination of fuels is sometimes used for heating. In this paper, the heating load in a single house in Hebron, Palestine was modeled as internal gain. Then the model was calibrated using internal environment measurements (internal temperature) that were taken through two monitoring phases for a single house in Hebron, Palestine. A validation method for a single house was presented using the internal temperature depending on the monitoring phases. The results show that the model was calibrated and can be used for optimization.

Keywords: Energy modelling, DBES Calibration, Indoor environmental measurements, Statistical indices.

1. Introduction

Many of the developing countries face several challenges like fuel poverty, water scarcity and overheating due to climate change [1]. Despite that these are global challenges, they are more urgent in Palestine due to the political instability. In addition, urban growth and higher standards of living have raised the per capita energy consumption by 8.6% between 2007 and 2014 [2]. This was coupled with the absence of sustainable consumption of energy [3]. One of the main reasons behind the lack of sustainable consumption in the housing sector is the poor quality of housing in terms of thermal performance. The combination of these challenges has several implications for Palestinians. Lack of access to safe and affordable energy in the housing sector affects households' safety, wellbeing and decreases the chances of achieving thermal comfort.

During the last two decades, energy in the building sector received more attention from the government and related organizations. In 2004 the first Energy-efficient Buildings Code was published [4]. Then, in 2013, the Palestinian Green Buildings Guidelines (PGBG) were published [5], followed by constructing public buildings that were LEED-certified, such as the Palestinian Museum and the Abdelmuhsen Qattan Foundation building and Aqaba School, which both earned Palestinian Green Building Council Certification [6].

Due to its location, Palestine has a good potential to use renewable energy sources especially the solar energy as it lays in the north equator on the Mediterranean Sea [7]. This can help the country to overcome the problems of energy insecurity and affordability [8]. Shifting towards renewable energy should be proceeded by optimizing the energy consumed in buildings which can be performed using Dynamic Building Performance Simulation (DBPS) [9]. In order to decrease the discrepancy between the real building and the simulated model, a calibration process is needed [10]. In this paper, a single house building is calibrated opposite to actual monitored temperature in Hebron, Palestine.

2. Calibration and validation of the simulation models

Several studies [11; 12] have reported discrepancies that of up to 100% differences between DBPS model-predicted and the actual monitored data. To improve the accuracy of the DBPS model results to determine meaningful energy conservation measures, calibration is needed [13]. The main goal is to approximate the DBPS model results to the real data as closely as possible [14].

Four main categories of calibration methodologies were presented by Reddy et al. (2007): manual; graphical-based; calibration based on special tests and analysis procedures and automated techniques [15]. The following is a brief explanation of each:

a) Manual calibration methods based on an interactive approach rely on the users' experience and understanding of building physics [16]. This is one of the most common methods used for calibration [13; 16; 17; 18]. Although it is time consuming, this method incorporates human intelligence in the process of calibration [19].

b) Graphical-based calibration methods rely on comparing time series plots. Apart from classical and time-series plots [20] and recently involved 3D Comparative Plots and calibration signature [16].

c) Calibration based on special tests and analysis consists of short- or long-term monitoring combined with special tests, such as wall thermal transmittance measure or blower door tests (difficult to perform in occupied buildings) or other in situ tests [16].

d) Automated techniques for calibration, based on analytical and mathematical approaches, which can be useful for non-expert users [19; 21].

3. Criteria of goodness to fit

Standardized statistical indices were proposed to assess the performance of a model to replace the previously used simple per cent ratio [16]. These later became international reference criteria for the validation of calibrated models, recommended by recognized bodies like ASHRAE [22].

- Mean Bias Error (MBE) (%) can be defined as the sum of errors between the measured (real) and simulated data and is a good indicator for the model's overall bias [23]. This is a non-dimensional bias measure (i.e. the sum of errors), which means that positive bias compensates for negative bias (the cancellation effect) and thus a further measure of model error is also required [13; 24]. The (MBE) can be calculated using Equation 1.

$$\text{MBE}=\frac{\sum_{i=1}^{n}(\hat{x}_i-x_i)}{\sum_{i=1}^{n}x_i} \quad , \qquad (1)$$

Where x, $\hat{x}$ are the sampled data and predicted data respectively; and n is the number of samples. An MBE of 0 suggests that there is no bias in the model and the accepted MBE value for calibration in ASHRAE must be within ±10% if the model was developed by using hourly data [22; 24].

- Root Mean Square Error (RMSE) (%) is a measure of average deviation from the true value [23]. It is a non-dimensional bias measure and can be only calculated if the true values (the monitored data) are available [23]. For every point, the error (difference) is calculated and squared, then the sum of squares errors (SSE) is added for the total periods and divided by the number of points, giving the mean squared error (MSE) [13]. The root mean squared error (RMSE) is the square root of the MSE [13] and can be calculated using Equation 2.

$$\text{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}(\hat{x}_i-x_i)^2}{n-1}} \quad , \qquad (2)$$

Where x, $\hat{x}$ are the sampled data and predicted data respectively; and n is the number of samples. This metric can range between 0 and ∞, where a lower value is desirable [24].

- Coefficient of Variation of Root Mean Square Error CV(RMSE) (%) is a statistical measure that determines how well a model fits the data by capturing the errors between measured and simulated data and does not suffer from the cancellation effect [13]. It identifies total uncertainty in the prediction of the model, reflecting the errors' size and the amount of scattering [16]. Lower values are desirable in this metric [24].

$$CV\ (RMSE) = \frac{RMSE}{\bar{x}}\ , \quad (3)$$

Where $\bar{x}$ is the mean of the sampled data. Global organizations such as ASHRAE, IPMVP, and FEMP have set their own standards for two of the previous measures of the baseline model, which are as follows for the hourly criteria (%) in Table 1.

Table 1 Protocol for calibration of DBPS models

Standard	MBE%	CV(RMSE)%	Source
ASHRAE Guideline 14	10	30	(ASHRAE, 2002)
IPMVP	5	20	(EVO, 2007)
FEMP	10	30	(US DOE, 2008)

Generally, energy simulation models for predicting energy consumption are considered 'calibrated' if they meet the criteria set out by ASHRAE Guideline 14 [22]. However, several models for the same building can meet these criteria and be considered calibrated. The following section explains the calibration method of the two buildings.

4. The building characteristics and system used

The building is a two-storey single house building with a net floor area of 240m2 and a ceiling height of 3.2m. It was selected as it is a model of the single house building typology in Hebron. The house is occupied by 3 adults. The house was built in 1993 using contemporary building materials and technologies at that time. Most of the ground floor is an open plan area, which consists of reception, salon, dining room, kitchen, WC, guest room and a sunroom. The second floor comprises three bedrooms, two living rooms and two bathrooms. Figure 1 shows the ground and the first-floor plans of the single house.

Since the building envelope was made of concrete, concrete hollow blocks and stone (which all have high durability), minimum maintenance had taken place since the house was built. Thermal insulation was used in the western façade, which faces the dominant wind during winter. Most of the windows of the house are 2.0 x 2.2m2 with aluminium frames and single glazing. External shutters and internal curtains are used to control the internal environment.

The building is naturally ventilated all day during summer. During winter, it is naturally ventilated for certain hours during the day and occupied spaces are heated during the day. A combination of energy sources is used to heat the house i.e. electricity and LPG.

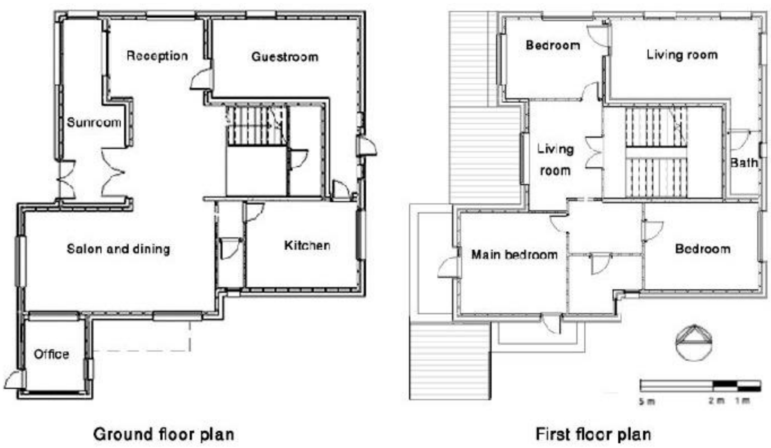

Figure 1. Ground and first floor plans of 1 the single house building

5. Method

The method used for data collection comprised of:

5.1 Semi-structured interview with the household

In order to have a comprehensive picture of the households' behaviour, extensive interviews took place, concerning the behaviour of the household such as typical occupancy periods, and adaptive measures used such as the patterns of opening and closing windows and the patterns of using heating and cooling systems. This data was used later to develop the profiles used for modelling as explained in section 6.3, 6.4 and 6.5.

5.2 Environmental measurement and longitudinal monitoring

Calibrated Extech RH10 loggers (±0.1°C) were used as part of the monitoring phase to assess the actual operational performance of the dwellings [25]. The data loggers comprised a sensor part and a record system that saves the readings. Three data loggers were used for monitoring, two inside the dwellings and one outside. The Extech RH10 loggers recorded the indoor air temperatures and relative humidity (RH) in the living rooms, as well as outdoor air temperature and (RH). The data loggers were named and a time interval of 5 minutes was set for each. Five minutes is the shortest period between the two readings. It was set to this time interval to increase the total number of readings that were used for calibration later on. The data loggers were set about 150 cm above the ground and away from any direct sources of heat or sunlight. They were also concealed to decrease their effect on the households' behaviour. Due to the limited number of available data loggers, only one data logger was used outside. It was set on a windowsill of the single house on the northern façade, away from direct sunlight. The data loggers were in USB form and the readings were downloaded manually onto a computer.

In this kind of research, a longitudinal approach is highly recommended to spread the data across time [26; 27]. Since the collected data will be used to calibrate the model developed using IESVE, the longitudinal approach was adopted and monitoring covered two periods. The first reading set was collected between 12th October and 1st November 2017, while the second set was collected between 28th January and 24th February 2018. After each monitoring period, the data loggers were collected and the monitored data downloaded into an Excel sheet.

5.3 Creating a weather file for Hebron

Climate is a key factor that defines the energy performance of a building. In order to use DBPS for predicting energy demand, weather files are needed for the location of the assessed building [28]. Weather files are samples of real weather data taken from a certain period that have similar average weather parameters to the actual but it is not the average of weather parameters over a certain period [29]. The simulation weather files can be sourced from various places like Weathershift, CIBSE 2016 Weather Files, Meteonorm, Australia Weather Files, Agrément South Africa or EnergyPlus Weather Files (EPW) [30]. In this paper, the validation of the building energy simulation model, a weather file that represents the exact weather conditions of the context is needed. Accordingly, weather data for the period between March 2017 and February 2018 was obtained for Hebron from the Palestinian Metrological Department on the 20th/March/2018 [31]. The main goal was to create a weather file based on formal measured data representing the actual weather in the context during the monitoring periods that cover the two periods of monitoring.

6. Developing (IESVE) Dynamic Building Energy Performance Simulation model

The detailed modelling encompasses geometric modelling of the buildings, the physical characteristics of the building envelope, the profiles of heating, cooling, lighting and appliances, occupancy of the users and the opening and closing of the internal and external windows, as will be explained in the following sections.

6.1. Creating the geometric models and exporting them to IESVE software

Using the Revit software, the buildings' geometry was considered in relation to the surrounding buildings, as seen in Figure 2. The model was then exported in gbXML (Green Building XML), a format that facilitates the transfer of information from the Building Information Models (BIM) to building performance analysis platforms like IESVE and the export was performed as per Autodesk (2018). Every interior space was defined as a room. All the shading devices were identified, including surrounding buildings. The location of the buildings was assigned based on Hebron latitude longitude coordinates: 31°31'45.66"N, 35°5'37.68"E. The previously developed weather file was allocated for the two models so that the models perform under the same climatic conditions of the real world.

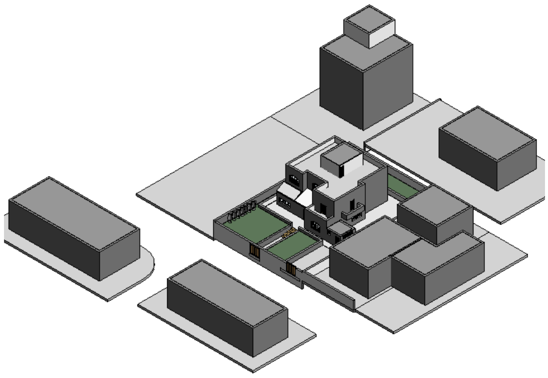

Figure 2. Geometry in Revit

6.2. Assigning building materials

Based on the data collected during the site visits as explained, the building materials of the envelopes were defined. The materials' characteristics were assigned based on the local materials specifications in the Building Energy Efficiency Code [32]. There were no guidelines before 2004 and no specifications were available, hence the most compatible guidelines with the modeled building was used. The full details of the materials like conductivity, density, specific heat capacity, resistance and vapour resistivity, in addition to the U value and thermal mass k of the buildings' envelopes, can be seen in Table 2.

Table 2 Building's components specifications

Building component	Configuration (cm)	U value (W/m^2k)	Thermal mass ($kg/(m^2.K)$)
External walls	Stone 15, concrete 15, concrete hollow blocks 7, plaster 1.5	1.5	160
Ground	Reinforced concrete20, concrete baking8, sand 5, mortar 2, concrete tile 2	1.5	175.7
Roof	Waterproof membrane 0.3, concrete baking 8, bricks and ribs 17, plaster 1.5	1.7	108.4
Ceiling	Concrete tiles 2.5, mortar2.5, sand 2.5, concrete baking 8, bricks and ribs 17, cement plaster 1.5	1.3	108
Internal walls	Plaster1.5, concrete hollow blocks 7, plaster1.5	2.4	66.8
External doors	Iron 0.5, cavity 2 , iron 0.5	4.2	---
Glazing (g) value 0.5, transmittance (T) 0.7	Single glazing	5.7	---

6.3 Assigning the heating and cooling systems

In the IESVE the ApacheSim is a dynamic thermal simulation program that uses first-principles mathematical modelling of the heat transfer processes occurring within and around a building [30]. Assigning the thermal conditions for the ApacheSim in the IESVE include defining the system, space condition, internal gains, air changes and building regulations. Since there is a discrepancy between occupancy and the (HC) profiles of the rooms, a separate thermal condition was defined for each of them. When defining the rooms' conditions, it was not possible to assign the individual heaters and fans used by the households in the IESVE models. After consulting the IESVE support team, they advised to consider the (HC) systems in these building as though they are continuously off and to add the heating systems as internal gains and the cooling load as a heat loss instead [30]. For this research, the (HC) loads were termed miscellaneous gains. The (HC) loads were calculated based on the voltage of systems and usage period. In addition, other internal loads were assigned for each room based on data from the physical survey and the semi-structured interviews. These internal gains included the lighting, people and appliances. At steady-state conditions, and based on the conservation of energy principle, the total heat output is equal to the total power input [33]. Although the cases here are not in steady-state conditions, the researchers assumed that the input energy is equal to the output. Moreover, the efficiency of the system is beyond the scope of this research and hence the output was defined based on watt-hour calculations. These were obtained from the system's manuals and the duration of usage as expressed by the households.

There are not any studies quantifying the infiltration rate in buildings in Palestine. Hence, the air exchange rate that was assumed by this study was the infiltration of 3.0 ach since the air exchange due to natural ventilation was assigned in the Macro-flow section. This value was assigned following consultation with the IESVE support team [30]. This value is not far from what the Palestinian Green Building Guidelines recommend which is 2.7 ach [32].

6.4. Assigning the users' occupancy profiles

There are four implementation approaches to occupants' behaviour models: (i) direct input where the user defines and inputs temporal schedules; (ii) Built-in Occupants behaviour (OB) models where the user selects one of the built-in models; (iii) the user function in which the user behaviour is modelled by writing functions or custom code; and (iv) co-simulation, which allows certain components to be simulated by different simulation tools running simultaneously [33]. In IESVE, user behaviour is modelled using direct input, just as other model inputs like building materials and geometry [34].

There are two general approaches when modelling the occupancy pattern in the residential sector: the individual approach and the family approach. The first approach obtains occupancy data based upon national survey data of people's time-use distributions, while the second relies on data regarding a family's schedule, based on the most common household occupancy patterns [35]. Because tracking down detailed information for the individual occupant is difficult, the 'family' approach is adopted in this study.

The usage of the rooms, heating and cooling systems, appliances and pattern of window-opening in each dwelling was discussed during the interview with the households in order to establish an occupancy profile. The interview revealed that the rooms were occupied for different periods. Besides the appliances, the heating and cooling systems and the opening of the windows (natural ventilation) were used in different patterns.

The occupancy patterns are generally affected by the number of users and the lifestyles which defines the time a person wakes up in the morning, the time spent at home and the time the person goes to bed [34]. Based on Aerts et al. (2014), there are three realistic possible occupancy states: (1) at home and awake (active); (2) sleeping (non-active); or (3) absent . Based on that, Figure 3 illustrates the pattern of using the building [36].

Figure 3. Occupancy profiles in the building

During a typical day, the ground floor is occupied by one member of the household during the day, while in the evening the household members move to the first floor. A separate occupation profile was used for each of the reception, sunroom, kitchen, living room and bedrooms. At night, three bedrooms are occupied. Since the other rooms' usage is for very limited periods, the occupancy of these spaces is neglected. The daily occupancy profile of each of these rooms is shown in Figure 4

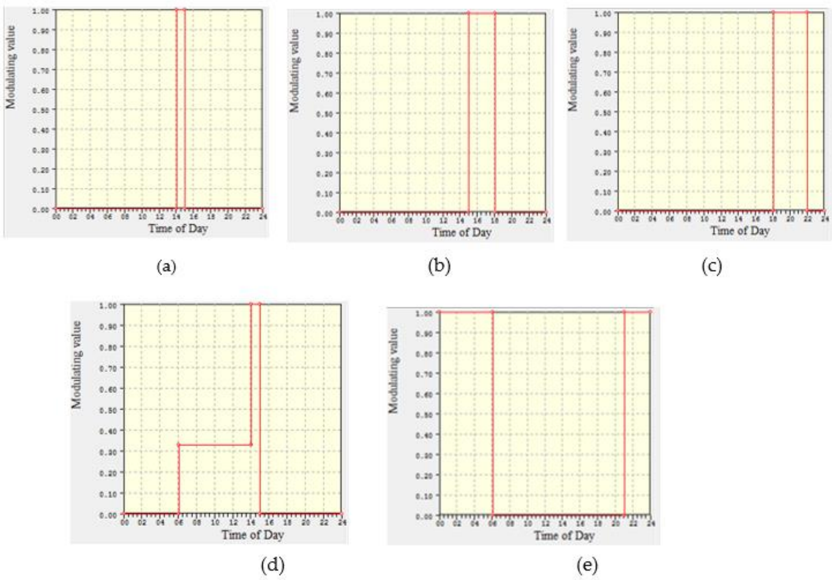

Figure 4. The occupancy profiles for the rooms in the(a)living room, (b)reception, (c)sunroom, (d) kitchen and (e) bedrooms

6.5 Assigning the heating, cooling and internal gains profiles

The heaters were on during the months indicated by the households (15th November-30th April) and were off during the rest of the year. The different heating systems were assigned based on the data gathered from the interview. The wattage was assigned from the manual. Since two elements are used for an hour on a typical winter day, the total wattage is 1200W in this case.

Internal gains were specified in the model according to the pattern of use as indicated by the household in the interview. The main source of lighting in all the rooms was florescent, estimated at 17W/m2. The profile of daily use was developed in the model based on the interviews. The lights were on usually between 17:00-20:00 in the occupied rooms.

There are three TV units in three different rooms (sunroom, reception and living room). Each of the TV units has a wattage of 100W. In the IESVE model, three different working schedules were developed for each TV unit depending on the usage. In the kitchen, the fridge is permanently on, and the household uses an LPG cooker which depends on Blue LPG cylinders of butane. The family indicated the cooker is used usually for 2 hours a day between 12:00 and 14:00. The maximum sensible gain from the users was assigned as 90W/person while the minimum latent gain is 60W/person. The number of persons was assigned depending on the space.

7. Calibration

Since more than one energy source is used for heating, it was not useful to collect the energy bills. No energy meter readings were involved so the calibration of the models was based on the internal monitored temperature. This approach was used in other similar research where energy readings were not available [17; 37]. There are no specific standards for calibration using the measured temperature. Research-based on calibrating buildings' temperature behaviour relies on the same energy validation protocols, rather than on specific temperature ones [17].

The uncertainty in the DBPS models was classified into four main sources by de Wit and Augenbroe (2002): (i) specification uncertainty (inaccurate system or building specification), (ii) modelling uncertainty (simplification of complex physical processes), (iii) numerical uncertainty (errors during simulation process) and (iv) scenario uncertainty (related to external conditions)[38]. As the researcher has no control over the modelling and numerical uncertainties, the goal was to decrease the first and the fourth effect on the simulation results. During the interviews, the households described their typical day in both summer and winter. Using the obtained data, the heating and cooling loads, occupancy profiles, heating and cooling and natural ventilation and the other system profiles were developed and input. In addition, local weather parameters were collected from Hebron weather station and a weather file was developed to reflect the actual climatic conditions that affected the building performance during the monitoring phase. Hence, this source of uncertainty was minimised.

The other source of uncertainty was the specification uncertainty. Regarding the external input data (i.e. assigned by the user and not embedded in the software), Macdonald (2002) suggested three distinct methods that can be used for calibration: changing one parameter at a time; changing one set of parameters at a time; or changing all the parameters at the same time. The last method is known as the Monte Carlo method [39]. In this research, the manual calibration approach was adopted and one parameter was changed at a time, which is simple and valid for calibration [17]. For calibrating the models, the U value of the external walls and the infiltration rate was used to calibrate the models. Although there are a lot of other factors that can affect the simulation results like the solar radiation, U and g values of the glazing, the colour of the envelope.

Three rounds of calibrations were done for the whole year focusing on the impact of two major parameters: the U value of the external walls and the infiltration rate of the windows. The model was calibrated based on the monitored internal temperature profiles (baseline temperature). For the living room on the first floor, the monitored data covered the period between 12th October and 1st November and in the sunroom on the ground floor between 28th January and 24th February. For this, building materials characteristic values were inputted using the local Energy Efficient Building Code [32] as it includes local building materials' characteristic values like conductivity and density. Other values were input based on the operator's judgment and experience, such as the infiltration rate. In the first round, all users, lighting and equipment schedules are inputted as they have been communicated or observed. In the second round, the envelope (external walls U-value and thermal mass) was increased by increasing the conductivity rate and density based on the value limits presented in the local Energy Efficient Building Code [32]. Since the thickness of the walls was measured during the physical survey, it was considered constant and unchanged during the calibration process. Table 3 shows the external walls' conductivity, density and U values, which were changed in the second round of simulation.

Table 3. External wall thermal characteristics used in the calibration of case 1

		Stone	Concrete	Concrete blocks	Plaster
Conductivity	Round 1	1.1	1.0	0.7	0.25
	Round 2	1.75	1.85	1.0	0.7
Density (kg/m³)	Round 1	2500	2000	1400	1500
	Round 2	2700	2600	1600	1850
U value (W/m²k)	Round 1	1.7			
	Round 2	2.5			
Thermal mass (J/K)	Round 1	*709.7kg/m²*			
	Round 2	*788.5 kg/m²*			

In the third round, the infiltration rate was increased from 3 to 5 ach and the MBE, RMSE and CV(RMSE) were calculated for each of the rounds. Table 4 presents the three calibration rounds including these values for each of the calibrated rooms and the overall weighted value.

Table 4. Characteristics of the three calibration rounds for the calibrated rooms for case 1

		Calibration characteristics		
		Round 1 (red)	*Round 2 (green)*	*Round 3 (blue)*
		HL 4.9 kWh *CL 0* *U value 1.7* *Mass 788.5 kg/m²* *Infiltration rate 3 ach*	*HL 4.9 kWh* *CL 0* *U value 2.5* *Mass 709.7kg/m²* *Infiltration rate 3 ach*	*HL 4.9 kWh* *CL 0* *U value 1.7* *Mass 709.7kg/m²* *Infiltration rate 5 ach*
Living room (n= 4046)	*NMBE*	-3.78%	-4.01%	1.02%
	RMSE	1.616504	1.558926	1.577039
	CV(RMSE)	8.581455	8.275794	8.37195
Sunroom (n= 2908)	*NMBE*	-10.70%	-9.70%	-2.10%
	RMSE	1.119067	1.106221	2.884535
	CV(RMSE)	26.43174	25.08063	23.09135
weighted	*NMBE*	-1.64%	-1.73%	0.413%
	RMSE	1.327083	1.295531	2.337771
	CV(RMSE)	18.96717	18.05324	16.93604

In the first round, the simulated temperature in both the living room and the sunroom was considerably warmer or colder than the recorded ones, as shown in Figures 5 and 6. In round two, the U value of the external walls was increased. Figure 5 shows that in the living room the second round of simulation matched the recorded temperature in the periods 13th-18th and 23rd-27th October and 29th October-1st November 2017. In the sunroom, the second simulation matched the recorded temperature between 20th and 24th February 2018. In the third round, the infiltration rate was increased from 3 to 5 ach and the simulated living area showed good values as the number of matching values with the recorded temperature increased, whereas the sunroom was still not in the acceptable range as seen n Figure 6. Nevertheless, the weighted indices of the two rooms are within acceptable ranges (16.9 for CVRMSE and 0.41 for NMBE). Based on these statistical metrics, the model can be considered calibrated. However, this should be considered during the optimization step.

The validation process included modifying the envelope U-values and increasing the infiltration rate. Figures 7 and 8 compare the monitored with the dry bulb temperature and the simulated temperature. In the living room, the simulated temperature is mostly higher than the dry bulb outdoors temperature at night and lower than the ambient temperature in the daytime in several days during the period between 12th October and 1st November. In the sunroom during the first half of the monitoring period (28th January-10th February), the internal temperature was lower than the dry-bulb temperature and higher than or equal to the dry-bulb temperature in the second part of the monitoring period. Moreover, in both the living area and the sunroom, peak simulated temperatures are mostly higher than the monitored ones. This should be considered during optimization of this model, as the actual results can be lower than the simulated after retrofitting.

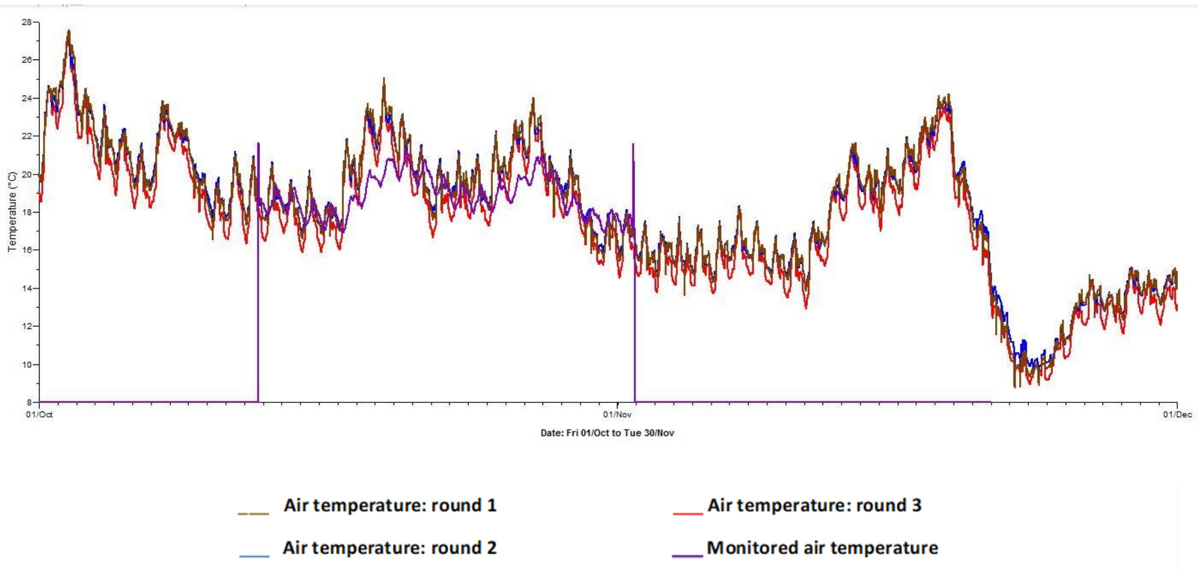

Figure 5. Simulation results of the three rounds and the monitored temperature in the living room for the period 12th October-1st November/2017

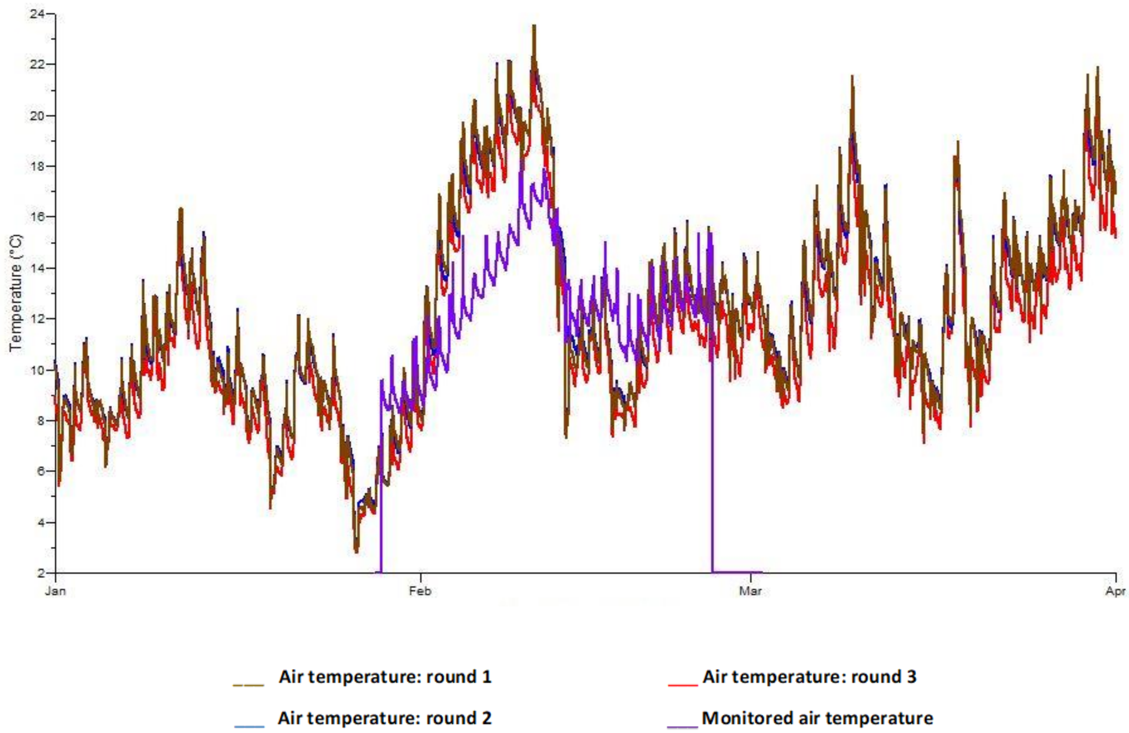

Figure 6. Simulation results of the three rounds and the monitored temperature in the living room for the period 12th October-1st November/2017

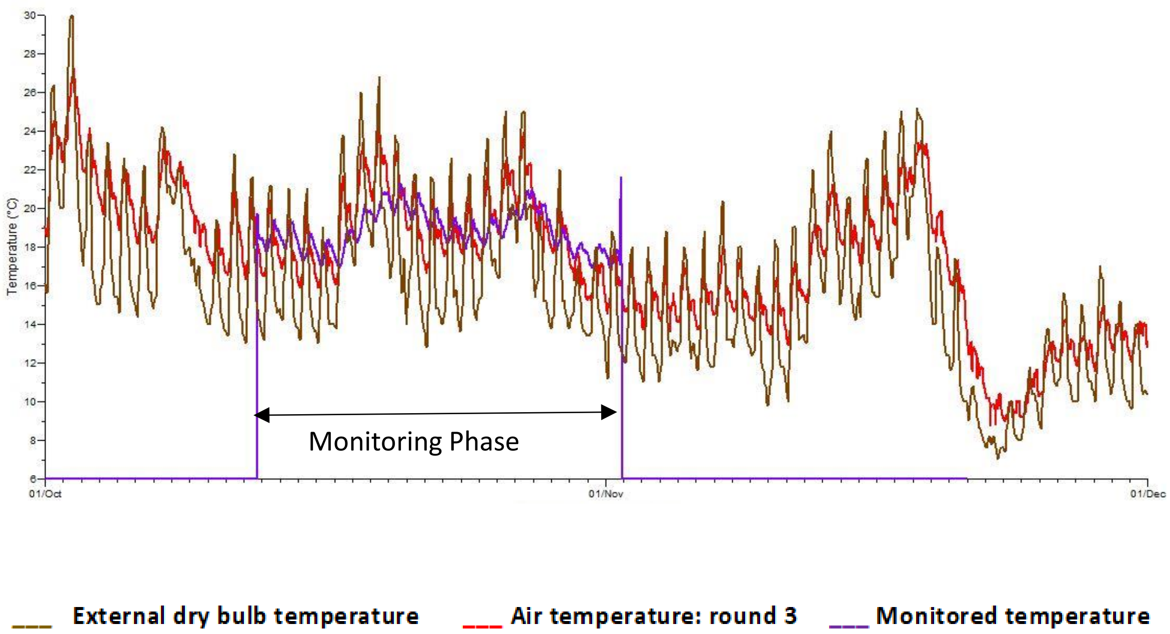

Figure 7. Simulation results of the third round in the living room, the monitored temperature and the external temperature for the period 12th October-1st November/2017 (Case 1)

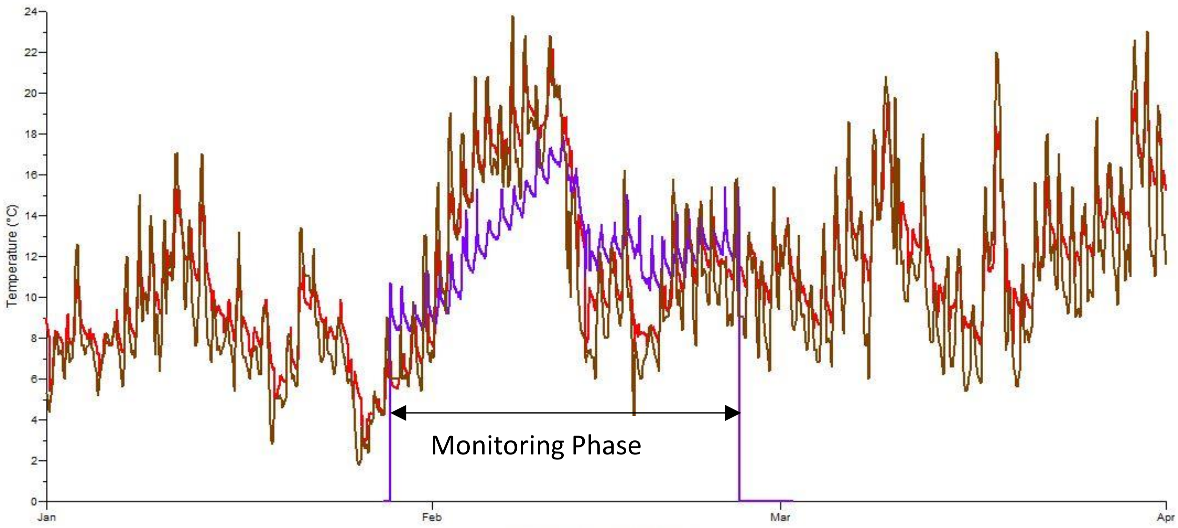

Figure 8. Simulation results of the third round in the sunroom, the monitored temperature and the external temperature for the period 28th January-24th February/2018

8. Conclusion

There is an urgent need to improve the energy efficiency of the existing building stock around the world to confront climate change and to respond to the energy prices. DBPS are essential tools to predict energy savings through energy optimization. However, calibrating these models is essential to calculate valid energy savings through retrofitting. The existing Standardized statistical indices which are the international reference criteria for the validation of calibrated models depends merely on energy bills. In certain contexts, like in the developing world, there is a need to use a combination of energy sources or to use certain types of informal fuels, calibrating the models through the energy bills is inapplicable. In this paper, a validation method for a single house in Palestine was presented using the internal temperature depending on two monitoring phases. The results show that the model was calibrated and can be used for optimization later on. The paper contributes to knowledge in the field by making available a calibrated model for use in this region, where there is a clear lack of studies. To generalize this method, more cases are needed to be calibrated using the internal environment measurements. Moreover, statistical indices should be developed for DBPS models depending on the internal environment measurements to be used when the energy bills calibration method is inapplicable.

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Session 6:

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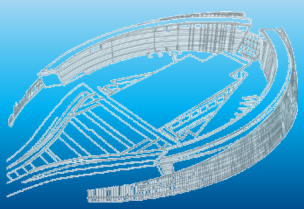

Aerial Infrared Thermography and Artificial Intelligence-Based Fault Detection and Diagnosis Methods for Building Energy Systems: A Review of the State-of-the-Art

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Abstract: It is estimated that buildings account for roughly 41% of global energy usage, which results in a 36% contribution to world-wide greenhouse gas emissions. Recognition of irreversible climate changes has accelerated the necessity to reduce energy consumption of buildings. The thermal performance of a building envelope contributes significantly to the overall energy consumption of a building. The accurate evaluation of energy losses through a building enclosure can facilitate the development of targeted and appropriate rehabilitation strategies which reduces overall energy usage and lowers greenhouse gas emissions. Over the last decade, infrared (IR) thermography has been established as a leading method for defining the surface temperatures of building enclosures. Technological advancements have facilitated the use of quadrotor unmanned aerial vehicles with digital and IR cameras as a method of performance evaluation in the building energy auditing sector. These airborne inspection techniques allow for faster and more accessible assessments; however, the interpretation and accuracy of the derived results requires further research into automation of assessment. Current methods of IR image analysis require professionals to analyze the data of plane 2-dimensional surfaces. Artificial Intelligence (AI) and Machine Learning (ML) can help increase the understanding and investigation of building envelope integrity, which will allow for representative and more applicable retrofit interventions for buildings. The focus of this paper is to present a comprehensive review of relevant scientific literature and recent developments in the field of thermographic computational envelope analysis coupled with drones and AI. This study classifies relevant AI methods and explores future possibilities, challenges, and advantages. It is found that the advancements and availability of AI and infrared thermography in the building energy, performance, and technology sector are opening doors to new research opportunities and beginning to optimize building envelope assessment techniques. However, there is limited research available in this field.

Keywords: Energy consumption; Infrared thermography; Artificial intelligence; Machine learning; Anomaly detection; Building envelope; Energy efficiency; Unmanned Aerial Vehicle.

1. Introduction

The sustainability of a building's energy efficiency can be quantified through its performance [1]. A building's performance is most impacted by defects in the envelope, such as air leakages, heat losses, moisture, or damaged thermal insulation [2], which consequently increases energy consumptions and greenhouse gas emissions. The building sector accounts for roughly 41% of global energy usage which in turn contributes to over a third of the world's greenhouse gas emissions [3]. The worldwide growing awareness of building's energy consumption and their resulting negative environmental impact has urged policymakers to focus on energy conservation and has sparked reduction measures in global carbon dioxide emissions from the building sector. As guidelines for new construction are amended to implement greener design, it is the existing building stock that must be evaluated and rehabilitated to effectively reduce the greenhouse gas emission (GHG) worldwide. The United Nations Environment Programme (UNEP) within the Sustainable Construction and Building Initiative (SCBI) has reported that many opportunities exist for governments, industry and consumers to take appropriate actions during the life span of buildings that will help mitigate the impacts of global warming [3] [4].

With energy loss through the building envelope being the leading contributor to poor building energy efficiency, the identification of inadequately functioning systems is required prior to the implementation of appropriate rehabilitation strategies. While energy modelling and intrusive openings are inefficient, costly and time consuming, infrared (IR) thermography has become a common practice for envelope default detection. In addition, advancements in infrared and digital imaging technologies coupled with the substantial price drop of IR cameras in recent years has increased the use of this non-intrusive inspection method. Thermal cameras are used to detect IR radiation that is emitted from an object's surface and are then converted into a thermal image comprising of temperature gradients that are interpreted [5]. The methodologies of building thermography investigations have been under development for several decades now and have advanced in capabilities as research and technology progresses.

The use of unmanned aerial vehicles (UAV) has recently become a contributor to the thermographic analysis industry granting more accessible and more accurate review methods. As the collection of infrared thermal images has evolved, the evaluation techniques of the imageries still require extensive developments. Current methods typically require an expert in building science and thermography to manually and individually evaluate the imagery and develop qualitative conclusions solely based on thermal patterns and knowledge of construction methods and materials in the assembly. This technique is inefficient as it is quite time consuming; in addition, this process is increasingly augmented when examining high-rise building envelopes as they require a considerably larger number of images.

This paper presents a comprehensive review of existing state of the art building envelope assessments methods, specifically with the use of thermography, Machine Learning and UAVs. This paper aims to address the review techniques of thermographic imagery and present a reference for the development of AI based analysis. A critical analysis of existing thermography techniques is not performed as it was deemed by the authors to be beyond the scope of relevant work addressed in this paper. Relative papers, published in the last 15 years (2006 – 2021), were selected based on a search criterion with the following keywords used: Thermography, Infrared Imaging, Drones, Unmanned Aerial Vehicles, Machine Learning, Artificial Intelligence, fault detection, building. The research neither means to be exhaustive or definitive, but simply aims to identify knowledge gaps and point out directions for future research and development in the energy audit, thermographic field coupled with AI.

2. Overview

2.1. Infrared Thermography

Infrared thermography has been used as a means of building energy auditing since the early 2000s, when portable IR cameras became affordable and available [6]. The nondestructive testing method functions by producing a sequence of two-dimensional, temperature distributed, images. The IR camera uses detector cooling digitization and video processing electronics to capture the radiation emitted by objects at temperatures above absolute zero which are then converted to digital images that can be viewed by the human eye. IR covers a portion of the electromagnetic spectrum from approximately 900 to 14,000 nanometers (0.9–14 μm). An IR detector cooling digitization device is a focal plane array (FPA) of micrometer size pixels made of various materials sensitive to IR wavelengths whose resolutions can range from 160 × 120 pixels up to 1024 × 1024 pixels [7]. The FPA detects photons and generates an electrical charge or voltage in relation to the number of photons detected at each pixel which is then measured, digitized, and used to construct a temperature image. These images are displayed through a colour palette where each pixel is a determined temperature, ranging from 0 to 255. The competitive market for IR cameras has caused radiometric IR images to not have standardized file formats, but rather proprietary and secured formats that vary from company to company. In addition to the many file formats that exist, each camera company provides a proprietary software for image analysis that only supports their own image formats. This competitive market strategy has caused the IR thermographic industry to "lock-in" its users and has limited the possibilities in cross-platform solutions and analysis.

Over the past two decades, IR thermography has evolved into a common building energy auditing tactic, both qualitative and quantitative. The qualitative testing approach identifies anomalies in the building envelope without defining temperature values and without translating to energy loss metrics. Qualitative IR assessments include:

5. Thermal characterization of walls, glazing and windows,
6. Thermal bridging and excessive heat loss areas detection,
7. Thermal insulation examination,
8. Air leakage inspection,
9. Moisture and water detection,
10. HVAC and electrical systems characterization,
11. Indoor temperature measurements, and
12. Human comfort assessment [6].

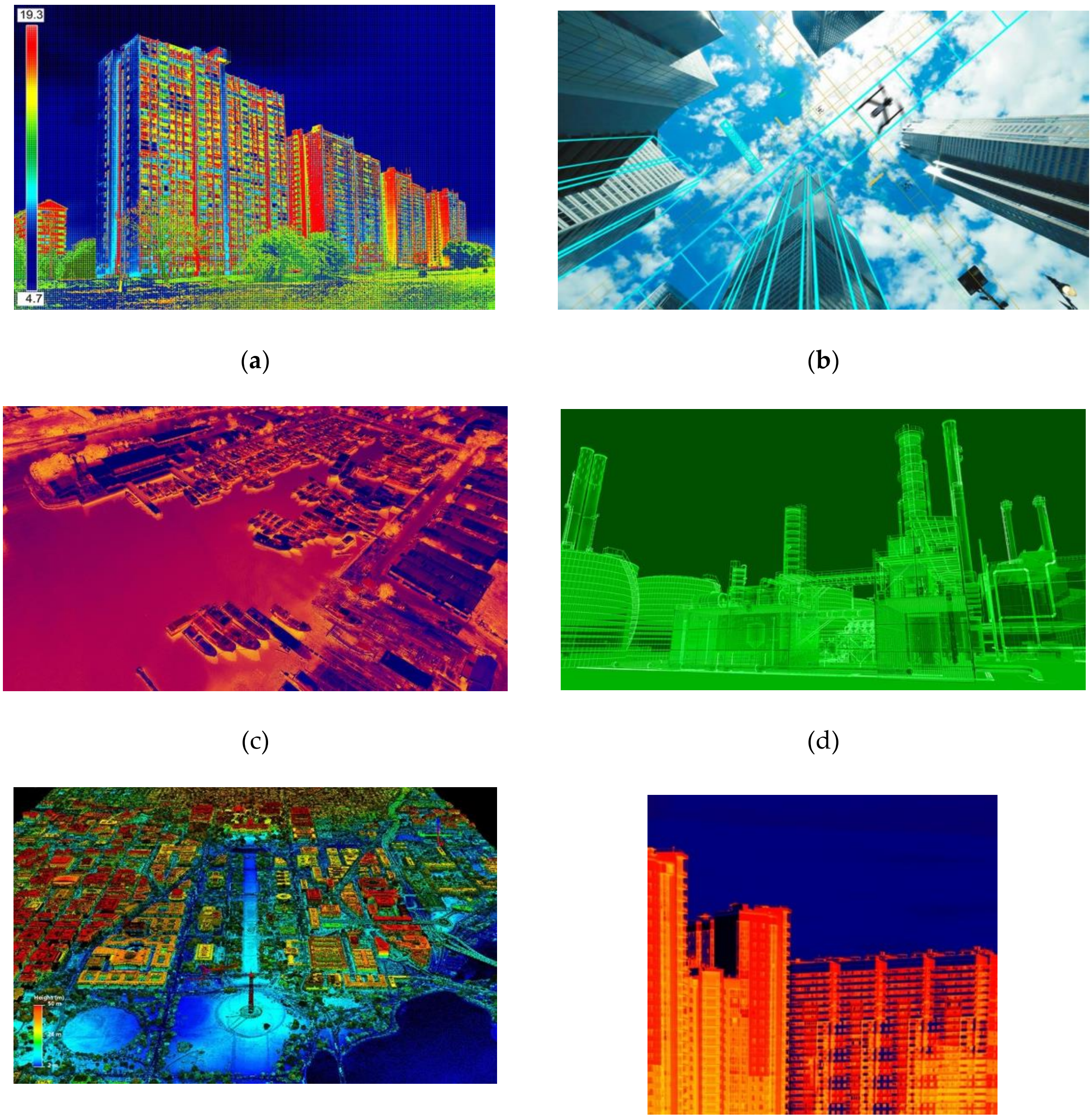
Quantitative analysis on the other hand, is used to quantify the thermal performance of a building envelope by presenting thermal transmittance values (U-values) based on the known interior and exterior temperatures. Quantitative building auditing methods include:

1. Determination of the percentage of areas with thermal anomalies,
2. Insulation levels detection,
3. U-value measurements,
4. Dynamic characterization of walls, and
5. Moisture content determination [6].

On top of the two aforementioned measurement methods, there are the following analysis schemes that need to be considered as well: passive and active analysis schemes are commonly used for building thermography. Passive analysis methods measure the temperature difference of a building occurring under normal in-situ conditions while active thermography requires exerting an external source of heat on a wall element to induce an effect within a material that will emphasize any defects within the system [5][6][8]. Active analysis methods that incorporate thermal stimulation are typically used in laboratory testing, historic buildings or product characterization. The use of active analysis has not been found for any energy assessment applications and the passive approach has been determined to be the most common for in situ defect detection.

2.2. Unmanned Aerial Vehicle Thermography

The use of UAV's, or simply, drones, have pushed the limits and boundaries of data capturing in the building fault detection field. The technological advancements in UAV systems and thermal image capturing have driven the IR building fault detection industry. The majority of commercial photogrammetry and remote sensing (PaRS) is performed with of-the-shelf micro-UAV and of-the-shelf cameras. Supported software for flight planning, flight navigation, guidance and control, and data post-processing exists [9]. A high level of automation has been developed to assist the building auditing market, who's workforce is generally less accustomed with traditional airborne systems. A drone's flight path will determine the image capturability through its distance from the test surface, bearing angle and altitude. These aspects are important to consider when developing a flight trajectory for the UAV system. Any adjacent buildings to the site under assessment may also hinder the image capturing process. Image processing is an important part of the drone analysis technique in order to create a comprehensive and complete image. Altitude, quality, timing, spectrum, and overlap are five conditions that will affect the post processing procedure. Segmentation or photogrammetry is performed using either direct geo-referencing, ground control points, manual tie-in points or a combination thereof. The segmentation process can be affected based on-site elements and conditions. 3D model generation is a post image processing tool that develops models for groups of buildings (geoclusters) or a single building. There are different software that exist for 3D model development which vary in workflow, model production time and quality of output [10]. Current 3D modeling using building images is typically performed using LiDAR and RGB formats where IR images are overlaid onto the model. This method performs better as the spatial resolution tends to be superior than IR images [10].



(a) (b) (c) (d) (e) (f)

Figure 1. Various uses of IR with UAVs (**a**) Infrared image showing lack of thermal insulation on residential building [11]; (**b**) Drone Flight Technology city [12]; (**c**) Seaports are seen using thermography technology with aerial drone cameras [13]; (**d**) Monochrome infrared drone 3D factory building scan for security purposes /intruder detection during night time [14]; (**e**) LiDAR and 3D point cloud of Washington DC [15]; (**f**) Thermal scanning of new multi-story buildings [16].

During the image capturing process, there are many elements that must be considered to avoid complications in the post processing stages. Reflections and shadows from buildings and other disturbances may influence the accuracy of the IR images. The stability of the camera being used for image capturing will have an impact on the clarity and composition of the IR images. The impacts of wind on the UAVs, more so at higher altitudes, will cause disturbances and may affect the stability during the image capturing process. Any precipitation at the time of assessment may also influence the drone, camera, and subject quality.

3.3. Artificial Intelligence Overview

In recent years, and especially with the technological development and price reduction in sensors and data acquisition systems, there has been a tremendous leap in all sorts of measurement activities within the built environment: copious amounts of data are collected daily in the building sector through sub-meters and smart sensors [17]. This data can be used to detect anomalies and their causes, for improvements and reductions in energy usage. Depending on the type of collected data, as well as the intended objectives, there are various approaches and methodologies that could be employed. The most common approach applicable in the built environment includes a group of algorithms known as Machine Learning, where data is analyzed through the construction of automated analytical models. It is a branch of AI based on the idea that systems, with minimal human intervention, are able to learn from given data, establish patterns and make decisions.

More specifically, the types of ML algorithms used for anomaly detection in the building sector can be subdivided as supervised learning, and unsupervised learning. on top of the two main subdivisions of ml there are also ensemble methods, hybrid learning, feature extraction and several other techniques that are used, see Figure 2. Applications for these algorithms cover abnormal consumption behaviors, faulty appliances, occupancy information, non-technical losses, and at-home elderly monitoring [17].

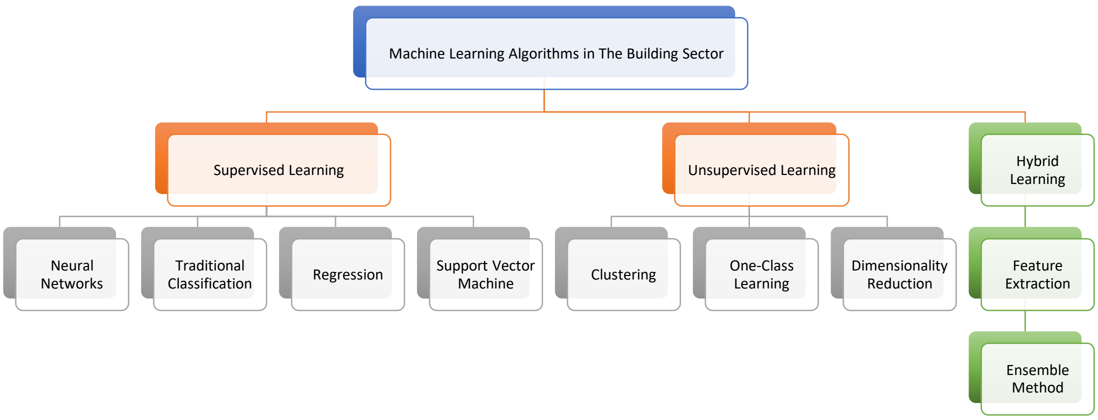


Figure 2. This is a figure that presents machine learning algorithms in the building sector.

Unsupervised Learning is a machine learning model which uses unlabeled data and through clustering and other grouping methods, finds patterns and underlying features to predict consumption observations. Several techniques of Unsupervised Learning include:

- Clustering:
  - Clustering algorithms group a set of objects in such a way that objects in the same group are more similar to each other than to those in other groups. Data in each cluster has similar statistical characteristics. In general, the statistical characteristics of faulty data are different from that of normal data and provide a means for detecting errors [18] [19] .
- One-Class Learning:
  - One-class Learning, also known as unary classification or class-modelling, attempts to identify data points of a specific class amongst all data points, by primarily learning from a training set containing only the objects of that class. The task of fault detection is to detect whether the monitoring data

belong to the normal class. Similarly, the task of fault diagnosis is to find which fault class the data belongs to [11] [20].

- Dimensionality Reduction
  - Dimensionality reduction is the process of reducing the number of random variables under consideration, by obtaining a set of principal variables. It can be divided into feature selection and feature extraction. Feature selection is used to subset the original set of variables in order to get smaller subsets which can be used to model problems. Feature extraction is used to reduce the data in a high dimensional space to a lower dimension space [21].

Supervised Learning is a machine learning model which functions as a Blackbox method and requires no information on building systems. Given a large sum of annotated data points, relationships can be learnt between input and output, features and targets respectively. Several techniques of Supervised Learning include:

- Artificial Neural Networks (ANNs):
  - ANNs are an approach that attempts to mimic the capability of the human brain neurons to process and handle large amounts of data so as to perform specific complex tasks. Each ANN consists of multi-layers (minimum two layers) of neurons and activation functions that form the connections between neurons [22].
- Traditional classification
  - In machine learning, traditional classification refers to a predictive modeling problem where a class label is predicted for a given example of input data [23].
- Regression
  - Regression analysis is a tool for building statistical models that characterize relationships among a dependent variable and one or more independent variables, all of which are numerical (continuous). The machine learning method allows for the predicting of a continuous outcome variable [24].
- Support Vector Machine
  - SVM is a supervised machine learning algorithm used for classification that plots data in a n-dimensional space. The SVM method aims to determine a separating hyperplane that distinguishes positive examples from negative examples. Given a set of labeled training data, it generates input-output mapping functions which are used for classification [25].

Ensemble Methods are techniques that create multiple models which are then combined to produce improved results. Boosting, Bagging and Stacking are types of meta-algorithms used mainly for regression and classification by reducing bias and variance to boost the accuracy. Feature extraction is a machine learning method which selects and /or combines variables into features, effectively reducing the amount of data that must be processed, while still accurately and completely describing the original data set. Several methods include distanced-based, density-based, graph-based and time-series analysis. Hybrid Learning techniques have also been used in the building sector as well some other methods including compressive sensing and visualization.

A recent study from Switzerland describes a machine learning-based surrogate model to approximate optimal building retrofit solutions; however, no application for infrared thermal imaging review was noted [26]. In 2019, researchers from China [17] published a comprehensive review of 195 research papers published between 2004-2019 on the implementation of AI in the fault detection and diagnostics of building systems, all focusing on mechanical, electrical and control systems in buildings. However, to the best of the author’s knowledge, no publications have been found where ML algorithms are used for building envelopes’ IR images analysis yet. Nevertheless, the valuable lessons can be learned from that study and similar approaches with detecting and examining building envelope deficiencies could be investigated.

While the building sector has just recently begun to implement ML into the auditing field, other disciplines have much further advanced with the use of these analysis tools. The field of medicine for example, has been using IRT and ML applications for Breast cancer detection, Diabetic foot disease, Skin cancer, Carpal Tunnel Syndrome, Dry eye disease, Back pain, to name only some [27]. The survey discovered that the majority of the biomedical applications on IRT with ML are by far in diagnostics of breast cancer (21 studies) in contrast to the very next item on the list, the Diabetic Foot disease (6); although this diagnostic method is still not widely recommended. The main ML algorithms used for these applications include:

- Artificial Neural Networks (ANNs):
  - As previously described above.
- k-Nearest Neighbour (KNN):
  - KNN is a supervised, traditional classification, machine learning technique which has no explicit training phase. KNN's purpose is to use a database in which the data points are separated into several classes to predict the classification of a new sample point. KNN algorithm is based on feature similarity. How closely out-of-sample features resemble the training set, determines how closely a given datapoint is classified.
- Support Vector Machine (SVM):
  - As previously described above.

Other ML algorithms used in the medical field include: the Naïve Bayes (NB), Fuzzy methods, Decision Trees (DT), Random Forest (RF) and AdaBoost [27]

Although the reported accuracy in the majority of these studies appear to be relatively high (e.g. >80 %), the sample sizes in many of the covered studies are quite small, ranging from a several dozen to 100 or so cases. This could potentially indicate that even in biomedical discipline, the field is still in its infancy. Moreover, the same study lists as a barrier that there is a lack of knowledge from the health professionals with regards to the principles and imaging techniques, which is a parallel that can be drawn with the case of building industry.

Another significant barrier also noted was the lack of a standard imaging file format which limits the potential for the data exchange and integration as well as the development of advancements in computer aided diagnosis tools, which is another similarity with the application of IRT in the building industry. A comparison of the ML classifiers performance in the biomedical applications is outside of the scope of this survey, however it is evident that there is much to learn from the biomedical field that can be translated into the building auditing sector and a clear analogy with application in the building industry can be drawn. Further investigation is required.

3. Gaps and Potentials for Future Work

Infrared thermal imaging as a means of building envelope assessment has grown over the years. With the advancements of technology and the accessibility of IR cameras, the use of the assessment tool has grown substantially. UAVs have also become a more common practice for the collection of thermal images. Research continues to explore the best methods for the collection of the thermal images. ML as a data analysis method has been growing over the years in several different disciplines. The building energy and construction sector has just recently begun to explore and incorporate ML techniques; and as of now, it is predominantly focused on building mechanical, electrical and automation systems, while addressing the coupling of Machine Learning methods and thermographic scanning of building envelopes is almost non-existent. However, the knowledge from application in the area of building systems fault detection and diagnostics, as well as from biomedical science could be translated into the existing best practices of thermography data collection for building assessments.

Separating the fault detection and fault diagnostic would be the first step (Figure 3); the methods on how to go about each of these main categories would also be different. In fault detection, a data-driven method based on a large number of IR images can be used to train AI systems to detect anomalies in thermal images. Deficiencies within the IR images or outlier u-values can potentially be identified using AI frameworks. This approach would still require a certain level of knowledge and expertise to help define the "training" framework but can be automated in a relatively straightforward manner.

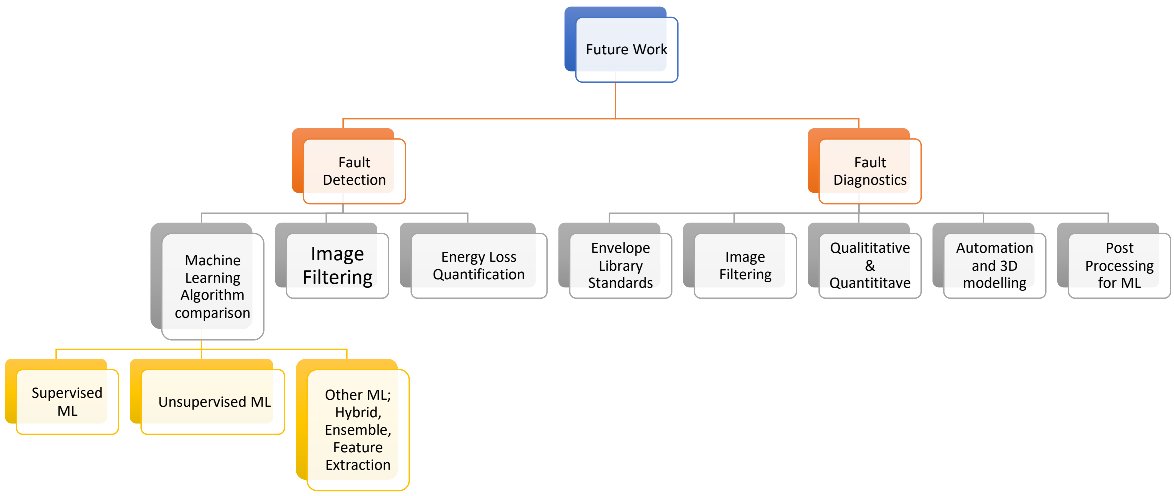


Figure 3. Possibilities for future work: building envelope fault detection can require data-driven algorithms, while fault diagnostics would require knowledge-based approach.

On the other hand, the knowledge-based approach would be more pronounced in diagnostics, where the required information would not be limited to the pixels and information that they carry within the image. In addition to detecting the faults and their symptoms, the correct diagnostics requires a deeper understanding of the broader context, the inter-relation between various building components/assemblies, physical and chemical processes that may occur and other elements. Additional background information would need to be prepared and fed into the diagnostic tool: information such as year of construction, types of envelope systems, wall/roof assemblies, thicknesses of individual layers, material properties, to name only some. For all these reasons, knowledge and experience from a building science expert(s) is essential. The knowledge-based approach combines a qualitative and quantitative assessment which is, consequently, more difficult to automate, but not necessarily impossible. For example, although there are so many variables that must be considered, building envelopes in general can be categorized into similar typologies. Curtain wall systems, or window wall systems are typically used as facades in high-rise buildings and have many commonalities even though they are proprietary products of facade manufacturers. Many other types of envelopes are developing as prefabricated or partially prefabricated assemblies, which additionally streamlines the process. Therefore, creating databases of information that could be fed into these knowledge-based approaches would be a starting point in this endeavour, followed by the systematic mapping of potential fault symptoms. Moreover, keeping in mind that the same symptoms could point out various faults or that same faults could manifest into different symptoms, a systematic organization of possible combinations would also be needed. Finally, codes and standards also help define typical construction typologies which can aid in the characterization of envelopes.

Additional barriers that will need to be bridged include the knowledge gap between building science experts and professionals in machine learning development. 3D modeling using Infrared imaging is limited with LiDAR and RGB being the most common image types for development, however, there is no research available for ML coupled with IR 3D models. Proprietary IR imaging formats and software tools are another limitation in exploration of the possibilities of data analysis and incorporation of ML into building envelope assessments.

All of this indicates that there is a substantial amount of work required in this field. Thermography and UAV systems have been under development for some time now, however, the combination of the two with ML is lacking. Comparison of existing ML algorithms for analysis of infrared images should be investigated and the possibilities with supervised and unsupervised learning algorithms should be explored. Development of a ML based framework and tools for identification of faults in thermographic building envelope analysis, both qualitative and quantitative, is possible. It has the potential to filter the large number of images that are taken for each site assessment in order to reduce the time spent by building science experts. Incorporation of automated UAV IR image capturing for ideal image composition with respect to ML analysis can be researched. Exploring the possibilities of 3D modelling applications with automated image capturing and ML is required. The Development of a framework for the combination of a knowledge based and quantitative based analysis could diminish research gaps. Incorporation of a standardized method for applying background information to simplify and target the ML analysis process is possible. Development of a library for classification of building envelope elements to reduce the variables and simplify the ML detection model should be explored. Figure 3 presents a breakdown of the possibilities of future research work in this cutting-edge field.

Supplementary Materials: No supplementary materials have been our study.

Author Contributions: Conceptualization, DG and UB and MH; methodology, DG; formal analysis, DG; investigation, DG resources, DG data curation, DG; writing—original draft preparation, DG; writing—review and editing, DG. and UB. and MH; project administration, UB. and MH; funding acquisition, UB. and MH.

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Assessment of Atmospheric Water Generation System for Photovoltaic Module Cleaning

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Abstract: The most effective PV cleaning methods involve water-based surface cleaning that incurs tremendous overheads in terms of water supply infrastructure and water use cost. The current article discloses an alternative approach of PV cleaning through an onsite atmospheric water generation (AWG) system by utilizing PV power most efficiently. The AWG design ensured to consume lesser energy to clean than the loss of power due to dusting to justify the effectiveness of the proposed system within the cleaning dusting interval. The proposed AWG system produced 440 ml of water-consuming 0.936 kWh energy in 3 nights with an average relative humidity of 66 % and an ambient temperature of 13 °C. A simple correlation developed to predict the energy produced by the panel during the daytime, the amount of water needed to clean the 300 W panel, and the energy consumed by the AWG system to produce the required amount of water. Employing Al Ain weather data, a 300 W panel produces 2.1 KWh in a day, which can generate 1 liter of water per night through the Peltier system consuming the same amount of energy that is reported enough to clean a PV with the efficient sprinkling system.

Keywords: Efficiency; Water Sprinkling; Atmospheric Water; Peltier Cooler; PV Cleaning

1. Introduction

Most of the utility-scale PV power plants are installed in the desert to avail low-value lands as well as assure no PV shading from surrounding to achieve economic feasibility. The desert environments, however, on one hand, renders increased dusting and on the other lacks the infrastructure to keep the panels cleaned that eventually increases PV cleaning costs tremendously. In Saudi Arabia, a 100 MW solar power plant has a strong seasonal pattern of soil accumulation rate. The losses vary from ~2 % to ~16 % in the least duties month to dustiest months with the cleaning cost of 0.72 SAR/kW and 0.12 SAR/kW respectively for the machinery and manual cleaning [1].

The traditional cleaning methods include nano-film based self-cleaning [2], electrostatic precipitator cleaning [3], and mechanical cleaning involving air or water flow [4].

Nano-film based self-cleaning exploits hierarchical nanostructures created on the surface of the glass by combining large honeycomb nano-walls with ultrathin nanorods. The dimensions of these structures are specifically selected to maximize the overall light absorption efficiency. The nanorods serve to reduce the surface reflectance and facilitate light penetration into the cell while the honeycomb structures enhance photon absorption by acting as effective scattering centers. Furthermore, due to its extreme hydrophobicity, the nanostructured packaging glass efficiently repels dust particles, preventing drops in efficiency over time [5]. The nano-film based methods have limitations to remove dust and cannot effectively clean in humid climates where the dust sticks firmly to the surface.

The mechanical methods are more widely used and applicable in a variety of climates due to the reliability of dust removal force, rapid operation, and enhanced performance independent of the environment. The automatic cleaning using wipers consists of a water pot to spray the water at a PV surface and a rubber wiper to clean that surface. This system operates automatically and needs a power supply to perform functions [6]. However, the mechanical cleaning systems suffer from a lack of water supply infrastructure to keep the plant cleaned ending up with massive investments in procuring and operating the cleaning equipment [7, 8].

The ongoing scarcity of water around the world and the recent drought in different regions have led to a surge of new research on water technology. Different methods have been used to produce the water from the atmosphere [9, 10] such as the artisanal method of fog harvesting [11], air condensation by cooling down the air below dew point [12], pressurizing the air or exposing it to the desiccants [13]. Among these methods, most of them required regular power sources to run the AWG system.

The idea of atmospheric water generation has been attempted in recent years, to address the needs of water. A self- contained water generation system contains a wind turbine, a compressor, and an evaporator connected to the compressor that receives pumped refrigerant and allows the pumped refrigerant to evaporate resulting in condensation of water on the exterior of the evaporator; and a collector that collects the water [14]. Although being stand-alone, the water generation system still relies on expensive components. Some other atmospheric water generation methods are under practice like water harvesting from fog and dew. The dew water is harvesting is being carried out using a solar-regenerated desiccant system, radiative cooling surface, and active condensation technology [15]. Hydrogel-based atmospheric water harvesting techniques used by researchers in Saudi Arabia. It comprises carbon nanotube, as a substrate polyacrylamide (hydrogel), and as a water sorbent calcium chloride was used. Because of its high water affinity, the hygroscopic salt in hydrogel helps the atmospheric water harvester to absorb significant quantities of water vapor from the air. The hydrogel provides the composite with a gel-like solid shape that retains salt and its sorbed water at night and allows for a daytime controlled evaporation [16]. In another research, a solar-powered heat exchange system is preferably used to drive a water collection device, which condenses vapor in atmospheric air to water. The device comprises of parabolic solar collector, fans, the heat exchanger comprises of a generator, a condenser coil, an evaporator, a solar collector controlling and tracking mechanism for solar collectors and means for collecting the water [17]. This invention involves bulkier, more energy-intensive, and expensive components like a solar collector and a tracking system. Another atmospheric water generator involves condensing coil, a storage tank, a fan, and a Coanda baffle in airflow communication between the first outer surface portion and the condenser coil [18]. In this invention, high power consumption devices like compressors, condensers, and fans used to generate the water and used the grid supply to run this system which makes it difficult to install in remote areas.

The prior research lacks a device tailored to specifically clean PV arrays besides meeting crucial criteria including but not limited to less power consumption, fewer space requirements, less cost, and more in line with natural phenomena for efficient use of resources. The proposed research prioritizes the natural phenomena over, power phenomena and on top of that relies on power that otherwise would only be discarded from the PV plants due to power quality and grid compatibility issues. Thus the research possesses several inventive steps sought after in the atmospheric water generation concept in conjunction with cleaning the large scale PV plants. The core difference between the mechanical cleaning system and the proposed AWG system is in the way of getting water for cleaning. It can solve water transportation problems for PV cleaning in water droughted areas by generating water at site consuming low power. Moreover, the proposed water generation system is low cost around 40 $ compared to the higher cost condenser and compressor-based water generation system because the system does not rely on more energy-intensive and expensive components.

2. Description of Experimental Methodology and Setup

The weather data to establish ambient conditions (ambient temperature, dewpoint temperature, rainfall, wind speed, and humidity) have been measured by using the onsite ʼʼ Davis Vantage Pro2ʼʼ weather station. Data acquisition system (DAQ) used to measure voltage, current, temperature, power interfaced with LabView. The radiations are measured in the form of voltages by using the pyranometers that later converted to radiation values through a calibrated equation in the DAQ measurement hardware using programmable software.

A prototype test set up was fabricated to produce water embodying the concept of dew point, adiabatic expansion, pressure changes in a confined cavity, condensation over a radiative surface, and electrically powered Peltier cooling effect. The fabricated system was mounted on the PV panel and tested in hot dry and hot humid weather conditions of Al Ain city in UAE to determine the amount of atmospheric water produced and its effectiveness for the PV dust cleaning system. The system is modified to make it fully automative and efficient power-wise by its design, the way it is programmed, the fabrication and insertion of intelligence in it. All the used devices and their measurement uncertainties are listed in table 1

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Parameter	Device	Model	Range	Accuracy
Solar radiation	Apogee Pyranometer [19]	SP – 110	-	±1%
Data acquisition	NI-Compact DAQ [20]	9178	-	±0.02%
Current	NI-Analogue module [21]	9227	5Arms - 20 A	±0.01%
Voltage	NI-Analogue module [22]	9221	-60 V - 60 V	±0.25%
Ambient temperature	Davis vintage pro2 weather station [23]	6152	-40°C - 65°C	±0.5°C
Wind speed	Davis vintage pro2 weather station [23]	6152	1 - 67 ms^{-1}	±0.5°C

3. Experimental setup

The experiment has been carried out at the ''Renewable Energy Laboratory'' Falaj Hazza Campus, United Arab Emirates University, Al Ain, United Arab Emirates. The site is situated at latitude and Longitude of 24.9° N - 55.5° E, respectively. All the sensors and the power output cables from the PV modules were connected to a NI-Compact DAQ through current and voltage modules to log the data.

The apparatus for the device for PV cleaning system mainly comprises of a Peltier module, customized heat sinks to draw out the heat from one side of the Peltier, fans to draw out the cooled air from the cooler side of the Peltier, voltage sensor, current sensor, temperature sensor, humidity sensor, dewpoint temperature sensor, and a controller. The device is lightweight and easy to integrate at the PV module.

Figure 2 illustrates the atmospheric water generation device. It comprises of an air duct, with two heads to in/out the air. A variable DC fan installed at one head aims at drawing the air from the ambient surrounding into the duct. In the duct, there are four Peltier coolers installed. The hotter sides of the Peltier cooler is connected with the heatsink, with three heat pipes, using a sandwich layer of thermal grease, while the cooler side of the Peltier is connected with the targeted cooled metallic sheet. As the Peltier gets cooled, the targeted metallic plate attached to the cooler side is also cooled. The air passing through the metallic targeted plate undergoes temperature drop to the point of condensation and below, thus it generates water to be stored in a tank to be used for the PV panel cleaning at a later stage. The cooled air passes through heat sinks using an air duct to draw out the heat from the heat sink.

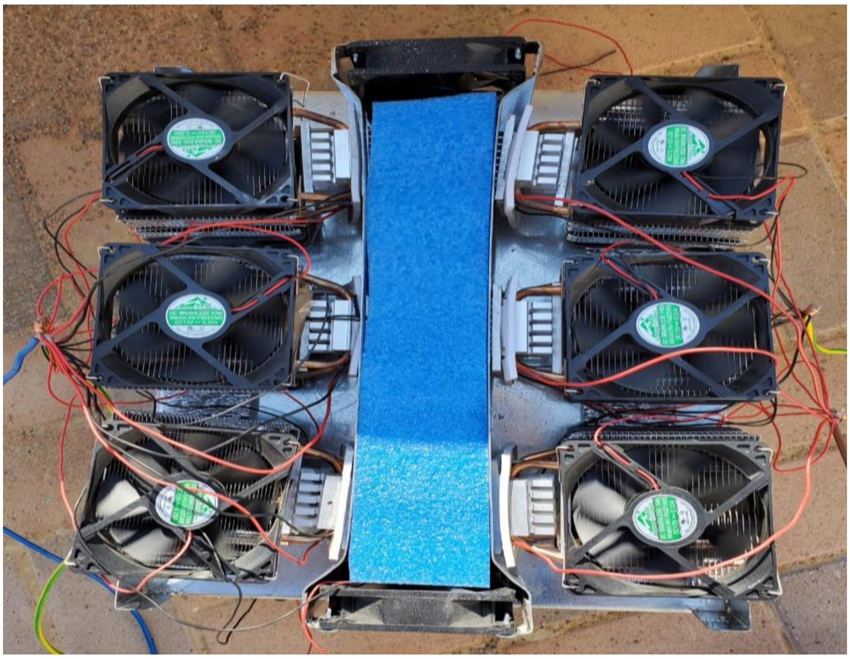

Figure 1. Atmospheric water generation (AWG) actual setup system

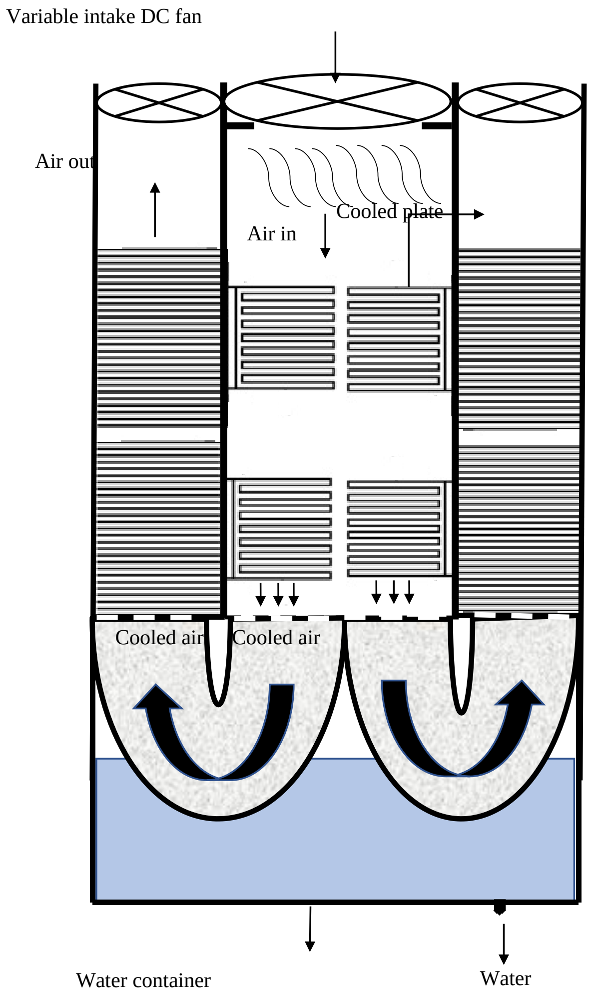

Figure 2. Atmospheric water generation (AWG) system

In figure 3, the device is mounted at a PV array, that will sprinkle water on the array when needed and the wiper will clean out the surface of the array simultaneously.

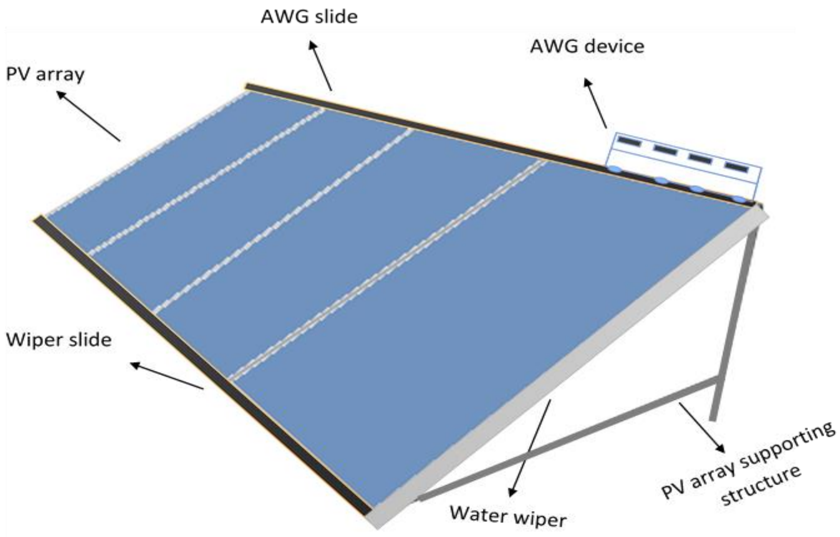

Figure 3: PV array with the AWG system and cleaning mechanism

4. Experimental results and discussion

The experimental assessment of the proposed AWG was conducted for three typical days of device operation in April. The results are described below with figures in detail. The below figures represent the trends of ambient temperature, wind speed, humidity, and dew point temperature for the three different days (day & night) of the AWG experimentation. Atmospheric dew point depends upon the air pressure and humidity level and varies accordingly. The dew point is the temperature that is enough to saturate water vapors in the air. The airborne vapors condense into a liquid when further cooled down [24]. When the air temperature reaches up to its dew point and then strike at the surface that has a lower temperature than air, the water will adhere at that surface. The ambient temperature and the number of water vapors in the air determine the dew point temperature [25]. The objective is to achieve the saturation temperature to condense vapors into the water using some passive and active devices. Since the relative humidity keeps changing in time and space, setup is required to assure the condensation at all conditions [26]. The hot and humid climate is very appropriate for water extraction from the air. At this stage, the air has a significant amount of vapors content that can be condensed into water by using atmospheric water generation (AWG) setup [27]. With the increase of air temperature, the water vapors carrying capacity of the air also increases, which means the same volume of air can hold more vapors, thus decreasing the chance for water production at elevated temperatures. Thus an AWG system has to adopt all means to reach the right temperature that could assure condensation to produce water.

As shown in figure 3 on the 1st day of the experiment the average humidity remained predominantly below 35 % during the day time (7:00 AM to 8:00 PM) and remained predominantly above 70 % during the night time from 8:30 PM to 7:30 AM. During the late afternoon and at night time, as the ambient temperature started decreasing, the relative humidity started increasing. The most ideal time to run the atmospheric water generation system or the time when the maximum amount of water can be generated is when the ambient air temperature is close to the dew point temperature (less than 10 °C) at a higher relative humidity being around 11 PM to 2:00 AM.

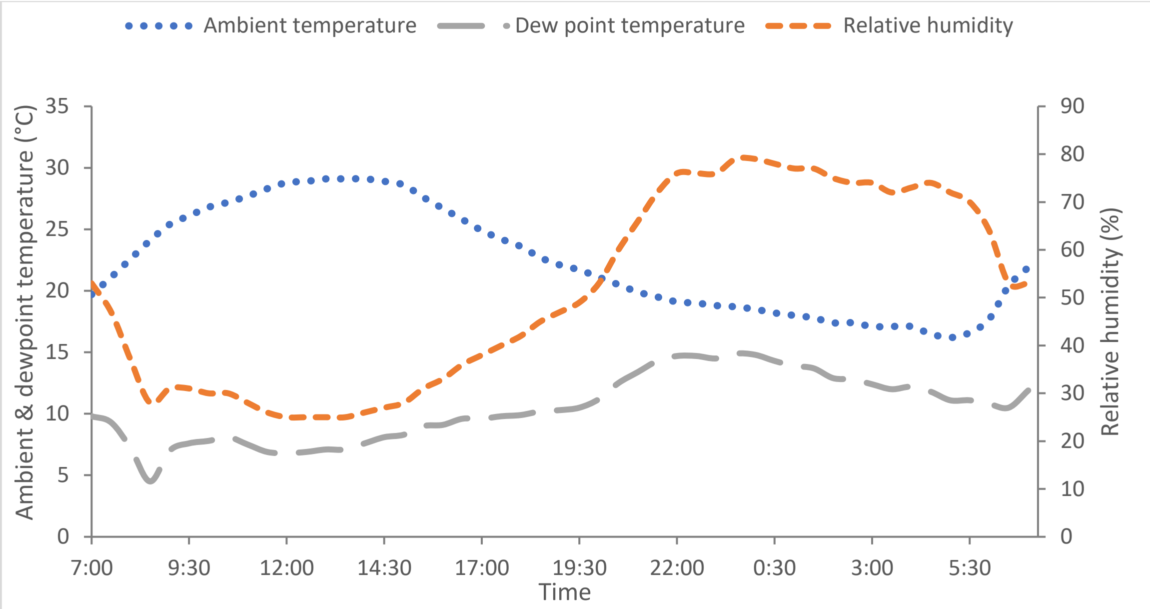

Figure 3: The measured relative Humidity, ambient air temperature and dewpoint for the 1st day of experiment at the site in Falaj Hazza Campus, UAE University, Al Ain, UAE.

For the 2nd day of the experiment, the relative humidity remained above 70 % from10:30 PM to 1:30 AM. The more suitable time to run the AWG system to generate maximum water with low energy consumption was around 11:00 PM to 1:00 AM when the humidity was above 70 % and the difference between ambient temperature and dewpoint was around 5 °C.

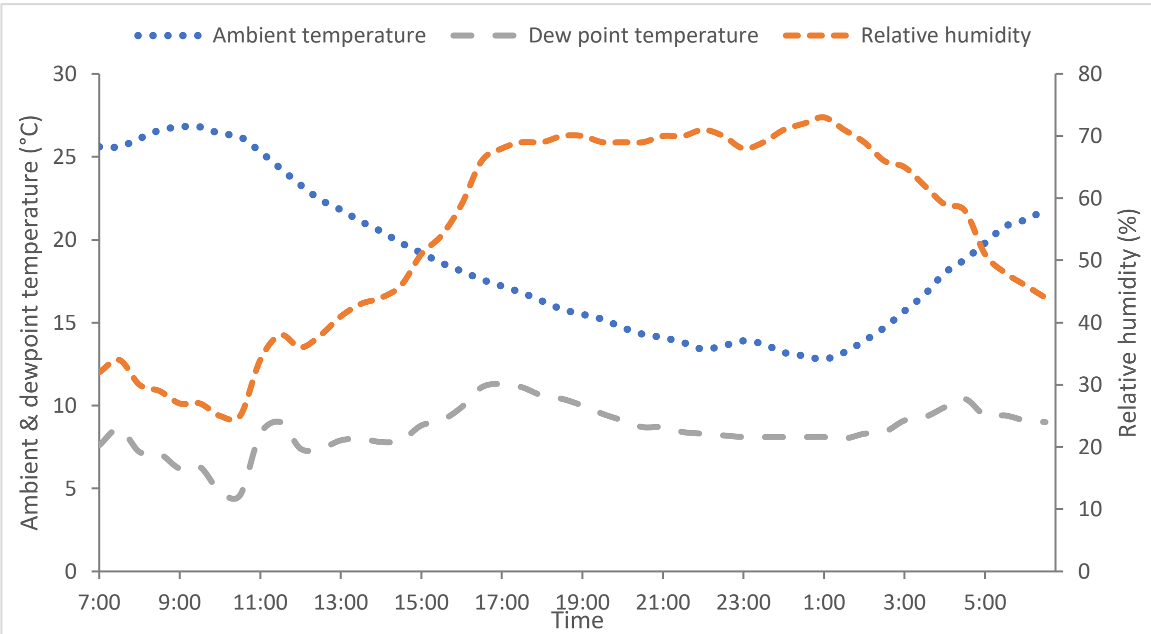

Figure 4: The measured humidity, ambient temperature, and dewpoint for the 2nd day of the experiment at the site in Falaj Hazza Campus, UAE University, Al Ain, UAE.

Almost the same trend was observed for the 3rd day as the relative humidity remained above 70 % from 7:30 PM to 2:30 AM. The difference between the dew point temperature and the ambient air temperature was reduced significantly from 10:30 PM to 1:30 AM, and that 3 hours are the more suitable to run the AWG system to generate maximum water by consuming less power, as shown in figure 5.

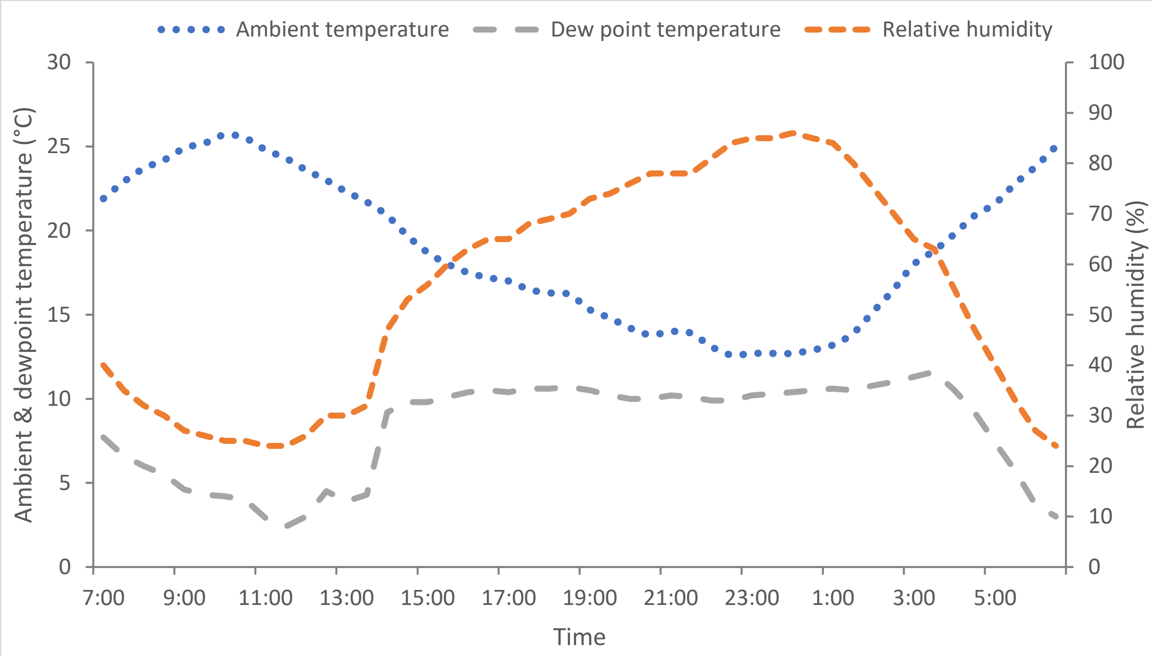

Figure 5: The measured Humidity, Temperature, Dewpoint data for the 3rd day of an experiment at the site in Falaj Hazza Campus, UAE University, Al Ain, UAE.

4.1 Water generation through the AWG system

The AWG system was run for 3 particular nights based on weather data in specific days to check the amount of atmospheric water generation. Usually, for this time interval, the humidity remained above 70% for the days of the experiment. A graph of water produced is plotted against the average and peak humidity of the air as shown in Figure 6. The average and peak relative humidity for that particular interval of time was above 70%.

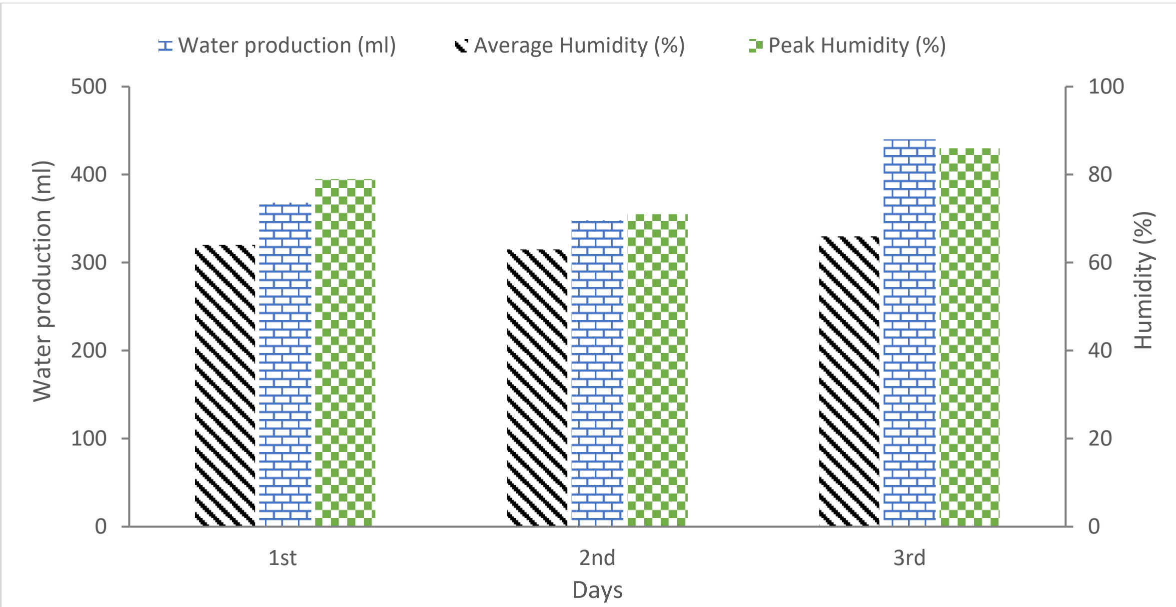

Figure 6: The produced water with respect to the average and peak humidity for the 1st, 2nd and 3rd day of the experiment at the site in Falaj Hazza Campus, UAE University, Al Ain, UAE.

The maximum water of 440 ml was produced on the 3rd day when the humidity reached up to 86 % for that particular day and remained above 70 % for almost 7 hours. The water production for the 1st and 2nd day was 368 ml and 348 ml respectively as shown in figure 7.

The rate of water production depends on the ambient temperature, humidity, the volume of air passing over the cooling plate, and the capacity of the device to cool the air. This reduces the air temperature, which in turn reduces the air's water vapor carrying capability. AWG system becomes more efficient with the rise in relative humidity and air temperature. For the 3rd day of the experiment, the ambient temperature increased as compared to the 1st day, but the more water generated on the 3rd day, because of the increase in humidity along with air temperature.

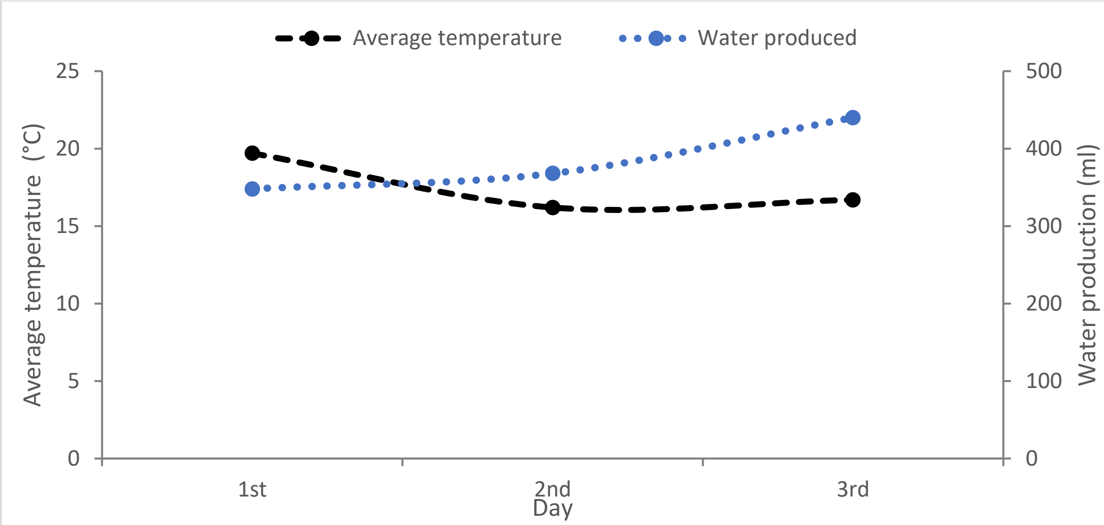

Figure 7: The produced water with respect to the ambient temperature for the 1st, 2nd and 3rd day of the experiment at the site in Falaj Hazza Campus, UAE University, Al Ain, UAE.

Novel water sprinkling techniques that are currently being used, consume approximately 1.6 liters of water to clean 2 m2 (300 W) PV module [34]. The consumed water amount can further be reduced to 1 liter by using the most efficient sprinkling techniques. A small scale AWG "device per panel" prototype with a power rating of 78 W was tested in Al Ain that produced 440 ml water-consuming 0.936 kWh energy per night. Since the conventional PV plants employ 300 watt PV panels, a simple correlation can be developed to predict the energy produced by the panel during the daytime, the amount of water needed to clean the 300 W panel, and the energy consumed by the AWG system to produce the required amount of water. Employing Al Ain weather data, a 300 W panel produces 2.1 KWh in a day, which can generate 1 liter of water per night through the Peltier system consuming the same amount of energy. By re-directing the energy produced by the same panel to the AWG system with extended capacity, approximately 15 liters of water can be generated in a night. In fact, It means after 30 days, thirty panels will be cleaned by using 1 Panel energy, which is slightly less than 3.5 % of the energy produced by the 30 panels during the 30 days. Extending this to a plant scale, a 1 MW of solar plant uses almost 4000 - 10000 liters of water (depend on the cleaning method) can be saved in 30 days by utilizing around 3.5 % of the energy produced by the panels which is half to the losses induced by a single cycle to get clean.

The power drop for one-month dusty modules is 7 % as compared to the reference cleaned PV module. This 7 % power drop in PV modules can be recovered by cleaning the PV panels using atmospheric water generated by utilizing around 3.5 % of the energy produced by the PV panels during the 30 days. According to the measured values of percentage drop in PV power output and energy consumed for water generation, the optimal time for cleaning the PV modules is 30 days. This AWG system not only decreases the power drop and improves the efficiency of the plant, but it also saves a substantial amount of water (which can be used for domestic or irrigation purposes).

A 300 watts Peltier based AWG system that produces enough water to clean 30 photovoltaic panels after 30 days costs about 50 dollars. If we extend this to a 1 MW plant scale, the total 111 AWG system will be installed to generate the amount of water required for cleaning the entire plant. Accordingly, the cost of the AWG system will be scaled up to 5550 dollars for a 1 MW photovoltaic power plant. If scaled-up the power plant more up to 100 MW, the cost of the AWG system will also be raised to 0.555 million dollars or maybe reduced substantially due to bulk installations.

4.2 Automation and future work

The automation part of the proposed research mainly involves two intelligent systems:

1. Intelligent system E1 to control the operation of the AWG system

AWG operation will be fully automated, controlled by an intelligent system E1, using a programmable Arduino platform coupled with the different electronic components e.g. sensors, switches, and relays. The switches and relays will be turned ON/OFF the AWG system according to pre-defined weather conditions e.g. humidity, ambient temperature, and dewpoint temperature. The humidity and temperature sensors values reaching the benchmark values where the air is most likely to condense thus turning ON the water generation system. The automation of the sprinkler and viper system will also be coupled with the Arduino environment which will turn ON/OFF the sprinkler and guide the viper for cleaning efficiently and effectively.

2. Intelligent system E2, for the power management of plant and AWG system

The second intelligent system E2 calculates the output based on input parameters and thus decides on whether to supply to the grid through the inverter, depending on the pre-set power quality conditions. When it discovers that the present condition to feed into the inverter, are not met, it redirects the power towards the Storage/AWG system in two different embodiments accordingly. Otherwise, the power is directed to the inverter, to convert the DC power to AC. The AC power is connected to the grid, depending on the limitations of power input the same as an inverter. If the supply voltage to the grid is less than the minimum required voltages to integrate with the grid then the E2 will divert the power from the inverter to Storage/AWG system through the charge controller, otherwise will let this be fed to the grid.

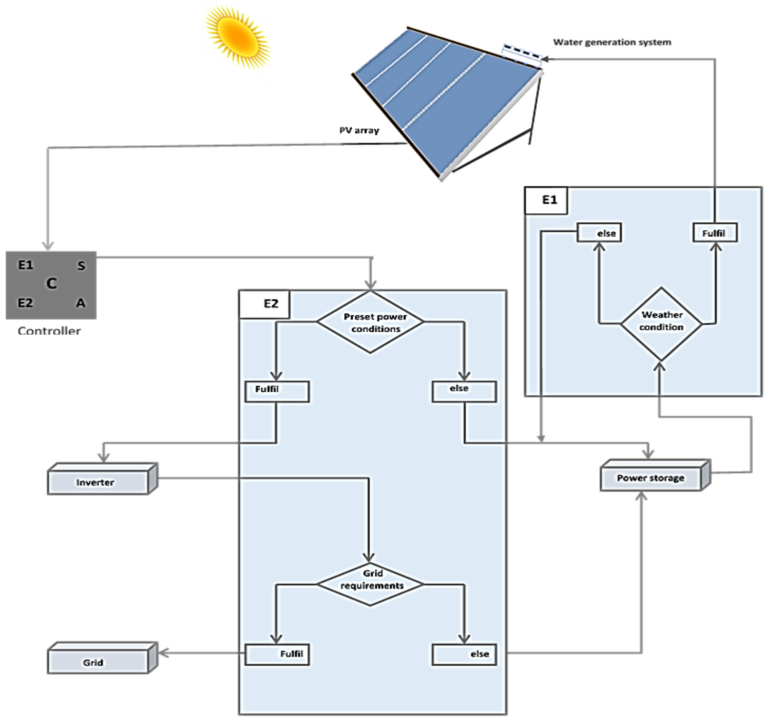

Figure 8: Atmospheric water generation system flow using controllers

The Inventive steps in the research which distinguished it from others are that it integrates a systematic and hierarchical passive and active design to generate water from the waste energy and does not involve additional energy inputs. The second inventive step involves including the Peltier cooling system which consumes substantially lower space and capital compared to the conventional compressor-based condensation systems. The contextual relevance of the device as another inventive step that entails producing atmospheric water in the harshest summer conditions of the desert environment which renders it more interesting with its airborne dusty environment to devise such an invention. The most important distinctive feature is the inclusion of intelligence, which provides benefits in terms of automatic operations, power savings, and power management.

Atmospheric water generation technology is growing rapidly to deal with the scarcity of water in remote areas but there are also certain challenges and limitations, which are observed during the experimentation. Such as, the AWG system becomes more efficient with the rise in relative humidity and air temperature, so, the instability of these factors was the main challenge during the research. The experiment was performed on the small scale, scaling up the system may also incur some sort of challenges in terms of control, connectivity and maintenance. The dusty weather in UAE also builds a challenge especially during the cleaning process when the PV panels are wet. This problem can be avoided by choosing a suitable time for cleaning.

5. Conclusions

A small scale AWG "device per panel" prototype with a power rating of 78 W was tested in Al Ain that produced 440 ml water-consuming 0.936 kWh energy per night. Since the conventional PV plants employ 300 watt PV panels, a simple correlation can be developed to predict the energy produced by the panel during the daytime, the amount of water needed to clean the 300 W panel, and the energy consumed by the AWG system to produce the required amount of water. Employing Al Ain weather data, a 300 W panel produces 2.1 KWh in a day, which can generate 1 liter of water per night through the Peltier system consuming the same amount of energy. By re-directing the energy produced by the same panel to the AWG system with extended capacity, approximately 15 liters of water can be generated in a night. In fact, It means after 30 days, thirty panels will be cleaned by using 1 Panel energy, which is slightly less than 3.5 % of the energy produced by the 30 panels during the 30 days. The inclusion of intelligence provides benefits in terms of automatic operations, power-savings, and power-management. The research can eliminate/relax requirements of water consumption, heavy equipment, manpower, and time required for cleaning large scale plants. Moreover, the proposed water generation system is low cost around 40 $ compared to the higher cost condenser and compressor-based water generation system because the system does not rely on more energy-intensive and expensive components.

Author Contributions: A.H.S.: Data curation, formal analysis, investigation, writing review and editing. A.H.: Conceptualization, methodology, and writing review and editing. M.S.L.: Supervision and writing review and editing. A.A.: Funding acquisition, project administration, aiding in results analyses and interpretation, and writing review and editing. All authors have read and agreed to the published version of the manuscript.

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Role of Building and Material Service Life in Life Cycle Embodied Energy Demand of Buildings

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Abstract: Energy use in the building sector is considered among major contributors of greenhouse gas emissions and related environmental impacts in Australia and worldwide. While striving to reduce the energy consumption from this sector, it is important to avoid burden shifting from one building life cycle stage to another; thus, this requires a good understanding of the energy consumption across the building life cycle. Both embodied and operational energy must be reduced to minimize the enormous energy footprint and associated environmental impacts of buildings. Previous studies have shown the significance of both the energy required for building operation as well as the energy embodied in initial construction of buildings. However, there is a lack of understanding about the significance of total energy embodied in replacement of materials over a building's life. This study aims to investigate the combined effect of building and material service life on life cycle embodied energy requirements of residential buildings. Life cycle embodied energy of a house in Melbourne for an assessment period of 150 years was calculated based on minimum, average and maximum material service life values for the building service life of 50, 100 and 150 years. A comprehensive hybrid embodied energy assessment approach was used for the initial and recurrent embodied energy calculation for each scenario. The combined effect of building and material service life variations was shown to result in a reduction in the life cycle embodied energy demand in the order of up to 61%. This shows the importance of building and material service life considerations in designing, constructing, and managing the buildings in efforts to reduce energy consumption by buildings.

Keywords: Life cycle embodied energy; initial embodied energy; recurrent embodied energy; building service life; material service life, maintenance

1. Introduction

Energy use is one of the largest contributors to environmental damage and global warming. Both globally and in Australia, the total energy consumption has increased significantly over last decade and is projected to increase further. Building construction and operation accounts for a significant amount of energy consumption and CO2 emission into the environment. Building-related energy consumption accounted for 36% of global energy use in 2017, which amounted to 40% of energy-related carbon dioxide (CO2) emissions [1]. A significant amount of this energy use is attributed to residential buildings. This problem is further exacerbated with the increasing global population, expected to reach 9.7 billion by 2050 [2]. As a result of this increase in population, the building sector is expected to add 230 billion m^2 of new floor area [1]. This situation requires all stakeholders in the building industry to incorporate strategies at all building life cycle stages to reduce the energy consumption associated with the building sector in order to reduce greenhouse gas emissions and avoid further degradation of the natural environment.

Previous studies have mainly focused on reducing the operational energy of buildings [3, 4]. This focus has led to accuracy in calculations of operational energy and design of energy efficient buildings. One example of significant reduction in operational energy is found in Denmark, where in last 25 years, operational energy requirements for new buildings has been reduced to less than one third [5]. In comparison, fewer studies have focused on the embodied energy demand of buildings.

Studies have shown that embodied energy demand of a building can be significant [6, 7], and therefore requires more attention in efforts to reduce energy consumption by the building sector.

Few studies have analysed the recurrent embodied energy required for maintenance and material replacement activities over a building's life [7-9]. Recurrent embodied energy associated with replacement of building materials and components is directly affected by the service life of buildings and their constituent materials. However, the significance of building and material service life, and recurrent embodied energy on life cycle energy of a building is not well known. The aim of this study was to determine what effect variations to the service life of buildings and their constituent materials have on life cycle energy demand associated with residential buildings.

1.1 Life cycle embodied energy analysis

The approach used to quantify the embodied energy demand of a building across its life is known as life cycle embodied energy analysis (LCEA). This approach is based on life cycle energy analysis, and enables to identify areas of energy consumption across the building life [10]. This approach also helps to inform improvements to the design, material selection and construction of buildings in order to reduce energy consumption and associated greenhouse gas emissions. The system boundary for a life cycle embodied energy analysis of a building typically includes the energy demand associated with the manufacture, construction and maintenance and demolition phases of the building [11]. This includes the initial embodied energy, the energy embodied in subsequent replacement and maintenance of components or materials, and energy required in demolition and disposal of materials.

1.1.1 Embodied energy assessment methods

A number of methods are used to quantify the energy required to initially construct a building as well as energy required for the maintenance and replacement of materials and components over its life. Commonly used methods are the process analysis, input-output analysis, and hybrid analysis [6, 12]. Each method has a different system boundary and hence, different energy inputs included in any analysis [13]. Therefore, it is important to select an appropriate method for embodied energy quantification as the results using different methods may vary significantly.

Process Analysis

Process analysis involves a combination of process, product, and location-specific data to evaluate environmental flows and effect. In this method, analysis usually begins with the energy input required from manufactures at the last stage and works backwards with each energy input calculated. This method involves process, product, and location-specific data; therefore, it is considered most accurate. However, these results are often considered incomplete due to the unavailability of detailed data for many of the main production process and complexity of the associated upstream supply chain [14]. In a study on a residential building, Crawford [15] found that truncation due to the use of process analysis was 59%.

Input-output analysis

In input–output analysis, economic data is used to trace and quantify the energy required to produce a product. A significant number of countries, including Australia, publish the results of inter-industry transactions (input–output tables) every few years. Energy flows within the national economy are aligned with monetary flows between sectors, based on fuel tariffs in order to develop an energy-based input–output model. A detailed process analysis, at its best may be able to trace the energy inputs and outputs of a product system to two or three stages upstream of the main process. The advantage of input-output approach is that it is systemically complete because it traces and aggregates energy flows within an entire supply chain. The biggest problem with this method, however, is that it is used as (or it becomes) a black box due to the aggregation of dissimilar products in individual sectors of the economy [12, 16] and so the applicability of results to any one particular product is limited. Other problems with this method includes errors related to price assumptions of different products, errors associated with the use of economic data and multiple time counting of energy embodied in delivered fuels [13, 17].

Hybrid analysis

In hybrid analysis, strengths of process and input-output analysis are capitalized by combining both methods, while minimizing the limitations of each method [12, 18]. Two main forms of hybrid analysis which are commonly used in embodied energy calculations are Process-based hybrid analysis and input-output hybrid analysis. In process-based hybrid analysis, delivered material quantities are calculated for a product and input-output data is used to complete the upstream system boundary for these materials [17]. However, the system boundary of a process-based hybrid analysis for a product has similar limitations to those of the process analysis as many of the direct inputs to a process may not be included [12]. An input–output-based hybrid analysis addresses these truncation issues associated with a process-based hybrid analysis for a product by using input–output data to fill in any remaining data gaps and complete the system boundary [6, 9].

1.2 Building service life

Building service life is the period of time which a building is expected to be in the service for its expected use. By increasing the service life of a building, the number of maintenance cycles and quantity of replaced materials and components are increased, resulting in an increase in recurrent embodied energy. On the other hand, reduction in the service life of a building will require the construction of the building again due to the occupancy requirements, resulting an increase in the initial embodied energy requirements over a specific assessment period. Therefore, it is important to consider building service life at the design stage, as it could significantly affect the life cycle embodied energy of a building due to the maintenance and replacement of its constituent materials or requirement of re-construction of a building [6]. Different assumptions made for the building lifetime may affect the appropriate selection of materials. Buildings that are designed for long service life, such as institutional buildings, should be constructed with more durable materials. On the other hand, for buildings where a shorter life span is expected (for example, a low-rise retail building in an area likely to be redeveloped), use of durable materials with high embodied energy would be considered a waste of embodied energy (Athena, 2006).

1.3 Materials service life

A material's service life is the amount of time a material can be expected to be serviceable. The ISO 15686-1 [19] and ISO 15686-2 [20] set of standards prescribe a factorial approach based on knowledge about materials and building technology, and is known as factors method. In this method, knowledge on service life of a product from a known reference condition is transferred to a project specific condition. The factors that are considered to be the key in determining the service life of a product include material quality, design and detailing, quality of workmanship, maintenance regime and levels, material durability and exposure to deteriorating effects associated with the local climate and environment. While service life can be calculated through the factors methods where knowledge about the reference service life is required, researchers have advocated the analysis of real life data and the need of establishing service life databases [21, 22].

Recurrent embodied energy of a building is directly affected by the service life of a material. As energy required in materials manufacturing and related processes still constitutes large amounts of fossil fuel-based energy, this recurrent demand for energy may result in a considerable ongoing burden on the environment, particularly in the form of greenhouse gas emissions, throughout the life of the building.

2. Methodology

In order to determine the effect of variation in the service life of residential buildings and their constituent materials, a detached house in Melbourne was used as case study. A detailed bill of quantities was used to quantify the initial embodied energy and recurrent embodied energy. Average service values for residential buildings and materials were gathered from a literature review and were used to calculate the recurrent embodied energy. After calculating life cycle embodied energy of the house with average material and building life, a number of variations to service life of building and its constituent materials were made, and life cycle embodied energy was re-calculated.

Case Study House:

The case study house used in the life cycle embodied energy calculations is located in Melbourne. This house has covered area of 292m2 and has a concrete slab, brick veneer external walls, aluminum windows and terracotta roof tiles, as shown in Figure 1. A detailed bill of quantities was used to quantify the life cycle embodied energy of the house.

Figure 1. Floor plan and elevation of case study house

2.1. Calculating initial and recurrent embodied energy

Initial embodied energy of the case study house was calculated by using input-output-based hybrid analysis. Delivered quantities of materials used in the construction of the house were multiplied by the hybrid embodied energy coefficient of the respective material, to determine the process-based hybrid embodied energy of the house. To complete the system boundary, the energy embodied in non-material inputs (i.e. the provision of finance, insurance, transport etc. needed to support the construction process) was calculated, referred to as the remainder of energy inputs, and added to the process-based hybrid embodied energy figure. A detailed description about the use of input-output-based hybrid analysis to calculate the initial embodied energy of the case study house is available in [8].

The recurrent embodied energy of the house was calculated based on the number of times each individual material would likely be replaced during the service life of the house. Material service life figures from the literature were assumed for the analysis (see Table 1.).

The embodied energy associated with the materials being replaced over the life of the house was calculated as per the initial embodied energy of the house. The delivered material quantities associated with each replacement were multiplied by the respective material embodied energy coefficients. These values included the direct and indirect energy associated with the manufacture of materials. To complete the system boundary, the non-material inputs or remainder associated with materials being replaced, were then calculated as per the initial embodied energy calculation.

The energy embodied in each material was then multiplied by the number of replacements for that material over the life of the house, and summed to determine the total recurrent embodied energy associated with the house. The exact number of replacements required for each material was determined by dividing the service life of the house, by the service life of the material, subtracting 1 (representing the material used in initial construction at Year Zero) and rounding up to the nearest whole number (to reflect the fact that materials can only be replaced in whole numbers). A detailed description about the use of input-output-based hybrid analysis to calculate the recurrent embodied energy of the case study house is available in [8].

2.2. Material service life variations

In addition to average material service life, minimum and maximum material service life scenarios were used to calculate the life cycle embodied energy demand. The material service life scenarios selected were chosen to reflect the extent of service life variability likely for a selection of the main building materials used within the house. A detailed literature review was conducted to obtain the minimum, average and maximum service life values of different materials used in the case study house. Material service life data of selected construction materials is shown in Table 1.

Table 1. Material service life data selected construction materials

Material	Service life (Minimum)	Service life (Average)	Service life (Maximum)
Concrete roof tiles	30	40	60
Bricks	Lifetime	Lifetime	Lifetime
Aluminium-framed windows	10	25	40
Concrete slab	Lifetime	Lifetime	Lifetime
Ceramic wall and floor tiles	20	60	100
Nylon carpet	7	10	20

2.3. Building service life variations:

In addition to average building service life of 50 years with average material service life, life cycle embodied energy was calculated for building service life of 100 and 150 years. In order to determine the effect of variations in building service life on the life cycle energy demand associated with the provision of housing over a longer period than the typical life of a house, life cycle embodied energy calculations were conducted for an assessment period of 150 years.

As this study seeks to investigate the combined effects of material and building service life variations on life cycle embodied energy demand of residential buildings, life cycle embodied energy with minimum and maximum material service life values was also calculated for building service life of 100 and 150 years.

3. Results and discussion

3.1. Base case results (with average material and building service life)

The embodied energy associated with the initial construction of the case study house was found to be 3,891 GJ (13.4 GJ/m^2). It includes the energy embodied in the manufacturing of materials, transportation, initial construction of the house and supporting services. Recurrent embodied energy associated with replacement of materials with average material service life values over an average building service life of 50 years and was found to be 2,677 GJ (9.2 GJ/m2).

Life cycle embodied energy of the case study house was calculated by adding the initial and recurrent embodied energy. Life cycle embodied energy of the house with average material service life values for a period of 50 years was found to be 6,568 GJ (22.6 GJ/m2). Initial and recurrent embodied energy were found to constitute 59% and 41% of the life cycle embodied energy, as shown in Figure 2.

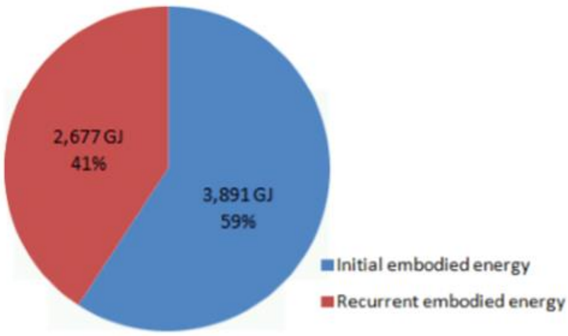

Figure 2. Proportion of initial and recurrent embodied energy

3.2. Effect of material service life variations

The recurrent embodied energy associated with the replacement of materials for the detached house over a period of 50 years, based on minimum and maximum material service life figures, were found to be 5,335 GJ (18 GJ/m2) and 1,756 GJ (6 GJ/m2) respectively, as shown in Figure 3.

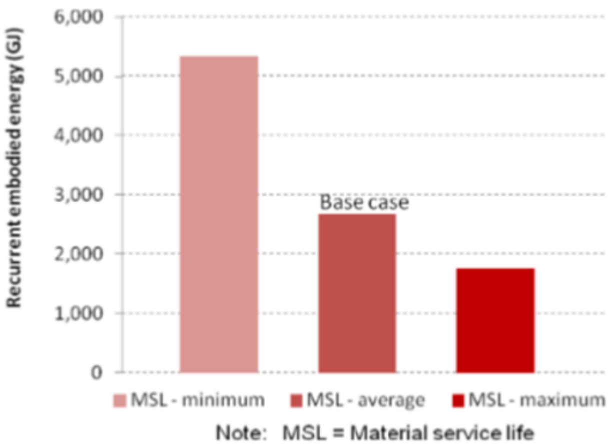

Figure 3. Recurrent embodied energy of the case study house with minimum, average and maximum material service life over 50 years

Life cycle embodied energy of the detached house for minimum, average and maximum material service life scenarios was found to be 9,226 GJ (31.7 GJ/m2), 6,568 GJ (22.5 GJ/m2) and 5,647 GJ (19.4 GJ/m2), as shown in Figure 4. The life cycle embodied energy over a period of 50 years, based on minimum material service life values is almost 140% more than the life cycle embodied energy of the house with average material service life values. The life cycle embodied energy of the house over the same period, based on maximum material service life values is almost 86% of the life cycle embodied energy of the house with average material service life values. Life cycle embodied energy was found to have decreased by 39%, when the minimum material service life scenario was changed to the maximum material service life scenario. This shows that when materials are poorly maintained and/or require greater frequency of replacement, life cycle embodied energy of a building may increase significantly. It also results in recurrent embodied energy representing a higher proportion of life cycle embodied energy of a building.

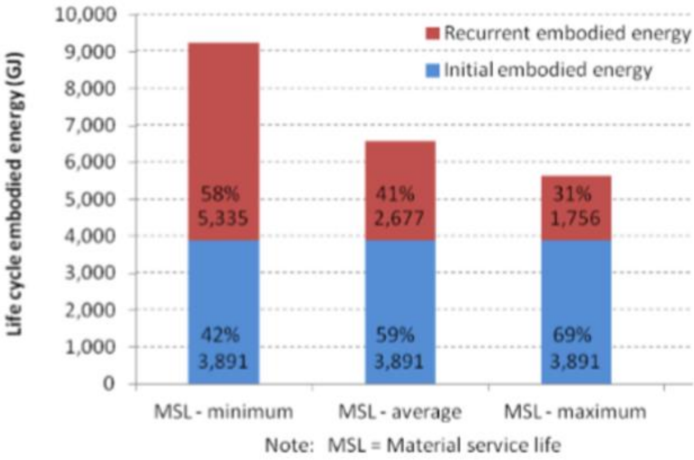

Figure 4. Life cycle embodied energy of the case study house with minimum, average and maximum material service life over 50 years

3.3. Effect of building service life variations:

In order to determine the effect of variations in building service life on the life cycle embodied energy demand associated with the provision of housing over a longer period than the typical life of a house in Australia, life cycle embodied energy of the house with building service life of 50,100 and 150 years was calculated for an assessment period of 150 years.

Initial embodied energy

Initial embodied energy is not affected by increasing the service life of building. Over an assessment period of 150 years, for a building service life of 50, 100 and 150 years, the cumulative initial embodied energy was 11,674 GJ, 7,783 GJ and 3,891 GJ (equal to the initial embodied energy of the house), respectively. This means that for a building service life of 50 years, the house is built a total of three times over 150 years and the total cumulative initial embodied energy over this period is three times the initial embodied energy of the house (ignoring possible variations in this figure over time due to changes in materials used, their production process and other factors).

Recurrent embodied energy

Recurrent embodied energy increased with an increase in service life of buildings, as more materials are being replaced over the longer service life of buildings. Recurrent embodied energy was found to increase from 2,677 GJ at building service life of 50 years to 6,188 GJ and 10,136 GJ for the building service life of 100 and 150 years, respectively.

For an assessment period of 150 years, recurrent embodied energy for building service life of 50, 100 and 150 years was also calculated. This means, for a building service life of 50 years, the recurrent embodied energy was calculated for 50 years and multiplied by the number of whole building service life periods within the 150 years (150/BSL) × REE_{BSL}). In the case, where the number of whole building service life periods was not a whole number, recurrent embodied energy for the remaining period was also added. Over an assessment period of 150 years, for a building service life of 50, 100 and 150 years, the recurrent embodied energy was 6,954 GJ, 8,439 GJ and 9,404 GJ, respectively.

Life cycle embodied energy

Life cycle embodied energy of the house with average material service life was found 10,080 GJ (346 $MJ/m^2/year$) and 14,027 GJ (321 $MJ/m^2/year$) for the building service life of 100 and 150 years, respectively, as shown in Figure 5. On an annual basis, this shows a 23% and 29% decrease in the life cycle embodied energy demand, when compared to the building service life of 50 years. This shows the advantage of prolonging a building's service life in order to optimize its life cycle embodied energy demand.

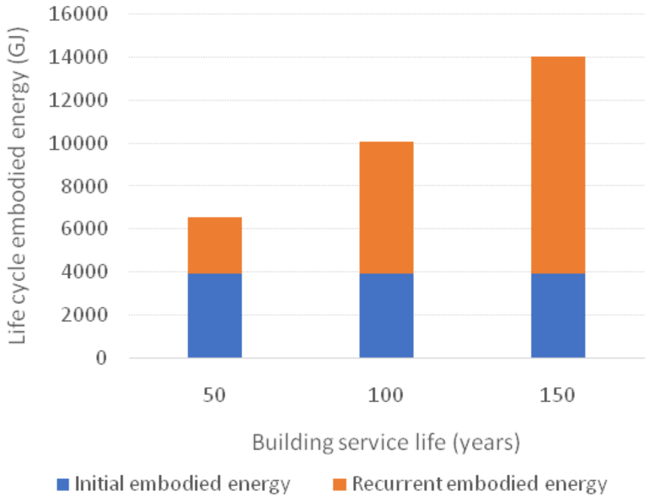

Figure 5. Life cycle embodied energy of case study house with average material service life for building service life of 50, 100 and 150 years

For an assessment period of 150 years, life cycle embodied energy of the house with average material service life was found 16,222 GJ (370 $MJ/m^2/year$) and 13,296 GJ (304 $MJ/m^2/year$) for the building service life of 100 and 150 years, respectively (see Figure 6). On an annual basis, this shows a 13% and 29% decrease in the life cycle embodied energy demand, when compared to the building service life of 50 years (18,629 GJ or 425 $MJ/m^2/year$). This again demonstrates the advantage of prolonging the service life of buildings in order to optimize their life cycle embodied energy demand.

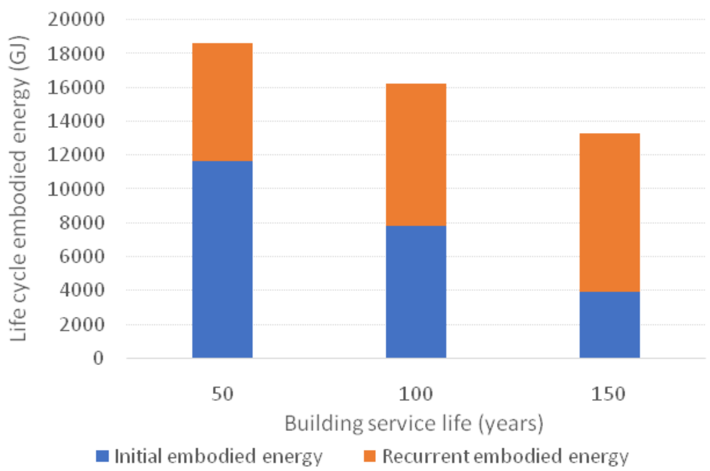

Figure 6. Life cycle embodied energy of case study house with average material service life for building service life of 50, 100 and 150 years over an assessment period of 150 years

3.4. Combined effect of building and material service life

Life cycle embodied energy with average material service life over an assessment period of 150 years was found to be 18,629 GJ, 16,222 GJ and 13,296 GJ for building service life of 50, 100 and 150 years, respectively. With minimum material service scenarios, life cycle embodied energy over the same assessment period increased to 27,679 GJ, 25,625 GJ and 21,944 GJ for building service life projections of 50, 100 and 150 years, respectively. Life cycle embodied energy with maximum material service life over the same assessment period decreased to 16,943 GJ, 13,224 GJ and 10,885 GJ for building service life projections of 50, 100 and 150 years, respectively (see Figure 7). This shows that life cycle embodied energy decreases with an increase in the service life of materials. This figure also shows that an increase in building service life results in a decrease in life cycle embodied energy demand over the assessment period of 150 years. The extent of the decrease in life cycle embodied energy demand was determined by analyzing the variation between the highest and lowest embodied energy results.

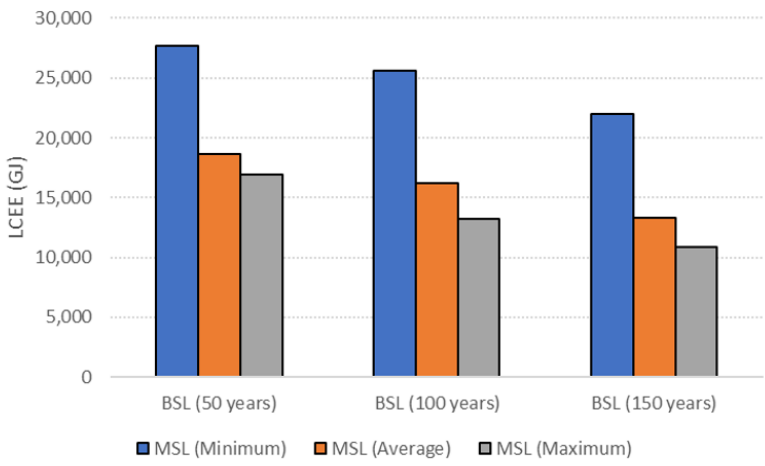

Figure 7. Life cycle embodied energy of the case study house with minimum, average and maximum material service life for 50, 100 and 150 years over an assessment period of 150 years

Life cycle embodied energy with minimum material service life for a building service life of 50 years was found to be the highest (at 27,679 GJ or 95 GJ/m^2). The main reason behind this high value of embodied energy for the building service life of 50 years was the need for two complete replacements of the house during the 150 years assessment period. This shows the importance of prolonging the service of buildings. Despite two whole building replacements, life cycle embodied energy with average (18,628 GJ or 64 GJ/m2) and maximum material service life (16,943 GJ or 58 GJ/m2) for a building service life of 50 years was significantly lower than the life cycle embodied energy with minimum material service life. This shows the importance of prolonging the service life of materials. Life cycle embodied energy with maximum material service life for a building service life of 150 years was found to be the lowest (at 10,855 GJ or 37 GJ/m^2). Variation between the highest result (27,679 GJ for minimum material service life for a building service life of 50 years) and lowest result (10,855 GJ for maximum material service life for a building service life of 150 years) was found to be 61% (2.55 times). This shows that extending the service life of buildings and their constituent materials results in a considerable reduction in their life cycle embodied energy demand. Usually, an increase in building and material service life has no, or limited adverse effect on the operational energy requirements. Therefore, a reduction in life cycle energy demand of buildings and associated environmental effects is possible by careful consideration of building and material service life planning at design stage.

4. Conclusions

A case study house located in Melbourne, Australia was used to determine what combined effect the variation in the service life of materials and buildings has on the life cycle embodied energy demand associated with a residential building. The initial and recurring embodied energy of the house for a building service life of 50 years were calculated using a comprehensive hybrid assessment approach, with material service life values based on average figures obtained from the literature. These service life values along with minimum and maximum material service life values were recalculated over an assessment period of 150 years. This process was repeated for the building service life of 100 and 150years.

When comparing the life cycle embodied energy results using maximum material service life values with minimum material service life values, a 39% reduction in life cycle embodied energy was found. A 29% reduction in life cycle embodied energy demand was found when building service life was extended from 50 years to 150 years over the same assessment period. Combined effect of maximizing the material and building service life was found in a reduction of 61% life cycle embodied energy demand. This study has shown that a variation in the service life of materials and buildings can affect the life cycle embodied energy significantly. This demonstrates that in an attempt to reduce the life cycle embodied energy demand of buildings to minimize the associated environmental impacts, it is important that the service life of buildings and their constituent materials be taken into consideration.

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Construction 4.0 Technologies as Potential Enablers of Mass Customisation Practices

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Abstract: Mass Customisation (MC) is a strategy to increase value generation by delivering products that fulfil specific customers' requirements through flexible processes and organizational structures. In the construction sector, the inefficiency of the production system often precludes MC in terms of deadlines, costs, and production management. Recently, industry 4.0 has provided new opportunities for production systems, bringing solutions for the current fragmentation of the horizontal, vertical, and longitudinal levels in the industry through high integration, connectivity, and real-time collaboration, along with the adoption of smart technology innovations that meet the demand for customised and sustainable products. Construction 4.0 (C4.0) has been proposed as the counterpart of industry 4.0 for the construction sector. This study is based on the premise that C4.0 technologies can boost MC and help to achieve greater levels of integration between people, processes, and customers. Therefore, this paper aims to identify which C4.0 technologies have the highest potential to enable MC practices. The study was divided into the following steps: (i) identify MC practices and C4.0 technologies in a literature review; (ii) categorize, simplify and select a set of them; (iii) create a matrix crossing technologies and practices; (iv) evaluate the potential contribution of the technologies as enablers for each practice, based on the perception of specialists; and (v) assess the potential of C4.0 technologies as enablers of the MC practices in the Brazilian context through an online quantitative questionnaire. The results indicate that Building Information Modelling, Mobile Computing and Applications, and Data Sharing are the technologies with highest synergy with MC practices, while "Social media" and "Modular construction" had the least synergy. The most unknown technologies were "Big data and analytics" and "Internet of things and services". This study helps the construction sector to understand the opportunities and constraints concerned with the implementation of these technologies in a MC context.

Keywords: Mass customisation; Industry 4.0; Construction 4.0; Practices; Technologies

1. Introduction

The fourth industrial revolution, also known as Industry 4.0 (I4.0), has brought new opportunities for production systems proposing methodological changes in the traditional operation of companies [1]. I4.0 offers solutions for the fragmentation between the horizontal, vertical, and longitudinal levels of the industry through the adoption of smart technology innovations and high levels of integration, connectivity, and real-time collaboration, responding to the demand for customised and sustainable products [2]. I4.0 involves, in addition to other technologies such as artificial intelligence, big data, building information modelling (BIM), and cloud computing, the technical integration of Cyber-Physical Systems (CPS) into manufacturing and logistics and the use of the Internet of Things (IoT) and Services (IoS) in industrial processes, which have implications for value creation, business models, downstream services and work organization [3]. According to Fatorachian and Kazemi [2], these enabler technologies influence and depend on each other, and their synchronized communication is necessary to have a successful implementation of I4.0. The visions for I4.0 are a new level of sociotechnical interaction between all the actors and resources involved in the manufacturing, and the possibility to incorporate individual customer and product specific features into different phases of the product development process [3].

This new paradigm has been earning more and more space and influencing other industrial contexts. As a counterpart of I4.0 for the construction sector, the term Construction 4.0 (C4.0) has been proposed. The I4.0 adoption can help the construction industry to transform into a technology-driven industry and to seek the performance improvement of other manufacturing industries [4]. According to Osterreich and Teuteberg [4], the I4.0 concept applied to this context involves a multitude of interdisciplinary technologies to enable the digitization, automation, and integration of the construction process at all stages of the construction value chain, where BIM, cloud computing, and IoT are just a few.

Mass customisation (MC) is pointed out as one of the key characteristics [5], as an enabling technology of I4.0 [2], and as one of the factors that make up the scenario of the physical domain of industry 4.0 [1]. MC provides products and services that fulfill specific requirements from different customers without a potential increase in product cost and delivery time [6 - 9]. This approach reflects the progress in design and production systems management, in addition to the increase in the customers' requirement level over the years [10]. The main purpose of this strategy is to provide superior value [11] through a vision centered on customers, seen as active participants in the value generation [12]. In this way, is possible to identify synergy between MC and I4.0 concepts. I4.0 technologies hold huge potential to fulfill customers' requirements [2-4], to deliver the ability to respond flexibly to the demand and suppliers, and to provide end-to-end transparency over the manufacturing process, facilitating optimized decision-making [3]. Fatorachian and Kazemi [2] argue that I4.0 allows the individualization of manufacturing processes, enabling the production of highly customised products at low volume, while still ensuring the quality of products and profitability. The increasing demand for customised and innovative products, added to the pressure for greater efficiency and responsiveness, requires highly flexible and responsive manufacturing systems and structures, capable of handling increased complexity, requiring high levels of integration, connectivity, and collaboration, which requires the adoption of intelligent technological innovations from I4.0 [2].

Although the recent I4.0 literature brings MC as one of its key benefits, the theme ends up explored from the point of view of I4.0. In addition, articles based on MC use I4.0 as a way to reach mass personalization production, as is the case of Wang et al. [13], not focusing on the practices related to MC strategy. Practices represent the tools or techniques that have been used successfully in real-life situations to improve performance or solve problems [14]. This research seeks to invert the point of view, bringing MC as a basis for discussion and seeking to investigate how I4.0 technologies can bring solutions to the successful implementation of MC strategy in terms of deadlines, costs, and production management. From now on, this paper adopts the term C4.0 to refer to the I4.0 technologies in the construction context. This study is based on the premise that the C4.0 technologies, when used individually or in combination, can boost MC to achieve better applicability of its practices and greater levels of integration between people, processes, and customers. It seems to be possible due to the C4.0 focus on the creation of smart products, procedures and processes [3]. Given these circumstances, there is the need for further research, as there is a limited exploration in the literature between both concepts from the perspective of MC. In this context, the following research questions arise: (I) What is the potential contribution of C4.0 technologies as enablers of MC practices? (II) Which C4.0 technologies and MC practices have more synergy? (III) What is the knowledge level of construction practitioners about C4.0 technologies?

To explore the synergy between both concepts, the knowledge level of professionals and the applicability of C4.0 technologies have been evaluated as enablers of MC practices. Technologies that have greater synergy with each of the practices, or set of practices, of MC will also be indicated. The sample selected for this research are construction professionals from the south of Brazil. A gap was identified in the literature regarding the compilation of MC practices, the understanding of the synergy between the referred practices and the C4.0 technologies, and the correlation between those technologies and the MC decision categories. According to Wikner [15], decision categories help to classify decisions and support the segmentation of complex decision problems into a structured and relatively independent way, facilitating decision-making. Since this study is theoretical-practical, the results found have the potential to guide companies in the decision-making process of prioritizing a set of technologies that could be used as potential enablers of MC practices. This potential to guide decisions can add value to the product, service, and process of the companies that customise their products, helping them to respond more accurately to customer requirements and to the demand for sustainable products.

2. Research method

The research used Mixed Methods Research, combining the qualitative and quantitative approaches within different phases of the research process [16]. The qualitative phase had four steps, starting by obtaining an understanding of the problem and ending up structuring an online quantitative questionnaire. The selection of C4.0 technologies and MC practices from publications and previous researches were classified as secondary data. On the other side, the quantitative phase was carried out in four steps, starting with the application of the questionnaire and ending up with the understanding and analysis of the collected data. The data collected through the online quantitative questionnaire, organized and analyzed for the first time, is primary data. This phases aimed to test the potential and limitations of the research problem, using a compact initial sample of respondents to expand the scope in the future by considering and adjusting the identified limitations.

2.2 Qualitative phase (selecting technologies and practices)

A literature review was built to identify customisation practices and Industry 4.0 technologies in the construction sector. The keyword search included civil construction, housing, house-building sector, customisation, mass customisation, practices, industry 4.0, construction 4.0, technologies, synergy. The search criteria were papers from 2010 onwards. From this search, it was reached ninety-nine MC practices and one hundred and forty-nine C4.0 technologies from different authors. The outcome was the synthesis and organization of the research findings. This set of practices and technologies was selected according to its relevance, grouped by similarity, and classified according to categories suggested by the literature. The technologies were disposed of in clusters and the practices were distributed in decision categories. This selection resulted in thirty-one MC practices and twenty-five C4.0 technologies, which were disposed of in a matrix crossing the practices in the rows and the technologies in the columns. The matrix of prioritization and relation was based on the Quality Function Deployment (QFD) [17], which works with a geometric scale (1,3 and 9), prioritizing the most critical relations.

Two workshops with specialists were conducted with the aim of refining and selecting the main practices and technologies, which would structure the questionnaire used in the survey. The total duration was 4 hours, including six professionals, of those, two academics and consultant from the technology and C4.0 areas, two academics from the MC area, and two academics from both areas. The shared assessment started with the classification of each one of the 775 QFD matrix cells resulted in the crossing of a technology with a practice. The discussions about each crossing should end up rating the cell with a given score. A score 9 means a strong relation, 3 means that there is a moderate relation, 1 means a weak relation, and empty cells mean no relation [17]. This score represented the potential contribution of C4.0 technologies in each practice. Based on these scores, the items were ordered by the sum of the rows and columns, bringing two results: an ordering within each technologies' clusters and practices and another global ordering between the categories. The final result was a matrix with scores in all cells and the ranking of synergy between technologies and practices according to the sum of the full row or column and also the sum of the scores of the items from each MC decision category or C4.0 cluster. From that ranked list, a selection was carried out with the purpose of synthesis to operationalize the instrument according to the following criteria: (a) give all MC decision categories an equal number of practices; and (b) select the two technologies with the highest score from each cluster for each of the MC decision categories, which will be explored and displayed in the results section. To reduce the time to fill in the questionnaire, the MC decision categories were used to represent their respective practices. In conclusion, the outcome of the analysis of the workshop data was a set of practices and technologies used to build the questions of the online quantitative questionnaire, which was the next research phase. The elaboration of the data collection instrument included around ten test rounds realized for refining and reducing the dimension of the instrument. After that, the survey was applied to the target audience.

2.2 Quantitative phase (evaluating technologies and practices)

The data collection instrument was designed in the Google Forms® platform. It was composed of three sections: (i) classificatory variables, such as profession, years of experience, educational background, among others; (ii) presentation of MC and C4.0 brief concepts to standardize respondents' understanding; (iii) evaluation of the potential contribution of C4.0 technologies as enablers of MC practices; and (iv) personal information. The questionnaire respondents were engineers, architects, engineering or architecture graduates, master's students, students and alumni of PPGCI, and others involved in civil construction. Data collection was carried out from January 11 to January 25, 2021. This phase of distribution of the instrument was held via WhatsApp® and e-mail. The responses and database were daily controlled. The analyzes, realized in Google Data Studio®, were descriptive with summary measures, infographics, and cross tables.

3. Results

3.1 Qualitative analysis

3.1.1. Selection of C4.0 technologies

Munoz-La Rivera [1], Oesterreich and Teuteberg [4], Sawhney, Riley, Irizarry [18], and Sawhney et al. [5], grouped C4.0 technologies and concepts into clusters (Table 1), identifying and classifying 47 technologies between the three scenarios. The Digital layer and Digital tools clusters [5, 18] are distributed between the clusters Simulation and modelling, and Digitalization and virtualization [4]. From an analysis of correspondence between clusters and the respective technologies of each one of them, the present work adopted: (a) physical domain, (b) simulations and modeling, and (c) digitalization and virtualisation. According to Oesterreich and Teuteberg [4], smart factory, which corresponds to the physical domain cluster (a), comprises technologies and concepts to automate the construction process and to create a “Smart Factory” for the construction environment, including items such as automation, cyber-physical systems, internet of things, modularization, among others. Simulation and modelling (b) deal with the high complexity of construction context through the improvement of the operations design, with the emphasis being placed on the emerging field of Building Information Modelling (BIM) [4]. Digitalization and virtualization (c) include items such as cloud computing, big data, and mobile computing, related to the integration of services, collaboration platforms, support of communication and collaboration, and collection and accessibility of data [4].

Table 1. Technologies’ clusters identified in the literature.

Clusters’ definition for this paper	Oesterreich and Teuteberg [1]	Sawhney, Riley, Irizarry [18]; Sawhney et al. [5]	Muñoz-La Rivera et al. [1]
Physical domain	Smart factory	Physical layer	Physical domain
Simulation and modelling	Simulation and modelling	Digital layer, Digital tools	Simulation and modelling
Digitalization and virtualization	Digitalization and virtualization		Digitalization and virtualization

3.1.2 Selection of C4.0 technologies

The definition of MC areas and decision categories was based on the literature review. According to Salvador et al. [19], the MC goal is to move away from mass production and move towards MC through the continuous improvement of the three organizational resources: solution space, process design, and choice menu, instead of trying to reach an idealized state of perfection. Ferguson et al. [20] and Rocha [10], on the other hand, argue that a customisation strategy needs to coordinate decisions related to the following areas: marketing, design, and operations. Marketing, or customer integration, is the interface between the company and the customer [10]. The product design translates the customisable attributes into product specifications, balancing the level of customisation to keep costs and delivery times reduced; operations management comprises the production of products, aligning the offered product variants to the production system and the supply chain [10]. In the same study, the author also suggests that the definition of an MC strategy should start by making some core decisions related to the scope of MC, and then move to the other three areas. The MC strategy can also be divided into decision categories. Some authors [21, 22, 23, 10] present a set of practices distributed among them. From an analysis of correspondence between the categorizations and practices proposed by Viana, Tommelein, and Formoso [24], Amorim [22], Fettermann et al. [20], Hentschke [21], Conte [25], and Rocha [10], the present work adopted the following MC areas and its two respective decision categories: (a) Core categories - solution space; and knowledge management; (b) Customer integration - prepare the context of the buying experience and the presentation of the solution space; and customer integration and relationship; (c) Design - modular construction; and options available according to the stage of construction; and (d) Operations - production planning and control; and flexibility of the production system.

3.2 Quantitative analysis

3.2.1. Matrix of technologies and practices

Figure 1 shows a matrix cutout to exemplify the analysis. The complete matrix includes all the 25 technologies in the columns and 31 practices in the rows allocated among three C4.0 technologies' clusters and eight MC practices' decision categories. The eight decision categories were distributed between the four areas of the MC strategy: core categories, customer integration, design, and operations. Each one of the 775 cells that resulted from the crossing was filled with a score suggested by the specialists. The items selected for the online quantitative questionnaire are shown in Table 2.

			Physical domain			Simulations and modelling		
			IoT / IoS	Modularisation	Prefabrication / Off-site construction	BIM	AR/ VR/ MR	Digital twin
CORE CATEGORIES	Solution spaces	Identify customizable items of greater value-added capabilities	3	9	0	3	3	0
		Offer innovative customisation units, such as related to sustainabilityand automation	1	3	9	1	0	0
CUSTOMER INTEGRATION	Customer integration and relationship	Monitore the buying experience to provide feedback into the process	3	0	0	1	0	0
		Prepare customers to the decision-making process	3	1	1	3	3	0

Figure 1. Technologies versus practices matrix' cutout.

3.2.2 Data collection instrument

The number of respondents was twenty-eight, with only twenty valid answers for the survey. It was challenging to find respondents able to answer the questionnaire, as it required minimal knowledge about C4.0, which is a topic that has recently started to be discussed and highlighted by academia and industry, and MC, a strategy whose practices are not widely known and applied in the construction context. Thence, section 2 was included seeking to align the minimum understanding of the two concepts with the respondents. Section 1 included three questions related to the characterization of the sample, such as profession, performance, and time of experience. After that, two questions were asked about the respondent's company size, including the number of employees and the number of construction sites in progress. Those two questions can also help to understand whether the scale of the company interferes or not in the last two sections of the section: "How much MC is used in civil construction"; and "What would be the ideal use of MC in the same context". Both questions regarded the respondent's current company or context. In the case of consultants or academics, respondents' experience with companies should be considered. Table 2 provides a characterization of the sample and the respondents' perception about the current and ideal use of MC practices in the construction context, presenting summary statistics of some variables. The profession of 52% of respondents was civil engineer and 48% architects.

Table 2. Characterization of the sample and respondents' perception about the use of MC practices.

Education level		Professional experience		Constructions in progress		Current use of MC		Future use of MC	
Master	45%	1–5y	45%	Not apply	35%	Rarely used (2)	40%	Very important (5)	50%
Higher education	20%	5–10y	30%	2 – 5	30%	Used (3)	35%	Fairly important (4)	35%
Specialist	15%	>10y	15%	6 – 10	10%	Widely used (5)	15%	Important (3)	15%
PhD	10%	<1y	10%	11 – 50	10%	Often used (4)	5%		
Student	10%			> 50	10%	Never used (1)	5%		
				1	5%				

Section 3 addressed the synergy between C4.0 technologies and MC practices by asking the question: based on your knowledge, indicate which MC practices (rows) can be facilitated by C4.0 technologies (columns). Therefore, the question had the structure of a matrix, in which each cell corresponded to the crossing of a technology with a practice. The respondent should select all the cells that are believed to have synergy. It was also included the option "I don't know this technology". The summary of the findings of this section is shown in Figure 2. This graphic ranked the technologies and practices from the highest (top-right) to the lowest (bottom-left) synergy. Numbers represent the MC decision categories: (1) core categories, (2) customer integration, (3) design, and (4) operations, while letters represent the C4.0 clusters: (A) physical domain, (B) digitalisation and virtualisation, and (C) simulations and modelling.

3. Discussion

The summary of findings is shown in Figure 2, aiming to illustrate the synergy between C4.0 technologies and MC practices, guiding the discussions of our findings from a small and initial sample in the Brazilian context. The analysis carried out by the experts pointed out that the decision category figuring in the first position was "Prepare the buying context and presentation of the customisation options", in which the technology "AR/VR/MR" presented the highest synergy, 89%. The second decision category with the greatest synergy was "Production planning and control", with "BIM" with the greatest synergy, 79%. "Data sharing" technology showed up as the greatest synergy in two decision categories: "Options available according to the stage of the construction work" and "Management of customer, process and employee information", with 74 and 89%, respectively. The decision category that showed the strongest synergy with the first technology was "Modularity", which presented 100% synergy with the "Prefabricated and industrialized construction" technology. In first and second places as unknown technologies, there were "Big data and analytics" and "IoT / IoS". The only technologies that all respondents know about are "Data sharing" and "Social media". In general, the technologies that showed the least synergy with the decision categories, with the lowest average percentages, are "Social media" and "Modular construction". The percentages displayed in the black bars indicate the average potential contribution of C4.0 technologies as enablers of all practices, on the top, and the average of how much each practice can be enabled by all technologies.

		Modular construction	Social media	AR / VR / MR	Big data and analytics	IoT / IoS	Pre-fabrication / Off-site construction	Simulation models and tools	Data sharing	Mobile computing and application	BIM	
		20%	25%	33%	34%	35%	39%	39%	43%	52%	53%	
2	Prepare the buying context and the presentation of the customisation options	11%	63%	89%	42%	47%	16%	58%	47%	68%	53%	49%
4	Production planning and control	42%	0%	21%	53%	32%	47%	74%	68%	74%	79%	49%
1	Solution space	37%	26%	53%	37%	42%	58%	58%	37%	68%	63%	48%
3	Available options according to the construction work stage	21%	26%	37%	21%	37%	42%	42%	74%	68%	68%	44%
1	Knowledge management	11%	21%	16%	68%	63%	11%	5%	89%	53%	68%	41%
2	Customer integration and relationship	11%	89%	63%	21%	53%	0%	32%	32%	68%	26%	39%
4	Flexibility of the production system	47%	0%	5%	32%	5%	58%	47%	42%	63%	68%	37%
3	Modules	0%	0%	11%	0%	11%	100%	32%	0%	0%	47%	20%
	I don't know this technology	5%	0%	5%	32%	26%	21%	5%	0%	5%	5%	11%

Figure 2. The potential contribution of C4.0 technologies as enablers of MC practices.

The decision category with the highest synergy with all technologies is "Customer integration" (2), with 44,47% average, closely followed by the "Core categories" (1) (44,21%) and "Operations" (4) (42,95%). "Design" (3) result (31,84%) can be related to the lack of papers focused on the investigation and compilation of MC practices from the design area. The selection of decision categories that would represent this area may have presented some weakness since they were not widely disseminated in the literature. In this way, an opportunity for research in this field of knowledge is identified. The highest synergy between C4.0 technologies' clusters and MC practices' decision categories, according to the respondents, is the "Simulation and modelling" cluster (C) (41,9%), followed by "Digitalization and virtualization" (B) (38,5%) and, lastly, "Physical domain" (A) (31,5%). A reason for this result can be the ease of understanding the technologies in this category, including "BIM", "AR/VR/MR", and "Simulations models and tools". These technologies have been widely disseminated, some of them expanding the field of construction knowledge and going into people's daily lives. This perception is reinforced by the technologies that, on average, were classified with the highest synergy among all decision categories. "BIM" achieved first place, with 53,22% of average synergy, followed by "Mobile computing and applications", with 52,05%. "Social media" (25,15%) and "Modular Construction" showed the lowest synergy.

Based on these results, it is possible to find a direct relationship between the results of this research and the current movements of the civil construction market and the research environment. The technologies that figured with the highest synergies are on a consolidation path in the Brazilian market, which has been adapting to those methodologies that seek collaboration, automation, and transparency. Data sharing joins them, even stronger in this context of a pandemic, which calls for the digitization of processes and real-time collaboration. Although MC still does not reach a considerable market share, the results show that looking at these technologies that are already on the market with a bias to promote CM practices can bring important results in civil construction. For the MC practices that are not performing well, the specific C4.0 technologies that presented higher synergy can be used to reach better results. In addition, there is an opportunity to study and disseminate "Big data and analytics" and "Internet of things and services", technologies that are unknown in the Brazilian context. Future studies can investigate the potential contribution achieved by the combined use of different technologies as facilitators in the operationalization of one or more MC practices.

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Energy Consumption in HVAC System and Occupants' Thermal Comfort Optimization Using BIM-Supported Computational Approach

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Abstract: Presently, buildings are vastly responsible for total energy consumption and GHG emissions in Hong Kong with indoor comfort being a major concern for the building industry. Comfort involves control of temperature, humidity, air velocity and indoor air quality interacting with occupants. Building owners are becoming increasingly aware of the importance of comfort with minimal energy consumption for the building occupants. As such engineers and experts are being challenged to design systems that provide a comfortable and energy efficient environment to solve this problem. The main aim of this study is to evaluate the indoor built environment of the IAS lecture theatre at the Hong Kong University of Science and Technology (HKUST). which is served by VAV type air-conditioning system and to investigate the effect of layout of diffusers on occupant thermal comfort in CFD as well as analyze energy consumption and CO2 emission by the system in eQuest. This study presents how Building Information Modelling (BIM) and Computational Fluid Dynamics (CFD) can be utilized to address thermal comfort and energy efficiency in buildings by optimizing HVAC system to provide well controlled environment. Indoor temperature, air velocity, CO_2 concentration, Predicted Vote Mean (PMV) and Predicted Percentage of Dissatisfied (PPD) were selected as the factors of evaluation with lightings, space cooling and other equipment being simulated in eQuest for energy analysis. Multiple scenarios with different numbers of occupants at different locations were simulated to assess the thermal comfort range which found the current design of the HVAC system could not sustain the high internal loading from the occupants when either all the seats were occupied, or only the back zone was occupied with the front seats vacant. In this paper, alternative method has been proposed for HVAC layout to address the simulated result of uneven temperature distribution which indicated design problem of overheating at the back rows and over cooling at the front rows, to achieve the desired comfort range with optimized energy consumption.

Keywords: BIM; thermal comfort; energy consumption, computational fluid dynamics, HVAC optimization.

1. Introduction

Human comfort in an optimized energy efficient built environment [McQuiston and Parker, 1982] is an integral part of sustainable design particularly in a densely populated and warm humid climatic zone [2] like Hong Kong where people spend 85% of their times indoor during daytime [3]. Therefore, it is imperative to create a good indoor climate for their wellbeing. Generally, the prospects for improving building environmental performance occur at the early design phase or preconstruction stages as the possibility of making changes at this point is thought to be best [Azhar and Brown, 2009]. Extraction of building information directly from a model is made possible by BIM, to perform various building performance analyses such as daylighting, building energy use, indoor air quality (IAQ) and thermal comfort. Occupant thermal comfort affected by temperature, humidity, and airspeed, is one of the crucial design criteria for building sustainability [2]. Lecture theatres, or large rooms, with unpredictable occupancy patterns, present a special design challenge for professionals [5]. The classic approach of measuring occupant thermal comfort by means of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) has been introduced by Fanger [6]. However, acquisition of data for the calculations of PMV and PPD requires time and specific instrument which may not always be available. Researchers have been looking for alternative tools for the prediction of thermal comfort and the recent findings show that Computational Fluid Dynamics (CFD) has become a popular tool. The installed ventilation systems must be designed to respond to the fluctuating fresh air demand but without excess supply of conditioned fresh air. The demand-controlled air-conditioning system, from which fresh air is supplied to meet its demand based on the levels of CO_2 in the room, provides a feasible solution that is being widely used [5]. According to the Hong Kong EPD guidelines there is a requirement of the CO_2- concentration not exceeding 0.1 % in non-residential buildings [7]. IAQ can therefore not be ignored as the regulations must be accommodated. Moreover, escalating energy costs in more recent times have caused increased interest in efficiency of operation. The wide use of HVAC systems also leads to up to 40% of the total energy demand in buildings [8]. Poor design of the control system accounts for this high degree of energy consumption. Many of these systems could not precisely measure the demand for cooling energy, leading to over-cooling and wastage of energy. Therefore, there is a need to optimize the design of the HVAC system while increasing the occupant thermal comfort.

Previous studies have examined factors influencing occupant thermal comfort with the use of airflow analysis. However, most research hardly explored the effect of layout of diffusers by BIM integrated CFD and energy simulation. This paper gives an overview of the current HVAC system configuration, its design specification, and operational criteria of the theatre. The primary objectives of the research are:

1. to evaluate the effect of the air distribution system in the lecture theatre towards the occupant thermal comfort through CFD simulation.
2. to propose alternative method for HVAC layout design which can provide optimum air flow to prevent uneven temperature and reduce the buildup of indoor contaminant in the audience area.
3. to analyze the existing energy consumption pattern with eQuest [9] which can be helpful in future to recommend further modification or newer methods for better optimization.

Before proceeding to the design stage, building a 3D BIM model of the lecture theatre is of the utmost importance to visualize the real scenario. Therefore, validation of simulated results to correspond to reality in terms of temperature, wind speed and CO_2 concentration is required. On-site measurements and observation will be carried out for the validation process. The findings and conclusion drawn from this study should have a significant contribution to the future of HVAC system design with the use of BIM. In long term, it could save time and cost in the design process while attaining the desired comfort range with optimized energy consumption.

2. Materials and Methods

The methodology has been illustrated in Figure 1. Collected data for the research are shown in Table A1 and Figure A1 in Appendix A. There are two air handling units (AHU 01 and 02) below the theater which supply air to 29 diffusers near the floor, 6 on the ceiling on the left zone and remaining 29 diffusers on the right zone respectively. The air to the middle zone is supplied by both AHUs and the supply air duct is located under the middle zone (row 6). It has a VAV type HVAC system programmed to deliver a specific quantity of air to the space. The system has no heating coil in it and operates with free cooling. It detects if the return air temperature is more than 24°C, then the feedback sensor automatically lowers it down to 19°C. The theatre is equipped with displacement ventilation where the diffusers are located under each row of seat on the vertical pane through which air is supplied directly to the occupied zone at low velocity forming a layer of warm air above the occupied zone and internal heat loads and contaminants being carried away by the return air [2]. This system is best suited for rooms where the room heights are more than 3 meters, hence appropriate for spaces like IAS theatre.

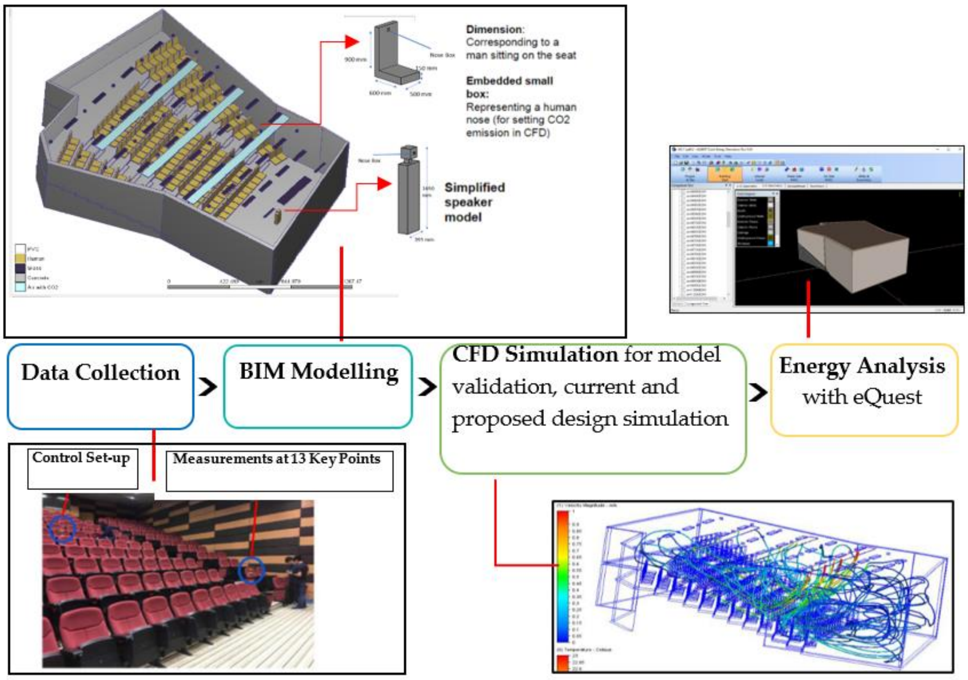
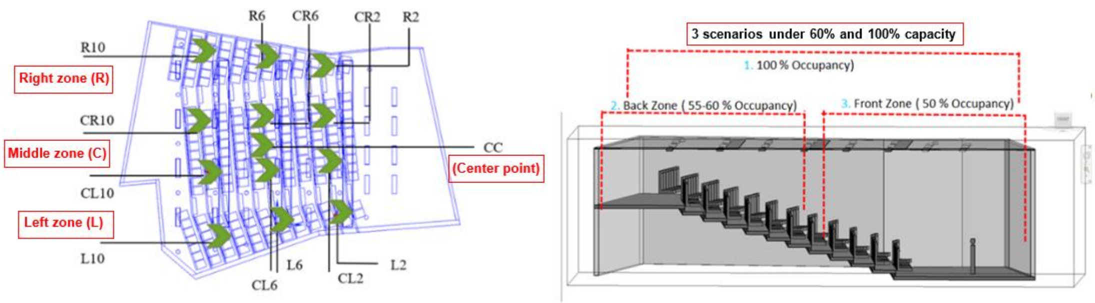


Figure 1. The first step was collection of information in two phases – field validation and scenario analysis. BIM model was created with Autodesk Revit using data from the lecture theatre which included seats, lighting fixtures, diffusers, seats with nose boxes and 1 human at the front zone as speaker which was then imported into Autodesk CFD [10] for scenario analysis with materials and boundary conditions assigned accordingly. The BIM model was exported to .xml file and converted to "DOE-2 File" under the ASHRAE defined climate zone for conducting energy analysis in eQuest.

According to ASHRAE, if area < 500 m^2, then one center point is enough for field validation. Although the area of the theatre is 241.043 m^2, for more accuracy of the verification, measurements were taken at 13 key points in alternative rows including center point in Row 6 [Figure 2(a)] to ensure continuous environmental change monitoring during point measurement. The location points were chosen to be uniformly distributed in the lecture theatre to study the spatial effects. The parameters that were measured are air velocity, temperature, and humidity.



(a) (b)

Figure 2. (a) Field validation phase - division of the theatre into 3 zones with 13 key points to measure the parameters (temperature, air velocity). 3 minutes were given for each point with reading at every 30s interval to monitor the change in velocity and temperature and to evaluate the temporal effects. (b) Scenario analysis phase - with full and half occupancy under 60% and 100% capacity. Measurement of CO_2 level with relative humidity were taken in the 13 points with each point at 10s reading.

Measurements of the flow rates in the AHU room were recorded directly coming from the return air, supply air and fresh air ducts [Appendix A] (Table A1). The required cooling capacity of the theatre is not very high as the usage rate is low given that only conferences will be carried out in the theatre occasionally, so the HVAC system will only operate when bookings are made. Even if there are conferences, seats do not fill up more than 50-60% as such the HVAC system always operates at 60% capacity.

As the supply air duct runs under row 6 which is at the center, the supply flow rate of the diffusers of other rows was calculated in accordance with the distance from row 6 which is assumed as the total supply flow rate. There are 6 rows above and 5 rows below row 6 excluding row 1 since row 1 does not have diffusers. Since the distance between alternate rows are the same,

$$\text{Geometric Factor} = \frac{\text{Total number of rows from row 5 to the furthest row} - \text{number of rows from Row x to Row 6}}{\text{Total number of rows from Row 6 to the furthest}} \quad (1)$$

For example, geometric factor for row 7 is (6-1)/6 = 5/6. The flow rate of a diffuser in row 6, y, is found by the following equation:

$$y = \frac{\text{Total supply flow rate of (AHU 01/ AHU 02)}}{\text{Total number of diffusers powered by (AHU 01/AHU 02)}} \quad (2)$$

$$\text{For example, y for AHU 01 will be} = \frac{\text{Total supply flow rate of AHU 01}}{\text{Total number of diffusers powered by AHU 01}}$$

So,

Flow rate of a diffuser in a particular row = y × geometric factor (3)

Velocity of a diffuser in a particular row = y × Geometric factor × Surface area of the diffuser (4)

Velocity of diffusers under 60% and 100% fan capacity can be determined by the above equations and applied in CFD boundary conditions settings. Furthermore, CO_2 concentration of the supply air is calculated by the mass conservation theorem. As we know, total supply air is the sum of fresh air and return air, therefore,

$$C_f Q_f + C_r Q_r = C_s Q_s, \quad (5)$$

where C_f = CO_2 concentration of fresh air, Q_f = flow rate of fresh air, C_r = CO_2 concentration of return air, Q_r = flow rate of return air, C_s = CO_2 concentration of supply air, Q_s = flow rate of supply air. C_f, C_r, Q_f, Q_r and Q_s were obtained by measurement in the AHU room with which C_s was calculated and applied in CFD settings.

To simulate the mixing of two fluids in CFD, scalar boundary was used to track their relative concentrations such as for the occupants, scalar boundary condition was set to 40,000 as exhaled air for occupants is 40000ppm (= 4% in air) [11]. Supply air velocity, temperature and CO_2 concentration were set for every diffuser [Appendix A] (Table A1).

For energy analysis, two primary scenarios with 200 occupants (100% Occupancy) and 100 occupants (50% occupancy) were selected. The sources of internal heat gains included: occupants (sensible and latent heat gain), lights (sensible heat gain only) and equipment [12].

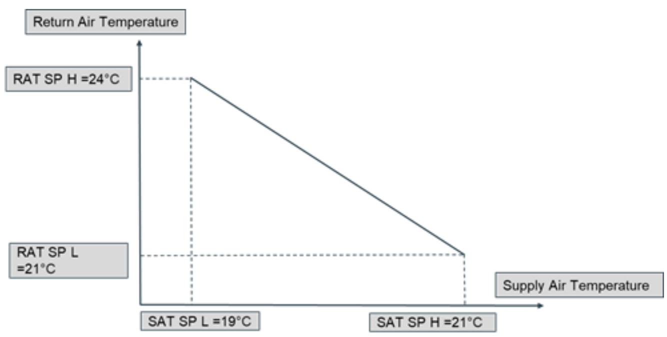


Figure 3. Cooling schedule showing the function of feedback sensor automatically adjusting the supply air temperature according to the measured return air temperature. When the return air temperature is more than 24°C, supply air is cooled to 19°C and the supply of chilled water is stopped when the RAT is less than 21°C. With reference to the DDC guide, proportional control is applied in

cooling set point [13] as such 50% of the throttling range should be taken as the set point sensor value. In this case, the throttling range is the average of return air temperatures i.e., 22.5^{o}C, thus 22.5^{o}C should be taken as the set point.

As the theatre does not operate 24/7 whole year, the daily levels of cooling capacity, occupancy, lighting vary. Therefore, daily, and weekly schedule for cooling, occupancy, and light are required in eQUEST to calculate the energy consumption. Equipment, lights, the HVAC system are on during the opening period. For lighting and equipment schedule, ratio of 1 is set during working hours; otherwise, ratio of 0.05 is set. During closing hours, the HVAC system is off while occupancy is zero. For cooling schedule, the HVAC system of the theatre is designed to follow the relation shown in Figure 3. Since free air cooling is used in winter, spacing cooling is off from November to March. Natural ventilation, infiltration, and solar radiation through windows are absent since there are no openings in the lecture theatre. The standards provided by EMSD HK were used for setting up the parameters which adopts an "Operating Schedule A: offices" according to PB BEC [14, 15]. See Table A2 in Appendix A for details.

3. Results

3.1. Results from CFD Analysis

3.1.1. Field Validation Simulation

Table 1. Comparison of measured and simulated flow field for Velocity and Temperature

	Measured Velocity (m/s)	Simulated Velocity (m/s)	Measured Temperature (Deg C)	Simulated Temperature (Deg C)
Average	0.2	0.1	22.8	22

The CFD model validation [Table 1] was carried out using collected data assuming the theatre has zero occupants. Temperature and air velocity of 13 points were compared between the results from CFD simulation and the actual measurement. The measured velocity is a little higher due to the presence of humans at that time. However, if it is omitted then the air flow range can comply with the actual value. According to ASHRAE [16], velocity < 0.2 is proved as excellent class. Hence, the air velocity in the lecture theatre falls under excellent class. The average difference between measured and simulated temperature is 3.5%. In practice, less than 5% difference would be acceptable. Therefore, it can be concluded the model validates the physical measurements for further simulation.

3.1.2. 100% occupancy scenario simulation results

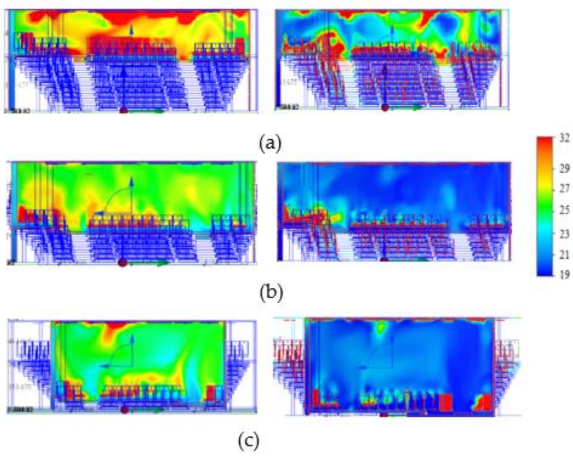


Figure 4. Comparison of temperature flow field between 60% (left) and 100% (right) HVAC capacity (a) Back zone (b) Middle zone (c) Front zone. A clear increasing trend from the bottom to the top row

is observed. The back zone due to absence of diffusers, sees the highest temperature scale (more than 27°C) which sharply differs from the range of standard temperature range 20-25°C [16]. In the front, middle zone and center point the temperature difference is minimal whereas at speaker zone it rises little. Only the temperature level at the speaker zone remains in 23~24°C range. The largest difference between the top row and the bottom row is 2.1°C which is considered a huge difference in a room and the difference could cause thermal discomfort to occupants.

CFD output shows the lack of supply air grilles at the back which results in a dead zone where the air movement is low. This zone has the highest values for the local mean age of air as air spends longer time in this region [Figure 5].

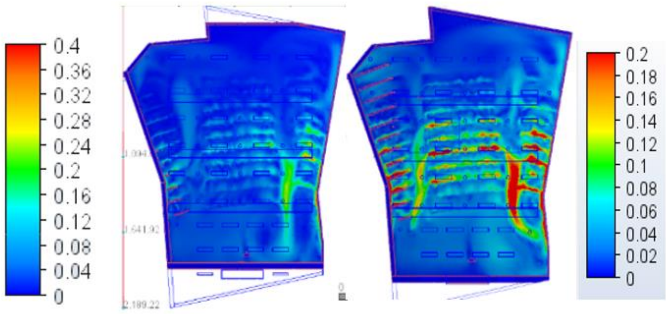
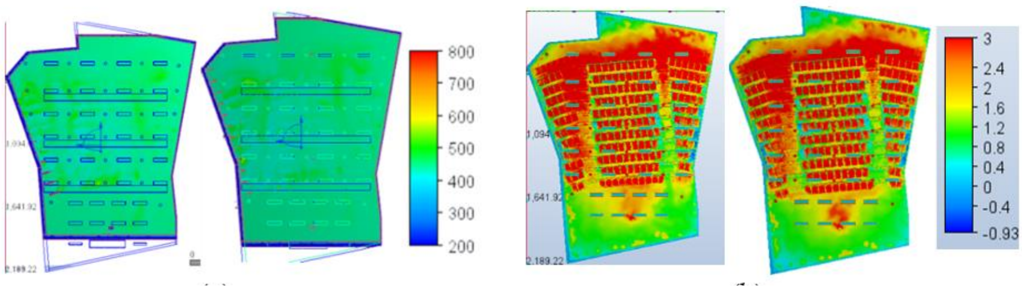


Figure 5. Comparison of velocity flow field between 60% (left) and 100% (right) HVAC capacity. Under 100% fan capacity, the airflow increases and reaches those zones which were not receiving any air flow before. However, the back zone remains as a dead zone. At the front zone with speaker, the air flow dropped to 33% which indicates the speaker will receive less airflow even after keeping the fan capacity at full speed.



(a) (b)

Figure 6. (a) Comparison of CO_2 flow field between 60% (left) and 100% (right) HVAC capacity. The approximate range for CO_2 level under both capacities is 430 - 470 ppm with the lowest being at the speaker zone and the highest at the back. (b) Comparison of PMV flow field between 60% (left) and 100% (right) HVAC capacity. PMV is observed to be the highest in the back zone. For 60% fan capacity, it reaches over +2 whereas in 100% fan capacity it decreases slightly below +2.

The overall level of CO_2 is evenly distributed across the occupied zones and falls under excellent class according to HKIAQ guide [7]. According to ASHRAE, standard PMV values range should be -0.5 to +0.5 and Predicted Percentage Dissatisfied (PPD) should be less than 10% to comply with the optimal thermal comfort in indoor environments [16]. The simulation shows poor performance of comfort as all the PMV values are above 0.5 indicating hot feeling. Even after increasing fan power to 100%, the PMV does not improve. PPD for all zones are well above 10% even after full fan capacity showing poor performance of the air distribution system.

3.1.3. 50% occupancy scenario simulation results at front

Under both fan capacities, the center point receives considerably higher air flow than other occupied zones due to being closer to the supply duct. But the back zone remains a dead zone with no significant airflow [Figure 7(a)] as the hot air from the front is attracted to the back although no occupants are present. Even though the temperature decreases with the increase of fan capacity to 100%, the back zone continuously remains the warmest zone [Figure 7(b)]. The PMV value ranges from 0.8 at the front zone with cooler sensation to exceeding +2 at the back zone making occupants feel very hot [16]. The central zone stays at a range of -0.4 ~ 0.4. The PPD range complies with ASHRAE standard at the occupied zones except for the back zone, where it exceeds 20% which indicates that more than 40 occupants will be feeling discomfort. The CO_2 level stays in the acceptable range indicating excellent class under both fan capacities.

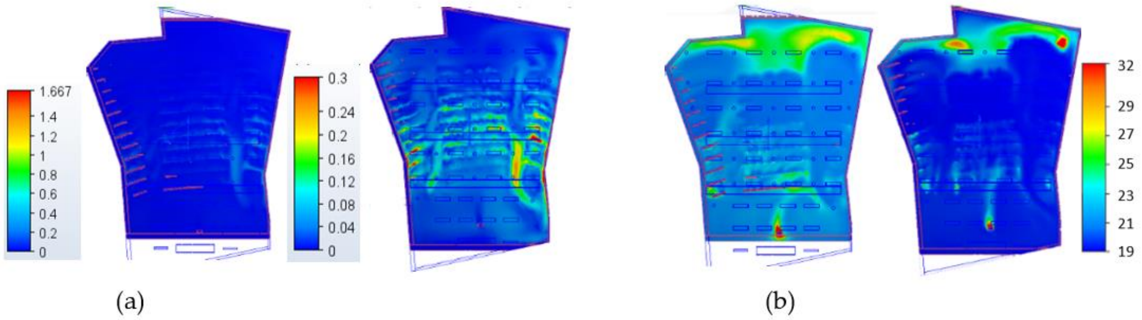


Figure 7. (a) Comparison of velocity flow field (m/s) with 60% (left) and 100% (right) fan capacity (b) Comparison of temperature flow field (m/s) with 60% (left) and 100% (right) fan capacity showing uneven distribution. The temperature at the back is seen to be higher than the front. The range for 60% HVAC capacity is from 20.6- 23.8°C and for 100% HVAC capacity is from 19°C - 21.1°C.

Similar simulation was performed with 50% occupancy at back indicating similar trend of temperature distribution with overheating at the back and over cooling at the front. Among the 3 scenarios of different occupants' locations, occupants sitting at the front work the best in the current HVAC design where temperature only a little below 20°C is observed at the middle rows and the speaker position in 100% HVAC capacity. In terms of temperature, 60% HVAC capacity works better than 100% HVAC capacity in this case.

In conclusion, despite increasing the fan capacity to 100%, the temperatures in three zones do not comply with the standard ranges of thermal comfort. Therefore, more optimized design is needed to achieve a comfortable indoor environment. The hot sensation at the back rows indicated design problem in the current HVAC system where temperature reaches 28°C which is 3°C higher than comfort level. The largest temperature difference under 60% operating capacity is 6°C between the back and the speaker position when all the occupants are sitting at back which is not acceptable within a room. As a result, higher cooling capacity and better ventilation are required. Overcooling at the front rows is another design problem where around 20°C is recorded at the front rows. The PMV of these rows are also below zero which is slightly cooler.

3.1.4. Proposed HVAC design simulation

At present, the supply duct runs below the center of the theatre which is why the maximum flow rate was calculated from Row 6. Traditionally adding an air diffuser at the back and air outlet at the front above the speaker position to dissipate the hot air without moving to the back would be proposed, however, these methods can come at a high cost. The proposed method is to relocate the main air supply duct at the back zone and calculate the maximum flow rate from the back most row (i.e. row 11 shown in [Figure 8]) and follow the pervious equations (1-4) earlier mentioned.

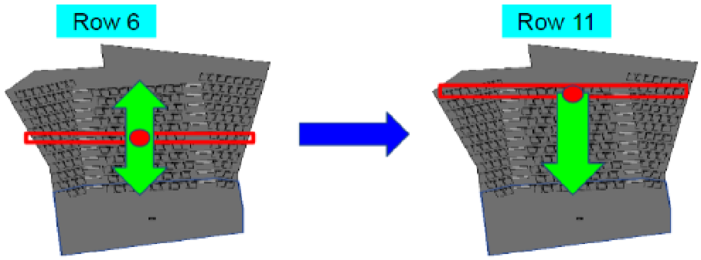


Figure 8. Relocation of supply duct from row 6 to row 11 for proposed layout. The supply duct is assumed to be supplying air flow at the back zone under 100% fan capacity to achieve the required air flow range at the back rows. The new design layout will reduce the cool air supply at the front while increasing the supply at the back rows.

$$\text{Geometric Factor} = \text{Total number of rows below row 11} - \frac{\text{Number of rows from Row x to Row 11}}{\text{Total number of rows below row 11}} \quad (6)$$

For example, row 10 = 10–1/10 = 9/10. According to the equation (2) y will be calculated to find the flow rate of a diffuser at row 11. Total supply flow rate would be the same as the original design. The velocity of each diffuser will be calculated by equation (4).

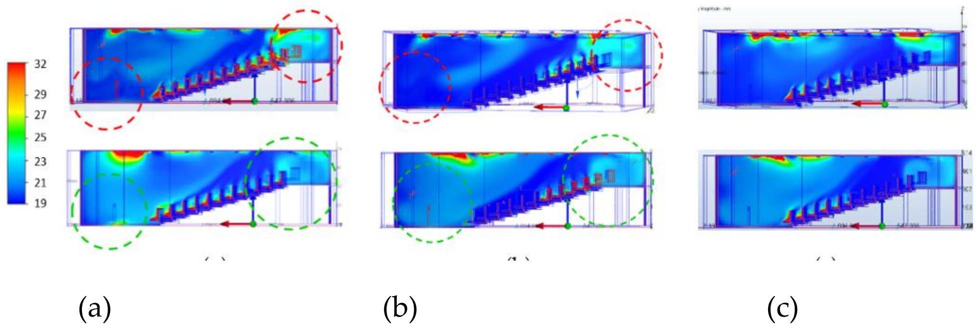


Figure 9. Temperature flow field (Deg C) - Comparison of current layout (top) and proposed layout (bottom) with 100% Fan Capacity (a) with 100% occupancy (b) 50% occupancy at back (row 7 – 12) (c) 50% occupancy at front (row 1 – 6). The range of temperature in the new design is 20°C - 23.5°C which is under the excellent class.

The problem of high temperature at the back and the uneven temperature distribution in the original design have been resolved by the new design. The temperature reduction between the original and new design varies from 3°C to 8°C. The largest reduction is 8°C located at the middle rows. Temperature has been substantially reduced to 23°C from 28°C at the back and the simulations show an even color in light blue throughout the theatre.

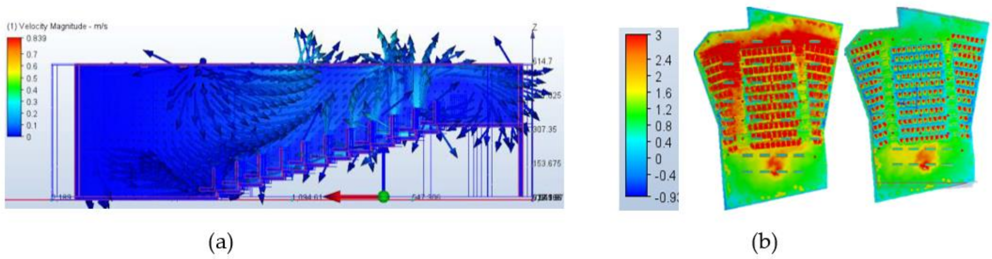


Figure 10. (a) Velocity flow field at 100% occupancy under proposed design. Airflow is seen moving upward due to displacement ventilation and jetting out from the relocated supply duct at the back before being exhausted via the outlets. Velocity sharply increases at the back zone indicating this zone is getting more air flow than before. (b) PMV Flow Field - Comparison of current layout (left) and proposed layout (right) with 100% occupancy under 100% fan capacity. PMV range decreases significantly close to 0 (neutral) in all scenarios with all the zones falling under -0.5 ~ +0.5.

The observed air flow is below 0.1 m/s showing even airflow distribution which is excellent class according to HKEPD standard. A decrease in velocity is also recorded at the front rows which may be caused by the alteration of the main supply air duct from row 6 to row 11. Range of CO_2 level is 424ppm- 450ppm for all scenarios. A reduction of CO_2 level of 11ppm is observed at the front rows while other rows remain unchanged. There is even comfort sensation throughout the theatre and most of the zones fall under 10% PPD which is excellent with 20% and 16% reductions recorded on left and right zones.

3.2. Results from Energy Analysis with eQuest

The difference between total annual electric consumption of 200 and 100 occupants is 25% and such large difference is the result of the substantial drop of chilled water consumption. Light is the only type of consumption that does not increase with the level of occupancy since the light schedule is always 1 ratio when the theatre is occupied in both occupancy scenario. Occupants may be scattered across the theatre for which whole room may need to be illuminated by turning on every light. The equipment schedule is set to vary with the level of occupancy. There are three overhead projectors, computers and an AV room which may also emit significant heat. The equipment load should increase with the level of occupancy since students may bring their own electronic equipment. Since equipment consumes energy and releases heat when being used, it is one of the major contributors of electricity consumption in the theatre.

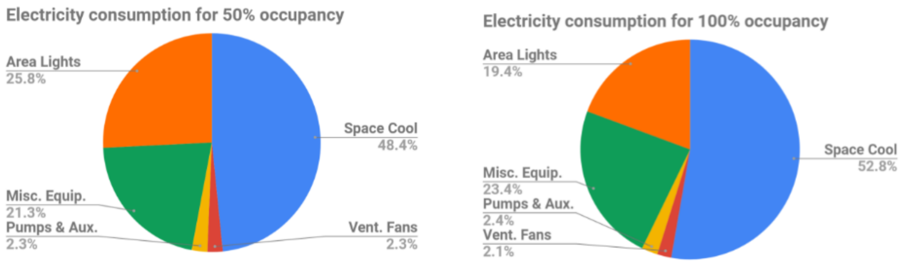


Figure 11. Comparison of Electricity consumption with 50% (left) and 100% occupancy (right) where space cooling is found to be the major contributing source for both 100 and 200 occupants respectively. Space cooling uses 45% more electricity when the occupancy increases to 100%, which means electricity consumption due to space cooling rises 0.9% for every 1% increase in occupancy. The second highest usage of energy is lighting which consumes 7090 kWh electricity in both scenarios. When the level of occupancy increases from 50% to 100%, electricity consumption from equipment rises to 46.5%, which is the highest among different types of energy use. It implies that 1% increase in occupancy causes the rise of electricity consumption of the equipment by 0.93%.

Since space heating is not required for buildings in Hong Kong and there are no refrigerators, water boiling machines and exterior lighting in the lecture theatre, the electric consumptions for refrigeration, space heating, heat pump supply, and exterior lighting are all 0. Electricity consumption of space cooling fluctuates significantly in a year. Since free air cooling is allowed in the winter, space cooling is off from November-March. In contrast, space cooling peaks in the hot season. In July, chilled water consumption, ventilation fans, and chilled water reach their highest consumption which result in higher electricity bill [Figure 12]. For the electricity bills, references from China Light and Power Co Ltd. (CLP), an electric company providing electricity in Hong Kong are used [17].

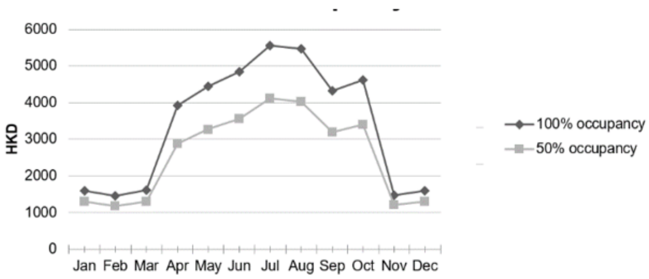


Figure 12. Electricity bill for a year with 100% and 50% occupancy showing the highest bill occurs in July as need for space cooling rises during hot weather. According to simulation, 18300kg CO2 is emitted annually due to electricity consumption and $40882 is the annual electricity fee for 100% occupancy in the theatre. For 50% occupancy, 13765kg CO2 is emitted and the annual electricity fee costs $30751.

4. Discussion

From the CFD simulations of the theatre, limitation of the existing HVAC system was discovered such as 8-h average time should have been given for measurement for validation as established by HKIAQ which was not possible due to time limitation. For both 50% and 100% occupancy scenario, average CO_2 level and air velocity are acceptable. Thermal comfort for 50% occupancy at the front is better than at the back in terms of floor temperature, the average temperature on nose level and the average vertical temperature difference. Therefore, it is recommended for the IAS theatre that all occupants sit at the front to experience a higher thermal comfort level if the occupancy level is equal to 50%. For both occupancies, the temperature at the back is undesirable due to poor ventilation performance. Reducing the level of occupancy at the front has an insignificant effect on the occupant thermal comfort level at the back. Therefore, modification to the layout of air diffusers is recommended as a remedy to the problem. The simulation result shows that the modification has made great improvement in terms of temperature, air movement, and CO_2 level. Large reductions in PPD are also observed between the original and the new design. The lecture theatre fulfils the requirement of an excellent class according to HKIAQ. However, theaters having different HVAC layouts may present different results. Hence, engineers and designers are recommended to utilize the CFD tool integrated with BIM which can apply different air-supply layouts and parameters including size, location, shape of the supply inlets, easily to evaluate the air distribution for the indoor environment, and compute PMV and PPD faster. This practice will ensure the decisions to redesign HVAC layouts according to the occupant behaviour and predict future patterns for both air quality and thermal without comprising both.

Similarly, results from the energy analysis for 50% and 100% occupancy by eQuest showed that space cooling has the highest electricity consumption in both scenarios. According to HK Climate Change Report 2015, the average carbon emission of a person in Hong Kong is 6000kg in a year [18]. Emission of 82,200kg per year from the theater will be equal to emission from 14 people in Hong Kong annually. There are more than thousands of buildings larger than the lecture theatre in Hong Kong and their total amount of CO_2 emission would be a lot. This proves that space cooling is responsible for a huge amount of CO_2 released. Therefore, improving the HVAC system is one of the best ways to reduce cooling energy consumption. Revising the layout without increasing the supply air flow rate is an energy-efficiency approach to improve the thermal comfort level and indoor air quality for the occupant. However, the supply air flow rate is automatically calculated by energy simulation models, the user has little freedom in changing the flow parameter making it is difficult to assess the amount of energy saved by lowering the supply flow rate using the energy simulation tools. Generally, modifying the layout without changing the supply flow rate has the potential of improving the thermal comfort level and indoor air flow without using additional energy to increase the supply air flow rate as well as concurring less cost. Therefore, the possibility of further modification to the layout should be studied in the future to implement such proposed method in other general use cases.

5. Conclusion

Public places such as theaters, offices, or other commercial buildings with unpredictable occupancy patterns, would not be comfortable without year-round control of the indoor environment. The thermal comfort of the building occupants with good indoor air quality are essential design factors for sustainable buildings and present special design challenges for professionals. BIM based simulation is considered as a crucial factor during the pre-design stage as well as in operational phase, to develop a sustainable building design. Contemporarily, researchers only carry out one type of simulation for each study. To study occupant thermal comfort level and the energy efficiency of the HVAC system, an integrated approach of BIM, CFD, and energy simulation was adopted in this project by analyzing different scenarios with Autodesk CFD and eQUEST to obtain a more comprehensive result within a reasonable amount of simulation time and show how the occupant can enjoy a high level of thermal comfort and indoor air quality after the modification.

Contributions: Quazi Samira Rahman, Tsz Hin Jeffrey Luk, Chun Fai Siu and Helen H. L. Kwok conceptualized the study. Helen H. L. Kwok worked on the methodology. Quazi Samira Rahman, Tsz Hin Jeffrey Luk, Chun Fai Siu and Helen H. L. Kwok worked on validation of the model. Quazi Samira Rahman, Tsz Hin Jeffrey Luk, Chun Fai Siu performed formal analysis. Jack C. P. Cheng provided the resources. Quazi Samira Rahman, Tsz Hin Jeffrey Luk and Chun Fai Siu worked on data curation and writing—original draft preparation. Helen H. L. Kwok worked on writing—review and editing. Quazi Samira Rahman, Tsz Hin Jeffrey Luk and Chun Fai Siu worked on visualization. Weiwei Chen and Jack C. P. Cheng worked on supervision and project administration.

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Appendix A

Table **A1.** Data collection from IAS Lecture Theatre at the HKUST

Data Type	Value
Height	14.2 ft
Area	2509.1 square ft (240.6 m^2)
Occupancy	200
Lights	26 Nos 52W round downlights
	32 Nos 56W double parabolic fluorescent luminaire
Diffusers	70 for displacement ventilations, 1 ceiling air inlet and 2 ceiling air outlets.
CO_2 Concentration	462 ppm (average)
Air Velocity	0.2 m/s (average)
Temperature	22.1^{o}C (average)
Relative Humidity	74% (average)
Total Air Flow Rate	2.83 m^3/s (60% fan capacity)
	4.73 m^3/s (100% fan capacity)

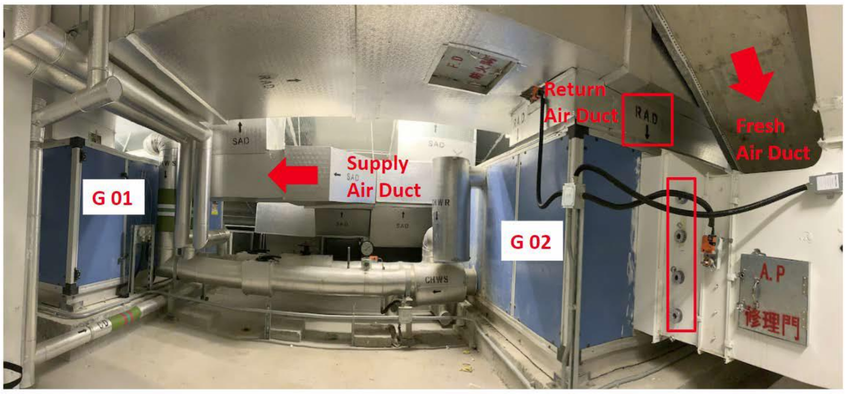

Figure A1. HVAC system arrangement in IAS lecture theatre

Table A2. Parameters used for Energy Analysis in eQuest

Data Type	Value
Climate Zone for Hong Kong [ASHRAE]	2A (Hot-Humid)
Operating schedule	9:00 AM – 5:30 PM, Monday-Friday, closed on weekends and holidays
Area per person	13ft^2
Sensible heat gain for seated occupant	245 Btu/h-person
Latent heat gain for seated occupant	155 Btu/h-person
Total light level	3144 W
Concrete wall thickness	0.656 ft
Operation of lights in closing hour	5%
Operation of equipment in closing hour	20%
Equipment Power Density	0.93W/ft^2
Required minimum OA flow/person	17 cfm
Required minimum supply rate ratio	0.3
Typical motor efficiency	0.86
Typical fan efficiency	0.6
Typical impeller efficiency	0.77
Typical chilled water design temperature	7^{o}C
Typical chilled water design temperature difference	5.5^{o}C

Table A3. Boundary Conditions for CFD Simulation

Data Type	Value
Air inlet scalar condition	0
CO_2 inlet scalar condition	1
Density for 400 ppm ambient air	1.2047g/cm3
Conductivity for 400 ppm ambient air	0.024W/m-K
Density for pure CO_2	1.773g/cm3
Conductivity for pure CO_2	0.0146W/m-K
Diffusivity coefficient for air and CO_2 mix	0.16 cm^2/s
Total Heat Generation for human	100W
Scalar boundary condition for nose level	40000
Iterations	1000
Thermal comfort factor	1 CLO value
Metabolic Rate (ASHARE standards) [2]	60

Relative humidity for field validation	69%
Relative humidity for scenario analysis	74%

Table A4. Results from Energy Analysis

Data Type	Value
Carbon Emission from theatre	0.50 kg CO_2/kWh
Total annual electric consumption (100 Occupants)	27530 kWh
Total annual electric consumption (200 Occupants)	36600 kWh
Total annual chilled water consumption (100 Occupants)	8068 kWh
Total annual chilled water consumption (200 Occupants)	127755 kWh

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The Transition to Renewable Energy: Should the Adoption of Innovative Energy Technologies be Made Compulsory?

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Abstract: For several years the world has grappled with a rising energy challenge, the current global COVID-19 pandemic has, however, added to this crisis and left an undeniable impact on society and energy use. According to the International Energy Agency (IEA), although global energy consumption dropped in 2020, there was an increase in household energy demand due to lockdowns around the world. In recent times, various innovative technologies have been developed to promote renewable energy or reduce energy consumption. The scope of this paper lies within the debate associated with mandatory policies on such building and energy technologies, and related stakeholder views. The conflict of opinion stems from the fact that although there is a need for these innovations, novel technologies tend to be expensive or sometimes, complicated. The aim of this study is to explore the two sides of this debate and outline a rationale for guiding energy and building related policies. This investigation was conducted using an exploratory qualitative model and a series of semi-structured interviews with eighty-six residents in the United Arab Emirates (UAE). The example of Building Integrated Photovoltaics (BIPV) was used as a case study energy innovation and study participants were selected from various occupations and backgrounds across the country. The thematic analysis of the findings suggests that there is a strong belief that mandatory policies are necessary to promote innovation adoption. On the other hand, however, it was the opinion of some study participants that complexities in application, high-cost and certain social dynamics discourage residents from applying said technology. It was opined that the government could reduce these challenges using various supporting policies and initiatives. The study provides a balanced debate to the case of innovation adoption in cities and provides guideposts for renewable energy policy formulation.

Keywords: Innovations, Building Integrated Photovoltaics, mandatory policy, renewable energy, stakeholder opinions.

1. Introduction

The built environment and building industry account for over 40% of global energy consumption, 36% of all CO2 emissions [1,2], and 28% of Greenhouse gas emissions [3]. The implication of these facts is that the building industry is in dire need of global strategies to reduce its negative environmental impacts. A considerable part of the energy used in buildings is needed for space heating and cooling. While heating, ventilation, and cooling account for 35% of primary energy use in America, projections suggest that China will reach the same level by 2022 [4]. However, the United States Energy Information Administration (EIA) has predicted that global energy demand will increase by 50% by 2050 [5]. The International Energy Agency has also stated that due to rising temperatures in the summer, the cooling demand for buildings has risen sharply, causing energy consumption to increase [6]. On the other hand, about 70% of electricity produced in the United Arab Emirates (UAE) country is consumed by buildings, with almost 70% used for cooling [7,8]. Additionally, the weighted average for per capita energy consumption in the Gulf Cooperation Countries (GCC) is seven times higher than the global average [9].

The UAE is a foremost emerging economy with over 10% of the world's oil reserve, and a leading hub for innovation. Abu Dhabi is the capital city and is one of its 7 emirates; others are Ajman, Dubai, Fujairah, Sharjah, Ras Al Khaimah and Umm Al Quaim. Of the 9.3 million residents of the UAE, about 80% are foreigners from over 200 countries of the world. Population growth, urbanization and industrialization in the UAE have led to the challenge of rising energy demands over the past few decades [10,11]. In addition, urbanization, economic growth, and financial development increase residents' purchasing power [12]. Combined, these factors directly and indirectly increase the propensity for greater energy consumption via appliance purchases, housing demand, city infrastructure and overall economic activity [12,13].

In response, the UAE 2050 National Energy Strategy indicates a planned transition to a modern 21st Century sustainable economy [14], aimed at having 50% clean energy in the energy mix by the middle of this century [15]. In line with this, there was a 360% increase in solar technologies adopted in the UAE between 2013 and 2018 [16]. Although the UAE has given significant attention to renewable energy and other sustainable policy initiatives, much of these require innovative technologies to meet these requirements. To be specific, the UAE has shown substantial interest in solar energy building technologies such as Utility-scale PV, Solar Hot Water Systems (SHWS), Building Integrated Photovoltaics (BIPV) and rooftop solar PV.

The current challenge, however, is that among UAE residents, there are multiple perceptions and opinions towards innovative solar technologies, compared with other conventional energy sources [17]. For countries like the UAE interested in innovative energy technologies, this scenario has sparked a layered energy debate. On one hand, innovative technologies are needed to promote sustainability but on the other hand, these innovations have been reported to be either expensive or complicated which makes adoption or diffusion a problematic venture [18,19]. The critical issue here is not a scholastic debate on merits and demerits of innovations but on mandatory policy which compels residents and professionals to adopt innovative technologies. In a recently completed PhD research by the first author [17]; this scenario was broadly investigated based on a rigorous literature review and a focus on Building Integrated PV as a case study. This current paper is a subset of that research and focuses on the policy debate: *should mandatory policies be made to compel the adoption of innovative energy technologies?* The aim of paper is to highlight the two sides of this debate and outline a rationale for guiding policy development.

The outline for this paper is as follows; Section 2 summarizes key literature that highlight the benefits and barriers associated with innovative technologies, and key energy polices in the UAE. Section 3 describes the qualitative research design that was used for this investigation while Section 4 presents the findings and discussion in line with the research question. Section 5 provides critical recommendations for research, practice, and policy development, and makes suggestions for further research. The conclusion of this study is summarized in Section 6.

2. Innovative energy technologies

Critics argue that innovations are difficult to measure, disrupt systems, and conflict with the status quo [20]; thus, creating stress on existing lifestyles and culture. Nevertheless, innovations solve problems, provide a new perspective to erstwhile complex challenges, and promote technological growth that generally benefits our way of life as humans [17]. The Organization for Economic Co-operation and Development (OECD) (2005) defines innovation, *"as the implementation of a new or significantly improved product (good or service), process, or delivery method, a new marketing method, or a new organizational method in business practices, workplace organization or external relation"* (OECD, 2005; pp 46).

Building Integrated Photovoltaics (BIPV) is an innovation in photovoltaic (PV) technology which converts the building from an energy consumer to an energy producer [21]. BIPV multi-functionality means that this innovation can serve multiple functions simultaneously or independently depending on its design. For example, BIPV can serve as a means of advancing net-zero targets [22], to allow daylighting and view; or to serve as safety glass, shading device, or a privacy screen [23–25]. BIPV represents architectural innovation and building component advancements which promote green product ingenuity as it harnesses renewable energy. Such product developments have been described as valuable radical innovations which embrace both a technological and business perspectives [26]. In the discussion on BIPV technology, these assertions, and concepts can provide a holistic guide towards understanding the potential characteristics of the BIPV technology. At the same time, they may be able to shed light on developing a sound, research-based strategy for facilitating its adoption.

2.1 The debate: benefits of adoption

There are significant benefits associated with the adoption of BIPV and these suggest a supportive perspective that it should be promoted by policies in view of the environmental need already highlighted in the Introduction. Four classes of added benefits from literature relate to the use of BIPV as an energy source or as a building material -including design, economic, social, and environmental advantages. Economic benefits are financial advantages which accrue to users; including cost savings [27,28] and material cost reduction [29]. Environmental benefits can be on a micro-level relating to the project [30,31] or macro/environment level relating to less embodied energy of materials [32]. Social benefits imply a direct impact on the lives on the individuals and community at large [25] and on the health of the public and the environment [28]. Finally, design benefits imply architectural design gains of BIPV as a building component such as aesthetics [33], view and daylighting manipulation [25,34] and as shading devices [33,35].

In a previous work, the significance of BIPV from an energy and building dimension was reviewed [36] to shed light on the benefits from a different perspective. The review expounded on the energy-related and design-related benefits of BIPV as a building component. BIPV maintains the clean renewable energy status of the PV technology but also goes beyond to address some of the challenges faced by utility-scale PV. As a decentralized or onsite energy generating source, BIPV provides power right next to the point of use. This addresses the transmission and conversion losses of utility- scale photovoltaics as it provides micro-energy power generation close to the primary load [37–40]. In the process, this removes the need for the transmittance of electricity over long distances from power generation stations and could incidentally reduce transmission and distribution (T&D) costs and line losses [30,31,41]. Capital expenditure for land, infrastructure and maintenance is also removed as the building envelope provides the needed supporting structure for the solar panels (Bakos et al., 2003; Byrnes et al., 2013; Sharples & Radhi, 2013; Yang & Zou, 2016). From a social point of view, BIPV also provides users with a degree of energy security, supply, control, and autonomy as it potentially encourages household load-shifting and reduced levels of energy consumption [42,43]. Cost benefits with BIPV and financial savings from Feed-in-Tariffs (FITs) lower cumulative costs and improve the cost balance such that the equivalent cost of electricity is close to zero [27,28,44].

2.2 The debate: barriers of adoption

In global terms, the existing literature affirms the presence of BIPV adoption barriers. In previous studies, barriers of BIPV have been elaborately described [18,19,45]. Several considerations raised relate to the economic, knowledge, design, and social, environmental, industrial as well as policy contexts. In relation to the policy aspects, there have been studies which highlight how it stands as a significant barrier in the bid to promote the adoption of renewable and innovative technology. Boesiger and Bacher (2018) argue that when owners and architects are not pressured by policy or politics, there is simply insufficient reason that persuades them to adopt BIPV [46]. Another study reported that based on low approval rates, local authorities seem to disprove BIPV, and this could hinder the possibility of having future projects [47]. The study also reported the lack of precise standards and codes for BIPV, while also noting that this does not give guidance for planning. Curtius (2018) also agrees that when BIPV-related building codes and standards are not established, diffusion is invariably hindered [18].

In the absence of policy guidelines to predefine which projects are approved or which codes to adhere to, Strazzera and Statzu (2017) reports that condominium dwellers who were interested in installing solar PV, complained of not obtaining an approval [48]. However, Curtius (2018) explained that in the approval and vetting process, Municipal building commissions aim to maintain or preserve the local character of the urbanscape [18]. As a result, BIPV façade proposals, for example, are met with very stringent constraints. The absence, inadequacy and changing character of government incentives were noted as limiting factors to the diffusion of BIPV. It was also reported that frequent policy changes or fluctuating agreements create stress in the administrative procedure for BIPV adoption [46]. Low government support combined with unwilling developers [45,49], as well as an overall lack of market establishment were noted as interrelated challenges [50].

2.3 Current UAE scenario

Member nations of the Gulf Cooperation Countries (GCC) include Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE); they are rich in oil and depend on this resource for domestic use, and export. It has been reported that all GCC countries are listed among the top 25 nations, globally, with the highest per capita carbon dioxide emissions [14]. The UAE consists of the seven emirates or states; Abu Dhabi is the largest, controlling 90% of all oil and gas reserves. Beyond its vast fossil fuel resources, the UAE has, however, shifted its attention to sustainability and energy accountability towards a safe environment [51], reducing dependency on non-renewable sources and increasing its economic diversity in the process. As a classic example of this, oil rents in 1979 contributed 60% of the UAE's Gross Domestic Product (GDP) and fell to only 18% in 2010 [52].

In 2008, Abu Dhabi invested $15 billion to build a novel ultramodern zero-waste, carbon neutral urban development called Masdar City 11miles outside the city for 50,000 people [53,54]. Since then, other investments in renewable energy projects have been made as shown in the list below:

- 1,013 MW Mohammed bin Rashid Al Maktoum (MBR) Solar Park, which is the largest solar park in the world
- 1,177 MW Sweihan solar power plant
- 100 MW Abu Dhabi's Shams 1
- Over 145 MW Rooftop Projects across the country (MESIA, 2018)
- 2 GW Al-Dhafra Solar PV IPP project

Beyond this list of mega renewable projects are government policies which support innovative energy technologies in the UAE. Specifically, there is also a push for programmes and green grating systems such as *Estidama's* Pearl Building Rating System (PBRS) in Abu Dhabi, Dubai's Green Building Rating System, and Ras Al Khaimah's *Barjeel* Green Building Rating system. As a focus on the national capital, Abu Dhabi, *Estidama* which means —sustainability in Arabic, was set up in 2010 as an initiative developed and promoted by Abu Dhabi Urban Planning Council (UPC). It aims for building, sustainability and related, system regulations which can, among other criteria, impact the consumption of energy and water with a 30% reduction [55], though its green building rating system; the Pearl Building Rating System (PBRS). It was developed using elements from the Leadership in Energy and Environmental Design (LEED), and the British Building Research Establishment Environmental Assessment Method (BREEAM) rating systems. This was done, however, by considering the unique local context, its environment, and related concerns [56].

One study suggests that the concept of sustainability in the UAE has grown across the country, and is recognized by the academia, research, and political sectors[57]. The authors also assert that the current target is to bridge the gap between policy formulation, and policy implementation. Thus, this research seeks to highlight the dissenting perspectives towards promoting innovations in line with these policy initiatives.

3. Method

A detailed description of the research design for this dissertation has been reported [17]. Beginning with a social constructivist worldview which has become embroiled in research philosophy, the study design aimed and worked with the notion that the construction of knowledge is based on the individual's social interaction [58,59]. It upholds the idea that in any social setting akin to a research context, knowledge is the result of social interaction, while experiences and backgrounds become the source of ideologies and opinions. A qualitative research approach is deemed appropriate when the priority is the evaluation of a subject by authentic human experience, unhinged by constraints of firmly defined prescriptive procedures, guidelines, or numerical statistics common to the quantitative ideology [60].

A series of qualitative interviews were conducted with 86 study participants in the UAE. The sampling was random but purposeful to elicit information from the most credible sources. Sequel to selecting the right participants from the defined stakeholder groups in line with theoretical principles and previous studies, developing the right questions, and determining the appropriate kind of interviews were also considered to facilitate the data collection process. These important steps were taken to guide the researcher during the interviews process. The interviews conducted were carried out in two phases: phase 1 was 18 informal conversation interviews, and phase 2 was 68 semi-structured interviews. A few pilot interviews were also conducted before each stage.

Participants included architects, researchers', PV specialists, engineers, policy makers and other residents from a non-technical background. The study was approved by the UAEU ethics committee, participants were sent prior notice to request consent and location, and the interviews were recorded after permission was given to do so. The interviews were an average of 30 minutes and were all conducted in English. The analysis of the interviews was conducted using a thematic and a comparative analysis of the transcribed interviews based on literature [61]. Networks and charts were used to outline, delineate, and summarize 660 pages of transcripts into multiple diagrammatic representations of the narrative which was distilled from the interviews. This paper focuses on the findings on the study which relate specifically to the role of policy in the diffusion of innovations.

4. Findings and Discussion

The interviews conducted revealed that there several aspects to be considered in the evolving debate on mandatory policies for innovative energy technologies. Two broad views were apparent in the narrative which ensued from the analysis, and they are discussed here as opposing views in the current debate. The first view is the position is that policies should not be made mandatory because BIPV, as an example of an innovation has significant technical and non-technical barriers. The second position suggests that since barriers can be systematically addressed by specific drivers, and there is a valid need for them, then mandatory policies are crucial. This section elaborates on these views using direct quotes from multiple study participants

4.1 Perspective 1: Mandatory policies should not be promoted

This perspective is supported by a multi-layered network of BIPV barriers which make adoption difficult and thus, suggest that it should not be supported by mandatory policies. These barriers are the findings of the thematic analysis and are related to knowledge and awareness, design, economic, social, and environmental concerns. These themes have been presented below to situate the position of the debate from this perspective

1. There is a lack of BIPV knowledge and awareness

The knowledge barrier identifies with the broad issues of awareness, information and understanding of BIPV as a technological innovation. Multiple participant opinions reflect the impact of a lack of general knowledge and awareness about BIPV. However, some opinions seem to border on skepticism and misinformation, lack of education and knowledge about design tools. Listed below are excerpts of participants' comments which back this barrier.

R09ARE: It is complicated because ninety-nine percent of the architects or designers do not have enough knowledge about PV. That is complicated.

R26OCE: If you went to most of the MEP consultants in this part of the world and demonstrated integrating solar panels into a building, they'd look at you with a blank face because they wouldn't have a clue.

R21PVE: *... I speak with people, they ask why the Shams Dubai installed PV on buildings... But people say funny things like, they think they won't have to pay DEWA for electricity bills, or they will use it for the ACs."*

2. There are major design-related problems

This concern covers issues that are related to the conceptualization, design, and installation of both the BIPV, and the PV system which supports it. Within these stages, barriers were identified by the interviewed stakeholders; these relate to the product, design requirements and the architectural design process. Participant views indicated fears related to poor aesthetics, design complexity, lack of space and lack of examples to compare it with.

RO4AE: *To me as an architect, currently using these solar panels to provide a good aesthetic for the structure for the building doesn't always work out. It's mostly ugly buildings; it's hard sometimes to integrate it to make good looking buildings.*

R56CE: *"If it looks like what I've seen then it will be big and bulky and just more functional looking; it wouldn't be the first thing I would go buy…just looking at it, I don't think I would like it.*

R11ARE: *Actually, it's a strange idea. It could open new doors for the clients or new door for questions for the client, and then new headache for the consultant.*

3. There are social dimensions that make it impractical

The UAE social community was considered of this investigation, in line with "context" and the social constructivist epistemology of this research. This concern identifies issues with strong bearings on the social life in the UAE. Home ownership and its related challenges to Expatriates, aspects of social culture and preferences of citizens, as well as the general lack of interest, highlight the considerations from participants which infer the impracticality of adopting BIPV.

R14ARE: *I would love to have technologies in my house, but you know it's not always in our hands. It's the owner's decision from the beginning and at the end*

R46CE: *The thing is if you are talking about expats or…I don't know people here, when everybody gets houses, they just rent whatever is available. So, they don't have the choice of putting something on the roof, you know it's not their own house.*

R62CE: *I only want the system if it's my house … to put a system on you landlord's property, number one it comes with permissions that you have to get and all kinds of different stuff. And then what happens next year if he decides he no longer wants to rent the house to me? I've got solar panels that I need to deal with, so…*

4. There are also significant cost/economic considerations

Participants also raised various shades of financial considerations in the adoption of BIPV relating directly or indirectly to the price the customer will incur in the purchase of a BIPV system. Areas identified include the presumed high cost considerations, long return on investment (ROI) and impact of the subsidy on conventional energy infrastructure provided by the UAE government – being a clear alternative to BIPV. Also, from a business/practice point of view, consultancy firms are faced with the priority of profit and economic benefits to justify their investments which further complicates the BIPV venture.

R03AE: *…clients are afraid to try it because it costs a lot*

R19PVE: *Look at the idea of the cost of BIPV. It is a misconception. I did my personal research, and it is just about 10-20% extra on the cost.*

R63CE: *I think it's the cost. The cost of the technology is expensive, and the comparative service or product, which is electricity, is relatively cheap*

5. There are clear environmental limitations of the technology

Solar technology is clean energy, it is renewable and sustainable energy from the sun, but its critics express its dependence on the sun, its intermittent supply and other environmental issues as key barriers. Since BIPV is based on solar PV technology, it has similar environmental challenges, and some more which are unique to the UAE such as the impact of sand and dust, the maintenance challenge, and high regional temperatures.

R05AE:	*I have to open a hatch in my ceiling, pull down a ladder, climb up it, get water thru the hatch on to my roof, get on to it, which has a parapet which is only 400mm high. So, really, I shouldn't be going up there, or asking any family members or people who work for me to go up there."*
R28OCE:	*The main problem is fine sand and fine dust going and settling and you know with a little bit of moisture it sticks to it. That is what the problem is. If you put them on the roof and there is some sand or something like that that settles, then it is blocked...but the main problem is the unscheduled maintenance that kills you*

4.2 Perspective 2: Mandatory policies should be promoted

This perspective argues from a proactive approach, using a systematic argument to debunk the first perspective. The opinions which build this perspective argues that, firstly, all barriers of BIPV innovation can be resolved using multiple strategies. Secondly it argues from a place of need, asserting and agreeing with literature, and making a call for sustainable energy initiatives. The results of the thematic analysis, as well as a comparative analysis to juxtapose BIPV barriers with drivers shows how each argued barrier can be addressed. The summation of this perspective is that since the said barriers can be addressed, and the need for BIPV innovation still exists, then mandatory policies should be put in place.

1. All said barriers can be addressed

The findings of the study which support this opinion is presented based on the adaptation of a force-field diagram: a tool that outlines interacting factors [19]. The approach is based on the fact that drivers can resolve specific barriers. For example, improved aesthetics is a design-related driver but can address design issues of beauty and used an as marketing tool to address the lack of information (knowledge-related barrier). Table 1 below presents an extract from the application of the modified force-field diagram (see Figure 1) which shows how drivers can be used to track and resolve barriers. The table, on the other hand, shows how each argument in Perspective 1 is argued against, by study participant comments to support Perspective 2.

Table 1: Resolution of barriers to innovation adoption

Barriers: Focus of Perspective 1	**Drivers: Argument of Perspective 2**	
There is a lack of knowledge and awareness	R40CU	*If it starts with them (people at high places), and they encourage people to save the planet, go with our renewable energy and stuff like that, they would immediately agree and then go with it*
	R11ARE	*I haven't met any person trying to market for solar panels. This is a very important point. It means that there is a gap between the manufacturers and the designers and the consultants. Actually, if we close the gap, it would enhance the percentage of using solar panels because architects can convince clients."*
There are major design-related problems	R15ARE	*The society here cares so much about the aesthetic or how things appear...I believe if you want to use it here, you need to come up with a unique architectural design; hide or professional blend these within the skin."*
	R17ARE	*In my opinion, the people who want to make a good system of integration building, they should consider it in the first start, not at the end. Once they start the design, they put it one of the goals*
There are also significant cost/economic considerations	R04AE	*Because not all people are interested except if it can produce (financially), I think, an economical benefit, that's what I think. That's how people are interested in the environmental sense of the solar energy and all these topics*

There are clear environmental limitations of the technology	R68DE	*Definitely UAE has big potential of coming up in this market, provided proper researches are there, and the studies should be suitable for this climate, from this geographic place."*

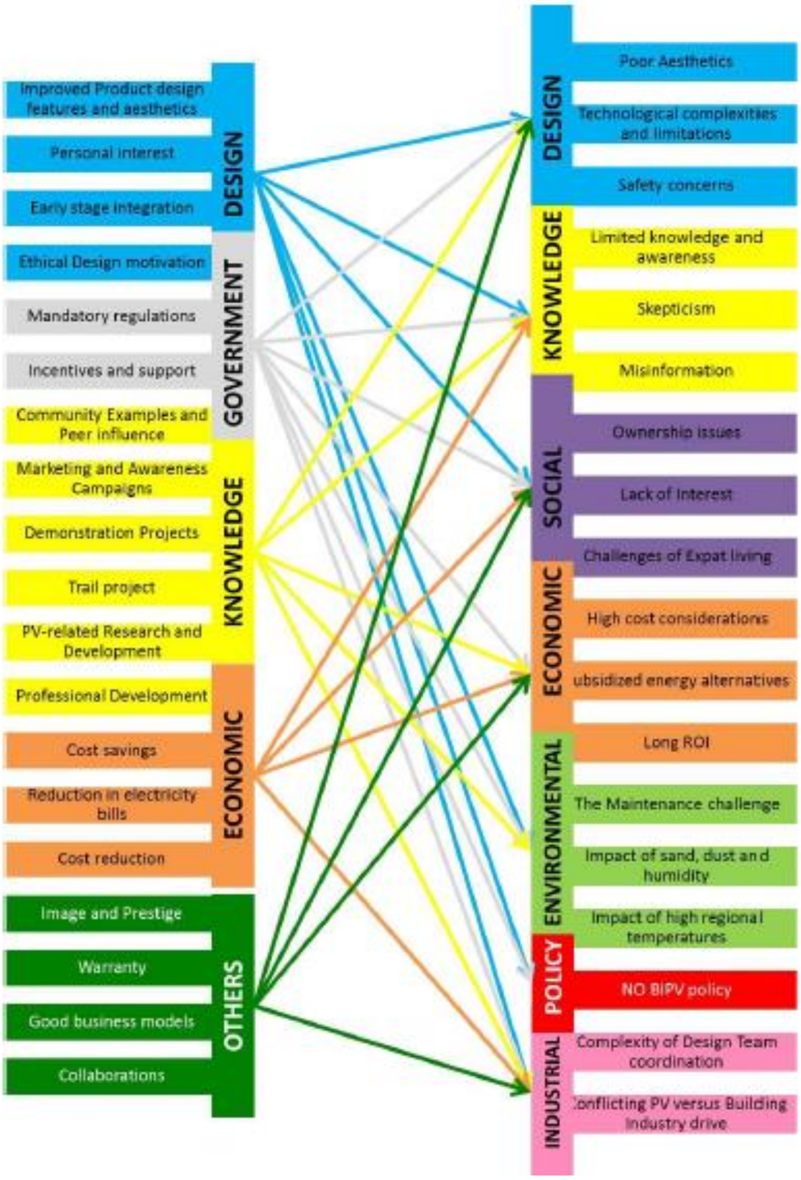

Figure 1: Drivers vs Barriers of BIPV

2. Even though there is a critical need for sustainable innovations people do not act without pressure from mandatory policies

As a starting point for this position, an architect who participated in this study stated that the building construction industry is ultimately driven by regulations. He went on to assert that, "*if it (BIPV) had been through the mill of (the UAE) Civil Defense (CD) and they were comfortable with it, and the Municipality was comfortable with it, then those are huge steps forward. So, that level of acceptance and understanding is massive"* (R05AE). Although he mentioned that the market tends to be *"price driven first and then regulations second"*, he inferred that regulations compel interest which may have been lacking in the first place. He also emphasized that if these regulations are supervised by the government, people will adopt the technology. He added though, that they may start by asking for green strategies to only meet the minimum regulations needed to secure a building permit (RO5AE). Mandatory regulations were thus presented as a positive force, a tool which gives people a 'why' should I adopt it? (RO4AE), also evoking a high level of acceptability and understanding (R05AE).

Another suggestion was made that the government make the application of solar PV/BIPV a policy, a part of the building code or regulations (R12ARE), with policy control to mandate it

(R18PVE). In agreement, two participants said that this kind of mandate would definitely make people start to use said technologies (R18PVE), because *"no one wants to pay a fine"* (R12ARE). On another note, rating systems such as *Estidama*, or DEWA and Abu Dhabi Manuals for Energy and Water (R29OCE), were raised as strategies to further encourage residents to adopt the BIPV technology (R03AE; R13ARE; R16ARE: R32OCE; R34OCE). Referring to *Estidama* which is compulsory for government projects (R09ARE), one consultant noted that as it needs a Pearl Qualified Professional (PQP) and has minimum regulations, *"you have no other choice but to comply"* (R11ARE).

However, there was another dimension presented to support this perspective: the place of supporting policies which promote incentives for adoption of BIPV. This point was mentioned from the position that mandatory policies should have a subset of incentive policies. Table 2 below shows a list of suggested incentives which study participants mentioned as a support mechanism in conjunction with mandatory policies.

Table 2: Suggested Incentives to support mandatory policies and innovation adoption

Incentives and support policies	**Participant suggestions**	
Funding and Subsidies	R28OCE	*The government should identify the problem as the maintenance and give incentives for companies or research institutions to work out solutions to automated maintenance*
	R47CE	*I mean if you get a government initiative, for example, that says "look, we are going to give you fifty percent off if you do so and so", especially if it's over time, you will have pretty much almost everybody rushing for it*
Grid Connection	It was suggested that this driver is important because without it, batteries would be needed (R32OCE) which ultimately increases the cost by as much as 60% (R27OCE). It was implied that the aim should be the provision of a license to allow for installation and connection to the grid (R25PVE).	
Net Metering and Feed-in-Tariffs	R31OCE	*So we are not working with a feed-in-tariff here we are working with the net metering; in netting you basically consume what you produce, and if you produce more it's going to be fed into the grid and then basically credited in the future months so that you can actually take it back from the grid; it's a netting mechanism which has been very successful*
Certification of Services, Products and Companies	Two consultants asked for the development of a list of approved suppliers and companies with guarantee of quality for solar PV products (R07AU; R33OCE), and these companies should have passed some pre-testing (R33OCE). This can be done by state electrical providers to help ensure some guarantee (R24PVU).	

Several other studies, agree with the current study findings: where there is no BIPV policy, residents are not compelled to adopt [18,46]. Due to this lack of policy-induced pressure to act, the sustainable drive and agenda of the UAE government needs a regulatory framework for BIPV. This may take the form of policies, with supporting codes and standards, or guidelines to direct specifications for product and building integration aspects such as, material selection, thermal properties, and fire protection. Other ideas such as set or flexible percentage of energy need covered by BIPV per building/household, grid integration, and specific policies or guidelines for financial incentives, maintenance, transfer of ownership, and approval process may well be required to further adoption.

4.3 Further research

Three identified aspects for future studies relate to methodology, scope, and region. Firstly, a quantitative study could be deployed to generalize the findings, explore a wider range of potential perspectives, and review existing policies from the view of residents. Secondly, there are specific issues which this study was not able to investigate due to the fact that it is one of the first in the region. Consequently, other researchers may choose to focus on a more structured scope such as the role of construction innovation principles and practices in the UAE viz-a viz the UAE building code. Elaborations from a theoretical, conceptual, ideological, or statistical position may be engaged. Finally, the UAE is composed of seven different Emirates with energy and governance patterns which differ slightly. In relation to energy and the built environment, studies which focus on a particular Emirate, reviewing the diffusion of innovations in line with policies may provide significant insight. Additionally, comparative studies across the country, reviewed with data from studies in other countries, would provide lessons and new insights which may be applicable to promote global renewable energy transition.

5. Conclusion

This study has aimed to answer the question: *should mandatory policies be made to compel the adoption of innovative energy technologies?* BIPV was used as a case study of innovative energy technologies and the study was conducted using a qualitative approach. The opinions of the 86 study participants were summarized into two distinct perspectives or sides to the debate under review. The findings suggest that one group of people believe innovations have barriers and are complicated, therefore mandatory policies should not be made. The other group argues that said barriers can be resolved by drivers, and only mandatory policies will compel people to act. This second perspective also provides suggestions for incentives and other support mechanisms which should be promoted along with mandatory policies.

In conclusion, the issue of mandatory policies in the study context requires a balanced, non-partisan consideration of the barriers, as well as the drivers, and the incentives necessary to reduce complexity, and remove the financial burden associated with the diffusion of innovations.

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Vertical Gardening: An Easy and Affordable Module for Domestic Installation in the Context of Khulna City

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Abstract: Vertical gardening is a common concept nowadays for sustainable design and space quality enrichment. With the flow of time, these modules and concepts are becoming more efficient and functional day by day. For different contexts, weather conditions and surrounding facts the choice of plants and soil mixture differs. This study mainly aims to introduce an easy and cost effective installation module for the context of Khulna City which is not only eco-friendly, energy saving and temperature controlling but also has a high aesthetic value and timeless texture for simple domestic buildings especially in warm humid climate. In this study we have tried to develop the module and taken care of every step such as frame making, soil mixing, plantation etc. and observed them closely day by day in natural weather and sun conditions. By trying and observing different plant growth rate, soil retention level and need of care we have selected a particular plant which gives the best result for plantation on a vertical tile module. Through the steps of research we have studied various literatures, reviews, theories and modular systems. This study involves contextual materials, plants and ingredients to develop a module of vertical green tile which is comparatively cheaper than most of the quality tile modules we usually use as finish materials on outdoor, semi-outdoors. This unique module and its cost effectiveness compared to normal tiles will encourage people to develop mass production and use them as finish material in the context of Khulna city in future which will not only bring them weather protection and aesthetic value but also will enrich the space quality, thermal comfort and architectural values.

Keywords: Vertical gardening, Cost friendly module, Easy Installation method, Contextual materials.

1. Introduction

Khulna, being the third largest cities of Bangladesh, falls a victim to rapid urbanization as a result facing hike in the rate of Land Use Land Cover (LULC) [1]. This situation is deteriorating when a lot of climate migration took place in the recent years and occupying the open abandoned urban spaces by making slums and squats to meet the demand of their shelter [2] which on the contrary, deteriorating urban open spaces and vegetation. As the city is losing its natural settings while giving room to the build-up area, the land surface temperature (LST) is also on the rise [3].

In order to mitigate the adverse climatic condition, incorporating green vertically to the outdoor and semi-outdoor walls can be a solution that is already found in history. Green modular walls have a greater impact than installing horizontal green because in the urban areas the proportion of horizontal surface available is almost half than that of the vertical green surface [4] Its functionality and benefits are also very diverse from ameliorating both indoor and outdoor air quality [5-7] to working as a good thermal insulator than hard surface [4] , from increasing the aesthetic value of the space to housing several microorganisms, birds and insects etc. is undeniable [5-7].

Unfortunately it is not widely used in this region. Our aim is to provide a green wall tiles module that is durable, cost-efficient, easily installable, aesthetically pleasant, environment friendly alternative to the outdoor/semi-outdoor conventional wall cladding module that is made up of local materials as well as choose a local edible, medicinal plant that grows horizontally with foliage that covers soil below it. We build a rectangular module in which the tray that holds the soil and plant measuring 1'6"/1'and made of local wood, and also used a local plant "Pudina" (*Mentha arvensis*) that is native to Bangladesh, the apple mint or round-leaved mint, is a member of the mint family Lamiaceae [8]. It is a herbaceous, upright perennial plant that is most commonly grown as a culinary herb or for ground cover which is also rich in medicinal and economic value. [9]

The foliage of the herb covers 90% the whole module within 3 months (presented briefly in the experiment). This creates a green layer that will provide a shading to the wall that will help to lower the indoor temperature [10], as well as it is edible and local people used to make beverage and oil out of its extra grown leaves [11] and also aesthetically pleasant when installed on the wall. If we install this modules at a large scale and insert vertically, it don't requires any horizontal space thus creating an efficient solution for rehabilitation of urban vegetation [12].

Moreover, incorporating this module in a mammoth scale in the city level, it is possible to revive a portion of urban biodiversity which can accentuate ecological conservation [13]. It can also cut off temperature while impacting positively in mitigating heat island effect of that region [14]. The vegetation present on the large walls possess therapeutic effect on the dwellers by creating a positive impact on their psychological comfort. Moreover, It positively affects the socio- economic wellbeing of people by improving city image at the same time increases property value [12]. It also serves the building by creating both thermal and acoustic protection [15-17]. Vegetated green module also absorbs dust, greenhouse gases, solar radiation prevalent in the atmosphere and plant's evaporative cooling effect accentuates comfort in the living areas.[4]

In this paper we have worked to introduce a contextual and cost effective green tiles module for semi outdoor or outdoor walls. Experiments were conducted to select the best plant, soil mixture ingredients, module size etc. We have tried to explore a local installation method with the help of local nursery experts and their expertise.

2. Materials and Methods

As mentioned before we have focused on the module based living wall system for semi outdoor and outdoor use only. From the well-known Classifications of living wall system according to their construction characteristics [10]

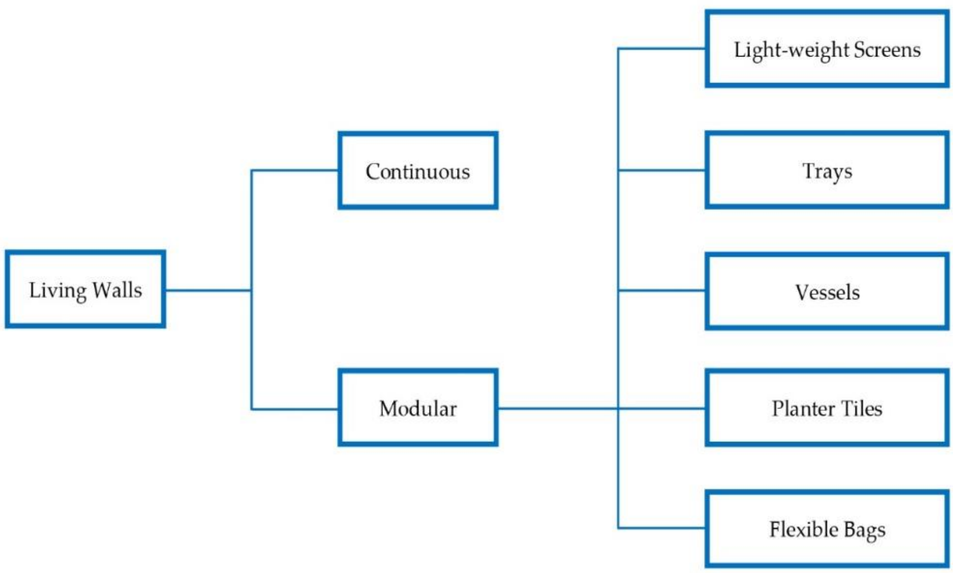

Figure **1.** Classification of Living walls According to Manso & Gomes

We have chosen the "Planter Tiles" system from the Modular section of Living Wall Classification from Figure 1 and started working on that particular section. Here we have followed the Action Inquiry Cycle according to the Applied/ Action Based Research Method as the main methodology to achieve our goals by respecting the local context and issues.

Our main study was based on a mixed method approach using concurrent procedures following Creswell method [43].The study was conducted in stages until the expected result of overall research was achieved.

The first stage was actually target fixing and working on research objectives. It has involved the literature review to gain the theoretical knowledge and understand the present working scopes of this experiment. By following the study, we found the cost, maintenance and availability issues, which we try to focus on in this research. This has helped us to fix our Research objectives.

In the second stage of this research, along with the literature and theoretical studies the team started the field survey to gather the practical information. Here the team was focused on the expert interviews and physical surveys of various nurseries. Various technical aspects about soil making (Table 01), plantation, module making and marketing were learnt from the experts and surveys.

Stage three is mainly practical work based. In this stage, we finally choose three plants (Figure 7(a) Figure 7(b) Figure 7(c)) from our survey outcome to experiment with. According to the previous studies and cost estimation we fix a module size (18" X 12" X 2") which is convenient in our local format. We also worked on its material, making and soil setting system (Figure 4, Figure 5 and Figure 6) which we will describe in detail later. We made the mixed soil with all necessary ingredients and completed the module for plantation. Planting the three types of plants in three parts (Figure 8(a) Figure 8(b)) of the module and marking them. After that, we waited for 2-3 weeks (Figure 9(a) Figure 9(b)) to observe their development .After observing their growth rate and quality we picked one-...... for further experiment (Figure 10 Figure 11 Figure 12). Then the selected plant was planted in the module and then it was time to wait for nearly 12-14 weeks for the result. (Figure 14)

In the last stage, recommendations and conclusions were made based on the survey data, market price analysis (Table 02) and practical module experiment .The qualities and quantities of plant growth were important parameters for the research conclusion and observation. A comparative cost analysis with the market price of local tiles had also done for better understanding of its cost efficiency (Table 03)

It is hoped that the result and recommendations will be useful guidance to assist further experiments on these issues based on the local context and market.

According to our action steps, the basic working flow chart of this research is shown below in Figure2.

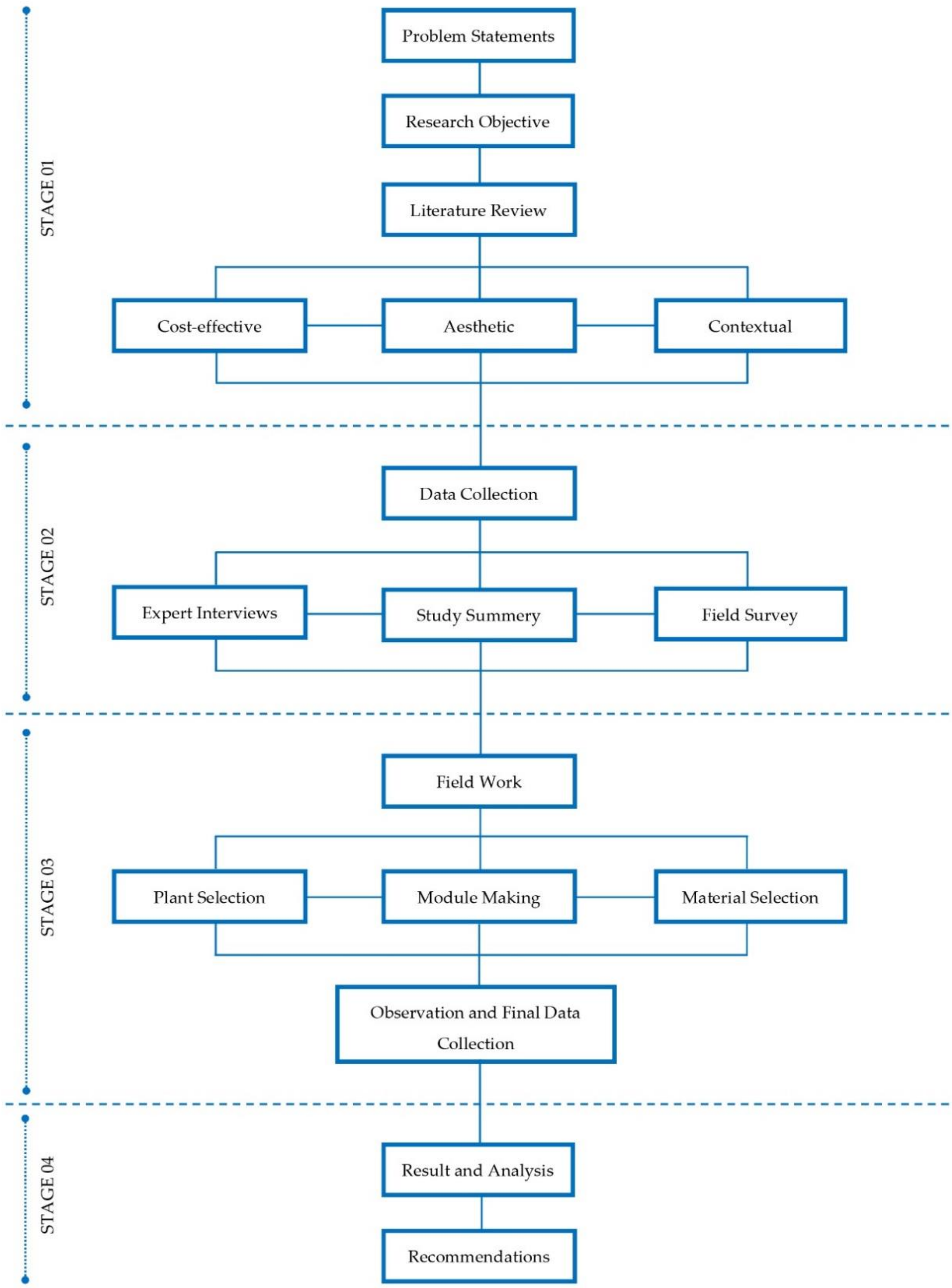

Figure 2. Diagram of Work flow

In order to achieve a better in-sight into the viability of a contextual planter tiles, semi -structured interviews were conducted with 23 gardeners in the locality who has been leaning to gardening for more than 5-20 years were the main target group for collecting qualitative data for our research. We covered 90% of nurseries from our locality and selected the participants randomly among the people who were involved in gardening there. Answers were recorded through note-taking. Unstructured interviews are one of the best ways for producing qualitative results which provide us an in-depth understanding of the present scenario and let us interpret experience, perception of the people involved [18]. Again the qualitative data collection took place after we observed the growth rate of the plants on the module and analyzed them on the basis of growth rate.

3. Design and Construction

3.1 Site Location

Site location and weather conditions are essential terms in growing the plants successfully. The ideal place to grow the plants is an open place which allows the module to face every weather conditions such as rain, sun and wind. The location also should give a full exposure to the sunlight. The site should be for the most part level and be located near a large population [19]. The module was positioned under full exposure to the sun outdoors where the module faced all the weather effects and had water sprayed timely on a continuous basis. The location was in the heart of the Khulna city and located between 22°49'19.8"N, 89°33'07.8"E [20].

3.2 Available Space

A well designed module should ease the maintenance and costing factors. The depth of the tray should be able to accommodate enough nutrient rich soil and other ingredients to grow the plants. On the other hand the weight of soil and plants and capability of water retention also influence the depth of the frame.

According to soil retention studies we needed an average soil depth of 3″ as required by the climate and expected height of the plant [21]. To lower the weight of the soil, we reduced the soil depth and fixed it as 2″. As we were thinking of the module as a replacement of ceramic wall tiles, we designed the module as 12″ X 18″. To minimize the weight and soil corrosion, the final size of the module was 18″ X 12″ X 2″. This would allow enough area to let the plants grow naturally and give us a sample of weathering effects on both module structure and plants.

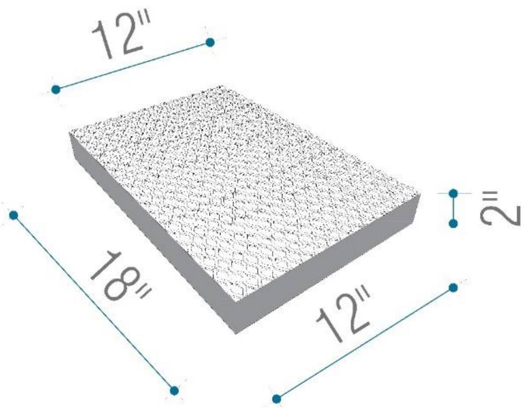

Figure 3. Measurements of the designed module

3.3: Design decision and Material Details

Perez, Coma and Martorell provided a basic categorization of vertical greenery method by construction systems, climate influence, plant species and different operating mechanisms into green walls and green facades [22]. Perini discussed direct and indirect greening systems, as well as indirect greening systems with a planter box as a green façade [23]. Almost identically, Bustami classified green facades into direct and indirect ones, and living walls into ones with modular trays [24]. Susorova and Bahrami also classified vertical greenery systems as green facades and living walls, to be exact: hanging pockets, framed boxes modular, wire cage modular, perforated boxes modular etc [25]. Medl, Manso and Castro-Gomes, Radosavljevic all studied and discussed the classifications of vertical greenery systems and divided into direct and indirect ones with ground- or modular box based planting, and other systems. Here Manso and Castro-Gomes helped briefly providing a much broader classification, and Radosavljevic followed the same classification. Both studies divide vertical greenery systems into green facades (traditional green facades as direct ones, and continuous and modular trails as indirect ones), and living walls (continuous ones as lightweight screens, and modular ones as planter tiles, trays and flexible bags) [10, 26, 27]. After studying all these papers and understanding all of their perspectives we decided to study the "Planter tiles" system as shown in fig00. We have started thinking about designing a simple, cost friendly, easy installable module which will be constructed by contextual materials and plants of Khulna city.

The materials used for frame construction was wood which was painted with damp proof paint to protect it from the soil damp. To enrich the soil quality for a low weight high nutrient soil we have used coco peat, TSP, Gypsum, Potash etc. To hold the soil we have used a thin metal net. To maintain the gaps between plants we have chosen a kind of net which supports our measurement.

4. Design and Construction Procedure

4.1 Construction Procedure

The construction process involved the design of the module which is shown at Figure 3. The height, width and depth was chosen by available wall tiles size to determine the weight of the module. We had chosen wood from *Cordia subcordata* that is known as "kerosene wood" usually found in local wood shops at a reasonable price. Moreover, this wood is a bit lightweight (density is 470-650kg/m^3 at 15%moisture content) & its volume fluctuates at a low rate [28] We collected the wood and made the wooden frame and painted the inner side of the frame with a damp proof coating.

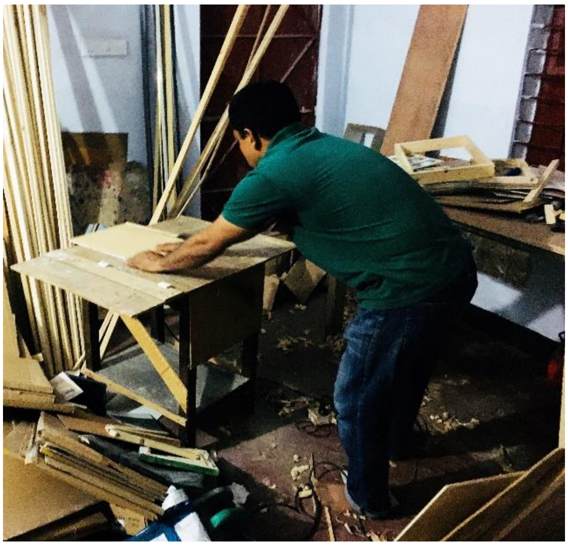

Figure 4(**a**)

Figure 4(**b**)

Figure 4(a) and Figure 4(b) represent the construction procedure of the wood frame and assembling of the base with it.

Figure 5(**a**)

Figure 5(**b**)

Figure 5(a) and Figure 5(b) shows that we inserted a metal net on the module. This metal net helps to hold the soil inside the frame and protect the soil mix from loosening. The metal net was bought from a local hardware shop and fixed with the module with nails by the authors by hand.

Figure 6(**a**)

Figure 6(b)

After constructing the frame we filled the module with soil mix as shown in the Figure 6(a) and Figure 6(b). The nutrients were selected by the opinions of local experts, nursery owners and as suggested in literature reviews.

4.2 Nutrient Selection

We have used this mixture that is collected from a local nursery with the help of an experienced gardener. 99.5% of the ingredients are organic and widely used locally as soil friendly materials.

We have used a mixture of Vermicomposting fertilizer that is made up of green waste, foods and rotten vegetables and fruits from which plants can extract nutrients like nitrogen, phosphorus, potassium, calcium and magnesium [29, 30]. The percentage of nutrient mixture is shown in Table 01.

Table 1: Percentage of nutrients in soil mix

Ingredient	Nutrient Percentage (%)
Vermi-compost	25%
Coco peat	35%
Local soil	30%
Neem cake	5%
Coal	4.5%
Osmocote 14-14-14	0.5%

Coco peat, an ingredient which works as a lightweight material and high water retention capacity and possesses a balanced pH level as well as other chemical attributes and also ensures proper aeration inside the soil and infuses more oxygen in the media [31]. Osmocote 14-14-14 a slow releasing fertilizer that provides nutrients for 5-6 months to the plants. Neem cake, locally used as a manure that acts as a natural fungicide and protects the soil from the attack of nematodes.

4.3 Plant Selection

Dr. A.N.Sarkar described the choice of plants for the experiment is fundamentally dependent on climate conditions, context, space quality and exposure of the wall. The selected plants must be light, spreading root systems and good soil retainer. It is also directed to choose evergreen plants, so that the module will fulfill its effect throughout the whole year [32]. He also directed ferns, herbs, spinach, vegetables, Lettuce, Mint etc. leafy plants as most preferable plants in his studies. These plants are selected depending on some serious considerations such as :

- Availability
- Less delicacy
- Low cost
- Soil retaining capability
- Evergreen
- Climate mitigation

Figure 7(**a**)

Figure 7(**b**)

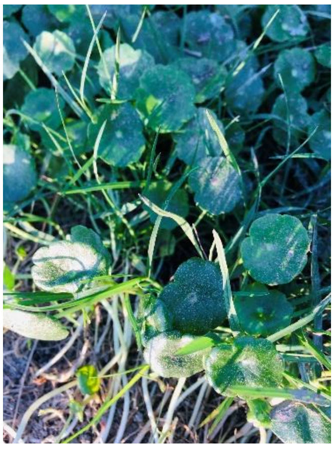

Figure 7(**c**)

To carry out the process we selected three different plants which are shown in Figure 7(a), Figure 7(b) and Figure 7(c) Mint (*Mentha arvensis*), Indian pennywort (*Centella asiatica*), Coin Plant (*Hydrocotyle vulgaris*).

4.4 Transplantation

After preparing the soil mix and the module we divided the available area into three sections. Each one portion was for Coin plant, pennywort and mint plant. Each plant was carefully planted in the soil mix and water sprayed for observation.

Figure 8(**a**)

Figure 8(**b**)

In Figure 8(a) we can observe the process of plantation ongoing. Figure 8(b) shows us the situation after a week from plantation. The soil started loosen up and the plants growth was not up to the mark. We sprayed water and tried to soften the soil mix so that it could hold up until the plants grew their roots enough to retain soil.

In figure 9(a) and Figure 9(b) we can notice pictures of the module after two weeks. Growth of pennywort looked very impressive. We can notice the coin plants struggling and mint plants were very slow. The pennywort was growing fast and started solving the soil retaining problem we faced one week earlier.

Figure 9(**a**)

Figure 9(**b**)

In Figure 10 we can observe the pennywort plants were fading their strength and became too long with less leaves. The mint plant started growing but the process was slow. This image was taken after three weeks from plantation.


Figure 10


Figure 11


Figure 12

Figure 11 indicates the situation after four weeks from plantation where we observed the growth rate of mint improved and looked very leafy. The coin plants were struggling to grow and the pennywort plants were lesser day by day. This image shows very few pennywort plants, little number of coin plants and a lot of mint plants.

Figure 12 here is presenting the situation after five weeks of observation from the day of plantation. The mint leaves were fresh and growing more and more day by day. The option of pennywort and coin plant was overtaken by mint as the pennywort failed to gather mass and the coin plant was unable to grow properly.


Figure 13(**a**)


Figure 13 (**b**)

In Figure 13(a) and Figure 13(b) we can see the massive growth of mint in the last three weeks. This image was taken on the 42nd day (six weeks after plantation) and it looked very impressive. After removing the coin plant and pennywort, mint plant had boomed its growth and gathered a leafy surface. The plants were healthy, fresh, leafy and green. We decided to wait some more days until it covers the whole surface with its massive leafy greenery.

Figure 14

Here we can notice a photograph of the 50th day of plantation in Figure 14. The whole module was covered with mint plants and retained the soil very tightly. The overall surface was looking green and leafy. While hanging on the wall it was looking perfectly like a module of a living plant which was easy to construct and maintain.

4.5 Weather Conditions

The timeline of our work was from January 4th to February 26th. The construction phase was from January 4th to January 6th. The observation phase was started on January 7th and the Final output was documented on February 26th. In Figure 15(a) and Figure 15(b) we have tried to show the temperature range in January and February 2021 in Khulna City. [33, 34]

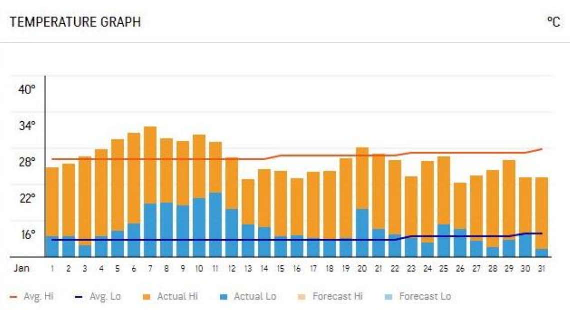

Figure 15(**a**)

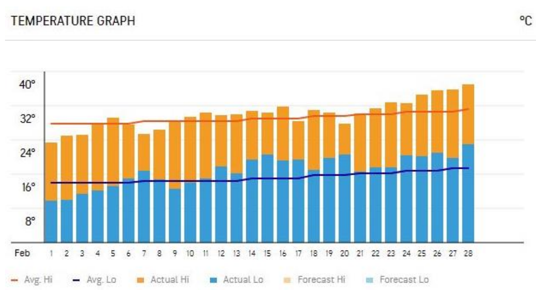

Figure 15(**b**)

5. Problems

While working we have faced various problems. Some of them kept us thinking about the solution and implying it to design a perfect green module. The problems we faced throughout the whole process were:

Leaking was the primary problem we faced. After spraying water to the soil mix it became wet and stiff. The extra water started leaking and the wooden structure was facing challenges to prove itself as a durable material for the design. As a result we decided to use a layer of insulation between the wooden base and soil mixture so that the water could hold inside the module and the frame was also saved from water damage.

Overweight was another early stage problem we faced. After standing the module vertically it started loosening up and a big crack on the soil surface was noticed after two days. To solve the problem we increased the percentage of coco peat and decreased the volume from soil percentage. It made my soil mixture lighter and also water soaked for a long duration.

During the growing phase we have faced the growth failure of the coin plant and the volume failure of the pennywort plant. At that moment we questioned our soil mix proportions and tried to remix. But the growth and volume of mint plants relieved us from the problem.

Soil Retention problems were faced when the plants were small. With time the root of the plants grew and it started improving its soil retention power. As the root system is a bundle root system so it could spread easily and needed less depth than other plants. The root system maintains its soil retention capacity and the problem was solved.

6. Results

6.1 The Design and Installation of the Module

The module was constructed with a lot of effort, thinking and time but after lacing the soil nutrient mixture, it started falling and leaking. After fixing the problems and giving some time to retain. We started planting after two days from construction. In the meantime the soil started to harden itself. To maintain the qualities we sprayed water to it daily. We divided the whole module into three parts and planted three kinds of plants but at last we succeeded to select the one we were looking for. We harvested the plant all over the module and aligned it vertically to a wall with full exposure to natural light, air and rain.

From our personal opinion, anyone with minimum expertise of using tools could have constructed it. The whole module was designed this way to make it more low cost and easy to build.

6.2 Maintanance

Over the problems mentioned earlier we tried to overcome those and tried to maintain with minimum effort. Most of the time the maintenance part becomes the most discouraging part for a modular system vertical greenery. To minimize these, we just let the module take care of its own as nature does it always. We just sprayed water twice a week to maintain the moisture of the water as it was winter. We recommend even not to do that if it rains.

Another important thing to note is that while working we noticed that the soil started fragmenting at the first phase but as we continued spraying water and the plant started growing its root helped to retain the soil itself.

6.3 Cost Analysis of the Module

SL no.	Material Name	Quantity	Total Price (BDT)	Square Feet Price (BDT)
01	Wood frame(recycled wood)	1 nos	50	50
02	Wood base	1 nos	20	20
03	Metal net (sqft)	1 square feet	8	8
04	Damp-proof paint(100ml)	50 ml	20	10
05	Soil(kg)	1 kg	5	5
06	Plant (10 nos)	10 nos	10	10
07	Nails (100g)	8 nos	10	2
08	Coco Peat (kg)	175 g	25	5
09	Vermicompost (kg)	125 g	10	2
10	Osmocote 14-14-14 (500g)	20nos	150	7
11	Neem Cake(100gm)	2.5 g	15	4
12	Coal (kg)	25 g	10	2

Table 2: Cost analysis of the module

As shown in Table 02, the total cost of the module is 125 BDT. (Around 1.5 USD). This cost only represents the quantity portion cost which is used for the module only. We saved some bucks by working ourselves. We only bought the raw materials from the market and constructed the essential mechanisms like frame fitting, basing, attaching the metal net etc. Following this model will cost 125 BDT per square-feet.

7. Discussions

7.1 Cost efficiency and Economic Benefits

Hop and Hiemstra suggest that vertical greenery systems increase the value of property, especially if they create extra outdoor or semi outdoor living space [35]. "A living wall is a unique way to add more greenery to your 'interior scape' design or exterior landscaping plan, and attracts more people interested in purchasing your property"[36]. According to the same website, having plants in and around a building can increase real estate value by up to 20%. Data provided by Jialin shows different percentages, suggesting that living walls have the potential to increase residential and commercial property values by 7 to 15% [37]. In a review Empirical studies presented in Table 11 show that the economic benefits of VGS differs across the world [38]. A scientific paper by Veisten assessed the market possibilities in Toronto, where vegetation measures would yield property increase for 6–15%, with a midpoint of 10.5%. "A cost–benefit analysis of the green wall case indicates that this measure is economically promising when valuing the noise attenuation in the quieter area and adding the amenity/aesthetic value of the green wall"[39]. Cost analysis by Meral states that living walls are the most expensive type of man-made vertical greenery system. "Considering the costs of two wall systems, it was observed that a green facade could be established with about 12.01 of the cost of living walls"[40].

Another economic benefit of vertical greenery is tax incentives. A paper by Perini and Rosasco states that "economic incentives (tax reduction) could reduce personal initial cost allowing a wider diffusion of greening systems to reduce environmental issues in dense urban areas, such as urban heat island phenomenon and air pollution" [41]. Like all the other countries our government has started this journey of inspiration as they have announced a 10% tax rebate if they do gardening on the rooftop, balcony or the compound. [42]

7.2. Comparative Analysis with Tiles

In Bangladesh there are several ceramic brands available who are leading the market. According to market surveys we have found various prices and sizes stated in Table no 03.

Names	Price (BDT Per Square-feet)
Terracotta Tiles (Various companies)	50-165
DBL Tiles	54-75
Mir Ceramics	50-80
X Ceramics	57-82
Akij Ceramics	65-85
The Great Wall	75-120
RAK Ceramics	58-125
Fu Wang	68-115
Star Ceramics	60-82
Khadim Ceramics	75-85

Table 03: Average cost of ceramic and terracotta tiles

Table no 03 shows that the ceramic tiles people generally use for exterior or semi-outdoor cladding costs around the same our module as costed. The cost of the module could be cheaper if it starts mass production. By using our module user can have a nice touch of green, refreshing mint plants on his walls which is eatable, causes no harm to nature, increase oxygen level in the air, emits zero carbon.

8. Conclusions

In recent years, using modular tiles on the wall has been proved to be an acceptable solution because it is easy to install, maintain, remove and reuse. It also helps to cover up walls due to their flexibility. However, the module and some modifications considering our local context, market status and availability of the materials have been conducted in this research. Due to cost-effectiveness, easy availability and flexibility in installation, this vertical green wall module will be widely accepted and appreciated according to the research findings whatsoever. Moreover, mint plant is very well-known for its medicinal value and its extract can be used in making oil, flavor etc. Currently improving the soil retention capacity of the intended plant root system and finding the best plant growth statistics have been undergoing. Thus the problems will be alleviated. Additionally, the leaking and overweight of the frames are under inspection to draw a stable margin out of our research statistics. Again, enriching our research by cultivating some other types of plants that will grow in the indoor setting, would be helpful to purify the air, and directly ameliorate the air quality and moisture content of the area. Automated maintenance of this module using reserved rain water will be introduced throughout the year and also make the module more and more lightweight while increasing its longevity. However, collaboration with material research would be an option to strengthen our effort and answer the questions like how could the system be more robust and lightweight in terms of interior vertical use. Further work in enhancing its sustainability, water drainage channeling and mitigating the further issues have been planned already.

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Conflicts of Interest: "The authors declare no conflict of interest"

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Technical Feasibility of Large-scale Wind Energy Production in Eritrea

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Abstract: With the rapid depletion of fossil fuels and alarming environmental concerns renewable energy utilization is becoming the best option for electricity production. Moreover, renewable electricity production from wind energy has become a notable objective globally for its enormous potential and technological advancement. The main objective of this paper is to investigate the technical feasibility of large-scale wind power production in Eritrea. The study was carried-out based on two different data sources (measured and modeled) containing time-series of weather data and a third reference data from Global Wind Atlas (GWA) was used for validation purposes. The characteristics and distribution of the wind speed for all data sets were described using Weibull distribution. Two turbines (Enercon E-82 and Vestas V90) were selected to test their performance in the proposed sites. Weibull distribution - representative of the original data sets- along with the turbines' power curves were used to determine the Annual Energy Production (AEP) and capacity factor (C_f) of the turbines. The Vestas wind turbine was found to have a better performance compared to Enercon turbine in both sites for all data sets. Furthermore, the influence of air density in AEP and C_f was investigated and the finding showed that as much as 12% variation on AEP was obtained in Dekemhare site which is located in the highlands of Eritrea. Though the variation between the measured and modeled data sets exists in both sites, the difference in mean wind speed, power density, AEP and C_f was more exaggerated for Dekemahre site. Referring to the measured data series both sites found to be very attractive for utility scale wind power production.

Keywords: Wind Power; Weibull distribution; AEP; Capacity factor; Dekemhare wind site; Assab Wind site

1. Introduction

Driven by the concern of rapid increase of global warming and its associated climate-change and environmental consequences much attention has been given to renewable energy resources in recent decades and projections of renewable energy resources for electricity production and other energy needs has become a notable objective globally. Among the prominent renewable resources wind energy is gaining popularity and acceptance for being emission free, clean and sustainable power source [1]. In the last decade, a dynamic growth and rapid expansion was recorded in renewable energy sector [2]. Moreover, with the continuous technological innovation, efficiency enhancement and reduction in both manufacturing and power generation costs wind energy has become among the most attractive renewable energy resources from both economic and environmental point of view [2, 3]. The penetration rate and the share of wind energy in the global energy market are showing rapid increase both in developing and developed nations [4, 5]. In the last decade (2007-2018) for example, the installed wind power capacity has increased drastically to about more than six-folds [6]. The cummulative global wind power capacity installed in 2010 was about 198 GW and it increased sharply to 600 GW in 2020 [7]. However, wind energy with all its advantages has the concern of being unpredictable as it strongly varied by temporal changes and spatial pattern. The stochastic nature of wind speed which has a cubic relation with the generating power makes precise wind power forecasting difficult and the resulting uncertainties impacts all the different players or sectors of the electricity generation system such as consumers and distributors [8]. Precisely or accurately quantifying the amount of power that can be generated from wind generators in a particular site requires understanding of the seasonal and inter-annual variability of the wind speed. To historically characterize the wind behavior and to have a better knowledge about the local long-term wind variability a long-period data set representative for longer timescale is required [9]. However, long-term on-site measurements data sets are difficult to get as it requires time and expensive devices. For this reason modeled wind speed data sets are also commonly used for wind resource assessment.

Several researches have been conducted on mapping (assessing) the potential of wind energy in different parts of the globe. These researches can be categorized based the scope and mission of the study, the techniques and approaches applied and the type of data sets used. Some of the studies focus on large scale on a regional and continental level based on freely available meteorological weather data (large scale web based data sets) while others are targeted on national or more specific site level to address more details [10]. For example, D. Mentis et al. used web based data sets from Vortex and NASA to evaluate the wind power potential of the whole African continent. The authors applied GIS based approach to identify and map the wind power potential of the continent and found several high wind potential sites including the southern Red Sea coast [11]. In [12] potential of wind energy in Europe was analyzed using emergy indices. The authors analyzed wind data from 90 stations throughout Europe using Emergy Yield Ratio (EYR) and Emergy Index Sustainability (EIS) for three types of wind turbine and they came up with a mapping that can identify the most appropriate potential sites for implementation of wind energy in Europe. Li Dong proposed a new approach for assessing the wind power potential of southern plains of US [13]. This new method is an alternative and improved way to the widely accepted/used approach, synoptic Pattern Analysis. The impact of large - scale atmospheric circulation pattern on wind power generation is also studied by [14]. The new approach however, is a way to establish a method to forecast the frequency of occurrence of such large-scale atmospheric circulation by clustering the synoptic weather pattern. And more recently, re-analysis data sets has become an essential research tool for estimating the wind power potential of a given site for its large area coverage and longtime spans [15]. However, it is reported many of the researches conducted on wind potential estimation based on reanalysis methodology lacks validation. I. Staffell and S. Pfenninger accredited the importance of validation on reanalysis datasets. They proved that reanalysis is a powerful tool for estimating wind power production, but it should be accompanied with careful calibration and bias correlation. The authors further acknowledged a significant spatial bias was observed while simulating the future and present wind power output in 23-European countries using the reanalysis approach [5].

In contrast, micro-scale wind power potential analyses are targeted to specific sites and rely on accurate and reliable ground surface data that can be obtained from data loggers installed at some height above the ground. Many similar researches have been conducted in and around Eritrea. For example, in Egypt in the Red Sea cost [16], Saudi Arabia [17, 18], and in Ethiopia [3, 19]. These papers focused in technical and economic assessment of wind power potential in the respective countries. Similar studies in Eritrea show that Eritrea has significant wind power potential for utility scale power production. In [20] a broad over view of wind energy potential of 25 sites through-out the three topographic regions of Eritrea was presented and high potential sites were clearly identified including the southern Red Sea cost and central highlands. The high wind potential sites of the southern Red Sea cost were also acknowledged in [21]. Though, several attempts have been made to assess the wind resource potential of Eritrea none of them deals with the technical feasibility of utility scale wind power development in the country.

The purpose of this study is therefore; to examine the technical feasibility of wind power development in Eritrea and to evaluate the effectiveness of modeled wind speed against the onsite measurement in the context of Eritrea. The result of this study is credited to give a clear understanding of the feasibility of large wind farm development and/or bulk wind power generation by estimating the capacity factor of the proposed sites.

2. Materials and Methods

2.1 Description of study Sites

The topography of Eritrea can be broadly classified in to three landscape regions. The central highlands the most populated region dissects the western and eastern lowlands [20], [23]. The Eastern lowlands which stretch around 1200-km along the Red Sea cost rises to altitudes of up to 1000-m while places as low as 100-m below sea level exist in the Denakil depression. This region is mostly dominated by warm climate and is believed to have outstanding wind potential for utility scale wind power production.

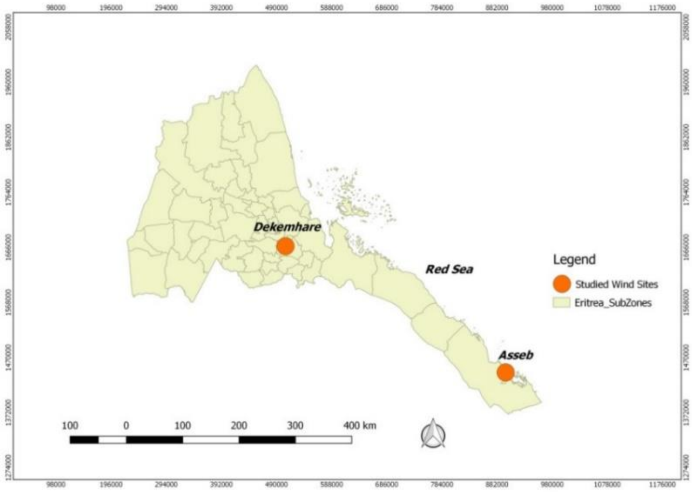


Figure 1: Map of Eritrea showing the studied sites

The wind patterns in the Red Sea coast are mostly dominated by monsoon winds and surrounding orography. The port city of Assab which is the focus of this study is located in the Red Sea coast as shown in Figure 1. The strong southeast monsoon winds that channeled through the Bab-El Mendeb (at the southern mouth of the red sea) tremendously boost the wind flow strength around Assab. However, the wind strength slows down as it furthered towards Massawa after it meets with the ever-existing northwest winds (Massawa is located in the coastline along the northwest from Assab). The majority of the air mass draws across the Eritrean highlands towards Sudan [21].

The central highlands include the high plateau and surrounding hills. These highlands rise as high as 3000-m and possess colder climate, dense population and high electricity demand [20, 23]. Winds in Eritrea as clearly discussed in [22] are created by combination of inversion layer dynamics, synoptic-scale gradients and local differential heating. In the complex topography of highland sites, it is necessary to analyze the inversion layer dynamics as it dominates the synoptic pressure gradient. The flow of the inversion layer through topographic barrier and the steep slopes in to the warmer basin of air accelerates the wind flow and creates high wind potential sites in the lee side of the lowest passes. Dekemhare which is 40-km from the capital Asmara is located in in leeward slope where cold and warm air interacts. The geographic information of the study sites are given in Table 1 and further topographic information is indicated in Figure 1.

Table 1. Geographical description of studied sites

Site	Lat	Long	Elevation(m)
Dekemhare	15° 4.82' N	39° 3.12' E	2000
Assab	13° 1.60' N	42° 38.94' E	20

2.2 Data source and analysis methodology

This study is based on three different data sets obtained from different sources. The characteristics and the resolution the data sets are described below.

Wind and Solar Monitoring Network, Department of Energy wind data: Wind speed data for year 2000 was obtained from the Ministry of Energy and Mines (department of Energy) Eritrea. The wind data (wind speed and direction) was measured at 10 minutes interval using RM Young model 05103 type wind sensors installed at 10 meter height. The station at Assab site has temperature and pressure measuring sensors in addition to the wind sensor at 10 meter height. This station has extra devices equipped with RM Young model 05103 sensors installed at 30 meter height.

Vortex data: One year high quality weather data was obtained from a private consulting firm called Vortex Company which provides cost-effective web-based service for solar and wind data. The one year high quality data was provided for Master's thesis work in 2018. The weather data which was recorded at 80-m height includes wind speed, wind direction, temperature and air density. The wind speed, wind direction, temperature and air density were measured for one year at an hourly basis.

Global Wind Atlas: This is freely available large scale data set which is based on atmospheric re-analysis data. This data set is employed for validating and comparing for the on-site measurement and vortex based data sets.

2.3 Weibull distribution

Several models are employed in the literature to describe the variation of wind speed with respect to time. The most widely used methods to represent the wind distribution over a period of time include but are not limited to Weibull, Rayleigh, Pearson, Johnson, Gaussian and log-normal [7,20,24,25,26]. Weibull distribution function is employed in this study as it gives best fit to measured data. The two parameter Weibull distribution is standard approach for describing the wind distribution in a given site. However, it has some limitation to precisely describe the wind characteristics of a given site. Because, it does not address the probability of occurrence of zero and low wind speeds. Low wind speeds however, are not necessarily to include in wind power estimation as they produce zero power because they are below operating range of the wind turbines.

The probability density function $f(v)$ and cumulative distribution function $F(v)$ are given by equations (1) & (2) [20, 24].

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left[\left(-\frac{v}{c}\right)^{k}\right] \quad (1)$$

$$F(v) = 1 - exp\left[\left(-\frac{v}{c}\right)^{k}\right] \quad (2)$$

where, v is the wind speed, k is the dimensionless shape parameter which indicates how peaked the shape is, and c is scale parameter shows how windy the site is.

From the different methods used to determine the value of c and k maximum likelihood method is used to determine the parameters as it best suited to time series wind data [24].

$$k = \frac{\sum_{i=1}^{N} v_i^k \ln v_i}{\sum_{i=1}^{N} v_i^k} - \frac{\sum_{i=1}^{N} \ln v_i}{N} \quad (3)$$

$$c = \left(\sum_{i}^{N} v_i^k\right)^{1/k} \quad (4)$$

The expexted mean wind speed v_m is then computed using

$$v_m = c\Gamma\left(1 + \frac{1}{k}\right) \quad (5)$$

Wind power density is an important parameter for estimating and quantifying the potential of wind energy available in a given site. It is independent of the size of the rotor and is expresed as power per unit swept area(kw/m^2) [26].

$$p/A = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (6)$$

where, A the area of the rotor, Γ is the gamma function and ρ is the air density, the density of air at a specific location can also be determined as a function of temperature (T) and altitude (z)[20].

$$\rho = 3.4837\frac{101.29 - z\cdot 0.011837 + z^2\cdot 4.793\cdot 10^{-7}}{T} \quad (7)$$

2.4 Extrapolation of wind speed to hub height

Most modern wind turbines have a hub height of more than 100-m. However, the wind speed used in this study is obtained from data loggers installed at 10-m and at 80-m for the vortex based data sets. Wind speed at turbine height is the point of interest in order to compute the available wind power potential of a given site. The wind profile log law equation is used to determine the wind speed at the desired hub height by extrapolating the wind speed from meteorological stations [20], [27].

$$v = v_r \frac{ln\,(z/z_0)}{ln\,(z_r/z_0)} \quad (8)$$

Where, $v_r$the wind is speed at reference height z_r and z_0 is the roughness length

2.5 Annual energy production (AEP) and capacity factor (C_f)

The expected power production of a specific wind turbine in a given site can be computed from the wind turbine power curve and the probability density function $f(v)$ of each wind speed [16].

$$E = \int_{U_c}^{U_f} f(v) * P(v)dv * t \quad (9)$$

where $P(v)$ is the wind turbine power curve, t is the time period and U_c and U_f are the cut-in and cut-out wind speeds of the wind turbine respectively.

The power curve should match with wind speed distribution of the particular site because it reflects the power response of a wind turbine to various wind speeds. However, manufacturers usually give site independent power curves, that is they estimate the power production of a given wind turbine at specific reference air density usually 1.225kg/m^3 for a range of wind speed values at hub height[28]. For that reason the standard or specific air density given in the power curve of a manufacture should be corrected to the local air density. The density correction procedure however differs for stall and pith controlled wind turbines.

For stall regulated machines, the power output is linearly proportional to air density and is expressed as [28]

$$P(u) = \frac{\rho}{\rho_o} P_o(u) \quad (10)$$

Pitch controlled turbines, however, behaves differently and the correction suggested by IEC 61400–12–1 standard focuses on correcting the wind speed instead of the power output and is expressed by [29]

$$u = u_o \left(\frac{\rho}{\rho_o}\right)^{\frac{1}{3}} \quad (11)$$

Capacity factor (C_f) is an important parameter for estimating the annual energy production of a given site and is expressed as the ratio of the actual energy output (E_{actual}) to the maximum possible energy output (P_{rated}) over a specific period of time.

$$C_f = \frac{E_{actual}}{P_{rated} * t} \quad (12)$$

3. Results and discussion

The results presented in this work are based on analysis of two different data sources as presented in section 2.2 and a third data set is used for validation purposes. The vortex based data sets are complete and ready for analysis but the on-site measurement series have some missing values which are common and a serious issue in wind energy potential assessment. This problem is clearly seen in Dekemhare site which has around 96 missing wind speed values. Though there are different techniques for estimating the missing values, the average-value method was employed in this work for its simplicity and accurateness. After the missing values were recovered and filled both the vortex based and on-site measurement series are extrapolated to the desired turbine hub height using the log law equation given by equation-(8). The roughness height z_0 was virtually estimated from goggle earth and the author's knowledge of the studied sites. However, fortunately in Assab wind site the station has two measurement series at 10 and 30 meters height. The roughness value z_0 is then derived from equation (8) as a function of the mean wind speed at 10 and 30-m height and the wind speed was accurately extrapolated to desired hub height (note that this applies for homogenous land). This method however, was not applicable for Dekemahre site for two reasons, the first reason: Dekemahre site wind station has only one wind measuring sensor at 10-m height and the second is it is surrounded by range of small hills in the east, north and south, where such topography features need more reading at several altitude to have a good and reliable estimation. For that reason the roughness length for Dekemahre was determined virtually and site visit. The mean wind speed, the Weibull shape parameter, k and scale parameter, c and power density, E at 100-m height for the measured and vortex based data sets are presented Table 2a and 2b respectively. It must be noted that the wind parameters and power density given in Table 2a are the characteristics of wind speed which are extrapolated from 10-m to 100-m, whereas Table 2b presents the wind parameters and power density extrapolated from 80-m to 100-m. The original data sets for both data sources (measured and vortex) will be presented later using wind rose plot for all sites.

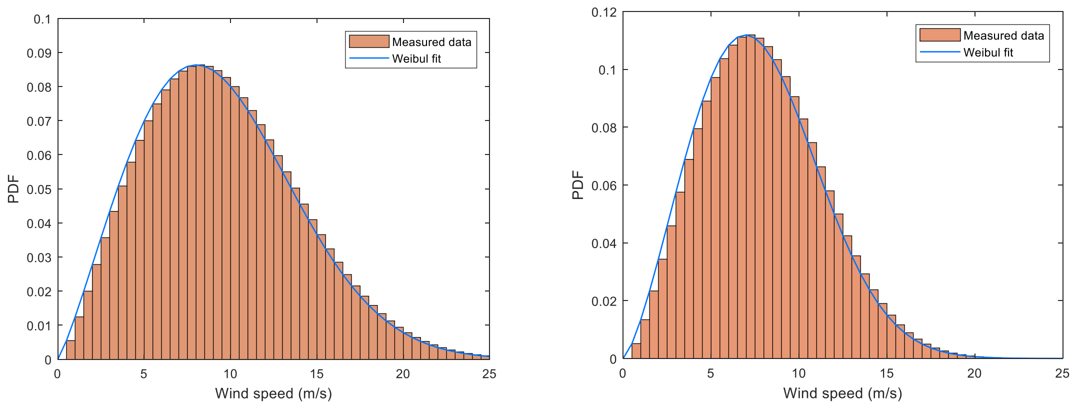
Table 2a: Wind speed characteristics based on measured data for year 2000 and power density calculated at standard air density (ρ_o=1.225 kg/m3) at 100-m height

Site	V_{100}(m/s)	c_{100}(m/s)	k_{100}	z_0	E (W/m2)
Dekemhare	8.79	9.87	2.44	0.075	658.13
Assab	9.38	10.57	2.19	0.03	882.02

Table 2b: Wind speed characteristics based on vortex data and power density calculated at standard air density (ρ_o=1.225 kg/m^3) at 100-m height

Site	V_{100}(m/s)	c_{100}(m/s)	k_{100}	z_0	E (W/m2)
Dekemhare	5.67	6.34	3.04	0.075	156
Assab	7.7	8.71	2.39	0.03	460

Two turbine models were selected to test their performance in response to the different wind speed values and its distribution in the proposed sites. The four operating characteristics of the two turbine models –Vestas-V90 and Enercon (E-82) – are given in Table 3. The performance of a wind turbine depends on temperature and altitude which ultimately affects the air density. Considering the default or the reference value of air density for all sites (ρ_o=1.225kg/m^3) is misleading as it treats all sites equally and ignores the variation in power production due to air density. In this work the variation of air density with altitude was given special focus and was recalculated based on the altitude and temperature of the studied sites. Assab site which is located at an altitude of 20 meters is almost at sea level and the air density is taken as default or the standard value but, in Dekemahre site the air density varies significantly and the effect in wind speed distribution is shown in Figure 3. Figure 2 shows the distribution of measured data and the fitted Weibull curve for Assab site.



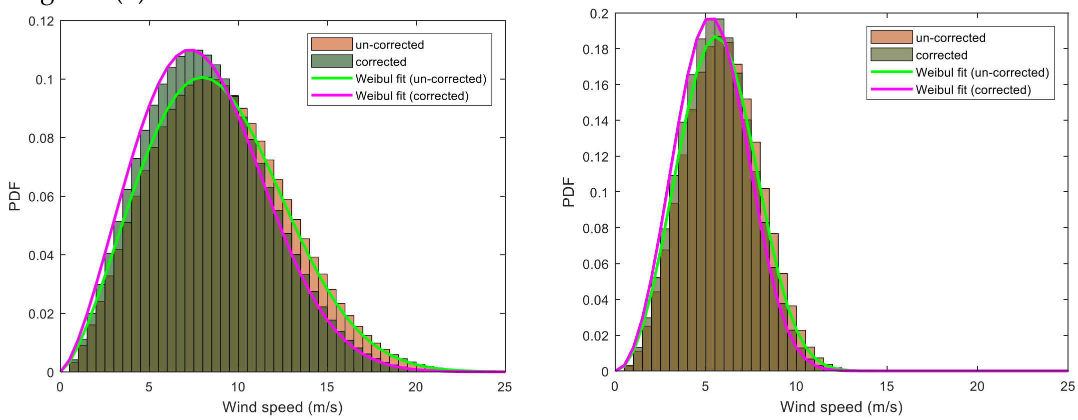
a) b)

Figure 2. Wind speed distribution and their corresponding Weibull fit in Assab site for (a) measured and (b) vortex based data sets at 100-meter height

Table 3: Selected wind turbines models and operating power curve parameters at hub height

Turbine type	Cut-in(m/s)	Vrated (m/s)	Cut-out(m/s)	Prated(MW)	Hub Height (m)
Vestas(V90)	4	14	25	2	100
Enercon(E-82)	2	13	25	2	100

Comparing the actual distribution of the wind speed to their corresponding Weibull curve the Weibull distribution fits the data well in both cases as shown in Figure 2(a) and (2b). It can also be clearly visualized the difference between the measured and vortex based data sets from Figure 2(a) and Figure 2(b).



a) b)

Figure 3. Wind speed distribution and corresponding Weibull fit for measured and vortex based data sets at 100-meter height for Dekemhare site along with corrected (normalized) wind speed distribution and Weibull fit for air density

Moreover, the difference in mean wind speed and power density for the two data sets can be easily computed from Table 2a and 2b. The mean wind speed varies by almost 17% which leads to a very high difference in wind power density of approximately 48% in Asab site.

Figure 3a and 3b shows the distribution of measured data along with Weibull fit for Dekemahre site, it also includes additional histogram and Weibull fit to address the effect of air density at that particular site. The difference in mean wind speed and power density between the measured data and vortex based data sets is more exaggerated in Dekemhare site. This may be due to the complex terrain of Dekemhare site which makes re-analysis data sets more uncertain. The wind power in Dekemhare shows significant reduction due to decreased value of air density at higher altitudes. To address this issue the air density at that particular site is recalculated (estimated) using equation (7).

The wind speed is then normalized or corrected using equation (11) in order to match with the given wind turbine power curve. The turbines used in this work have only one power curve at hub height calculated at standard air density (ρ =1.225kg/m3). The corrected and un-corrected wind distribution along with their respective Weibull fit is seen in Figure 3a and 3b.

Wind speed distribution along with wind turbine power curve can be used to estimate the wind power production of a given wind turbine in a specific site. Figure 4, shows the combined wind turbine power curves and Weibull distribution for Assab site for both measured and vortex based data sets respectively. The solid red line and dotted black line represent for the Enercon (E-82) and Vestas (V90) power curves operating parameters respectively. Both turbines' power curve have good match with the prevailing wind characteristics for the measured data sets for Assab site as shown in Figure 4(a). Such a good agreement between turbine power curve and wind distributions is expected to yield a very good capacity factor. The vortex based data sets shown in Figure 4(b) for Assab site also has relatively good match with both turbine's power curves. The performance and matching agreement of the turbine's power curve is relatively good for measured data sets in Dekemahre site as shown in Figure 4(c). In contrary both turbines had shown poor performance for the vortex based wind distribution for Dekemhare site as shown in Figure 4(d).

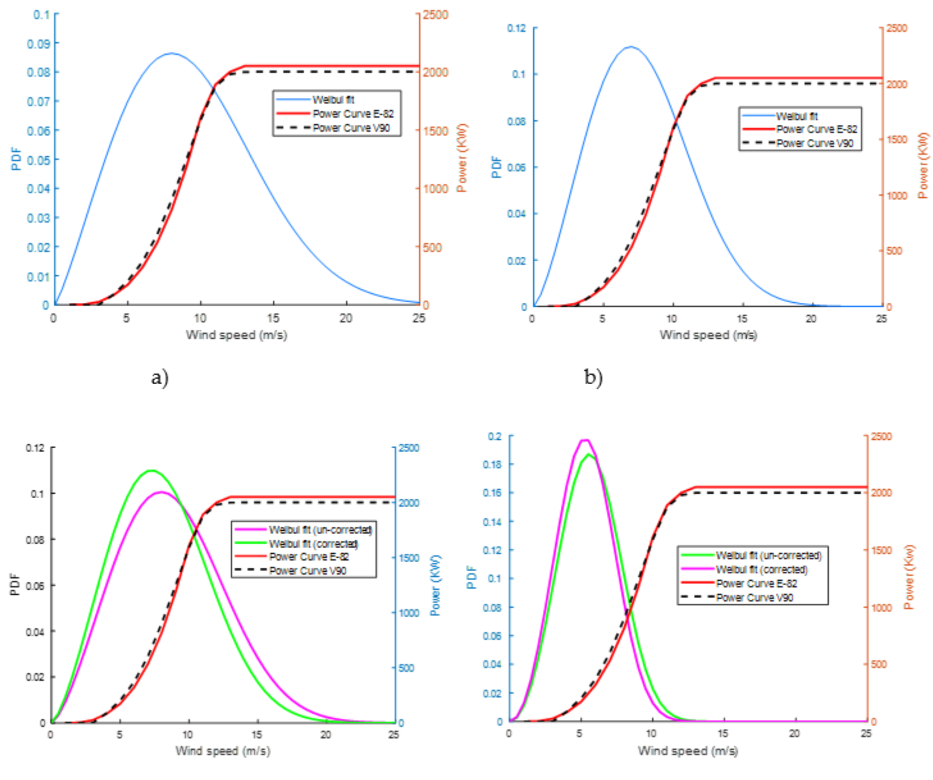


Figure 4. Weibull distribution that represents the wind data and power curve for two model turbines, Enercon-E82 and Vestas V90 a) measured data for Assab b) vortex data for Assab c) measured data for Dekemahre and d) vortex data for Dekemhare

Figure 5 shows the magnitude and direction of the original measurement series for both data sets by means of wind rose diagrams (wind speed is shown using color scale). The direction of the wind speed coincides and has good agreement for both data sets in both sites as shown in Figure 5. The wind pattern of Assab site is strongly dominated by southeastern winds. These winds are flowing towards the red seacoast from the Bab-El mendeb strait. The strong southeastern winds slows when flowing towards Massawa after meeting with ever-exiting northwestern winds and the combination flows towards the Eritrean highlands including Dekemhare in the direction shown in Figure 5(a) and 5(b).

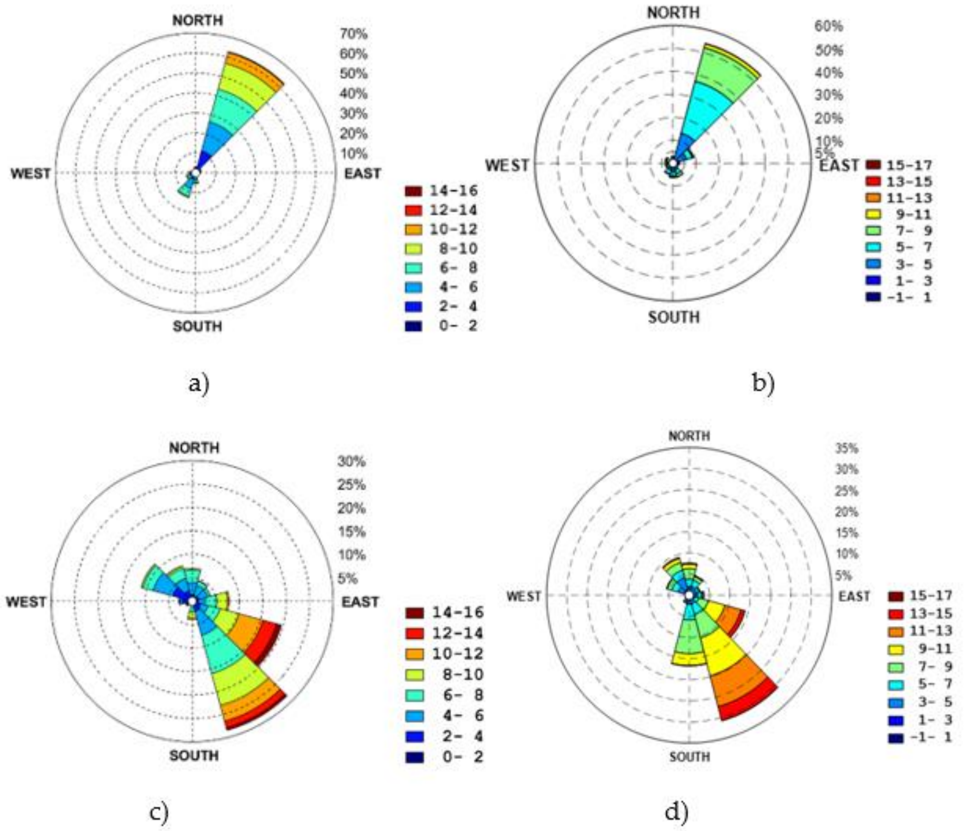


Figure 5. Wind rose diagram for measured at 10-m and Vortex at 80-m height. a) Dekemhare Measured. b) Dekemhare vortex. c) Assab measured. d) Assab Vortex

Knowing the wind speed direction helps in minimizing the wake loses by facing the array of turbines perpendicular to the prevailing wind direction.

Finally, the capacity factor (C_f) of both turbines was determined using equation (11) to easily compare the two sites energy production capacity. However, due to lack of data and facility the scope of this work is limited to one turbine and therefore the number and location of wind turbines and associated losses such as wake, and availability losses are not addressed in this study. Therefore, the capacity factor reported in this study is indicative and it is expected to reduce significantly when all the losses of wind farm layout are considered. Table 4 shows the capacity factor of the turbines for all data sets at 100-m height in the proposed sites.

Table 4: Capacity factor (C_f) values for both turbines at 100-m height

Site	C_f (Enercon E-82)		C_f (Vestas V90)	
	Measured	**Vortex**	**Measured**	**Vortex**
Dekemhare	0.51	0.19	0.54	0.21
Assab	0.55	0.42	0.57	0.44

Referring to the measured data sets the capacity factor for Assab site were 0.55 and 0.57 for Enercon and Vestas turbines respectively. Though these values are quite big comparing to other studies conducted in different places such as in [3, 10] but they are still in good agreement with the rough estimation reported in [21] for that particular site. Dekemhare site capacity factor varies significantly for the measured and vortex based data sets. The lowest capacity factor in Dekemhare site for vortex data sets maybe associated with the higher uncertainty of modeled wind speed (Vortex and GWA) in mountainous and complex terrains. The two turbines' performance however, showed outstanding performance for Dekemhare site for measured data series. Comparing the performance of the two turbines Vestas wind turbine outperforms the Enercon turbine for both data sets in all sites that this is reasonable since the V90 is designed for slightly lower wind speeds as the swept area is larger while the power rating is similar.

At last a third data source was accessed from the large scale data set –Global Wind Atlas (GWA) - for validation purposes. The wind speed and energy density at 100-m for the two sites is given in Table 5[30].

Table 5. Mean wind speed and power density at 100-m height from Global Wind Atlas (GWA) v3.0

Site	Mean wind speed (m/s)	Power density (W/m2)
Dekemhare	6.38	231
Assab	9.8	754

Comparing the power density and wind speed values for all three data sets (presented in Table 2a, 2b and Table 5) the measured values were always higher. Exceptionally the wind speed is higher for GWA than the measured values for Assab site. The difference in power density between the measured and modeled wind speed based results is relatively small for Assab site but extremely large for Dekemhare site. For both sites the power density for GWA is higher compared to vortex based results. The overall results show that the matching agreement between the modeled wind speed and measured value is much better for Assab site than Dekemahre site. Although further study and more detailed and in-depth analyses is needed, in this context however, the modeled wind speed works relatively better in smooth and open areas where wind flow turbulence is expected to be small.

The measured data set was acquired in 2000, a fact that implies an uncertainty when comparing to other data sets that are considered to be representative for the current wind climate (such as Vortex or GWA). The landscape may change over time, for example regarding surface roughness. However, according to [31] there has been very small changes over time for the wind resource in Eritrea (more precisely between 0 and 1% increase in normalized wind energy generation per decade), whereas many other regions in the world were found to show a slight decline in wind resource over time (explained in part by increased surface roughness). Therefore, the measurement used here may be considered as roughly representative for the current situation, justifying the comparison to Vortex and GWA.

4. Conclusions

This paper presents the wind power potential of two candidate sites in Eritrea. The two parameter Weibull distribution was employed to describe the wind characteristics of the sites. A comprehensive analysis was conducted based on two different data source and a third data source from GWA was used for validation and correlation purposes. The study revealed that under all circumstances the results of the measured values remain higher comparing to the other two (Vortex and GWA) except in one case. The difference in power density between the measured and GWA based results are small in Assab site in contrary the difference between the measured and the modeled wind speed reaches as high as 75% for the complex highland site Dekemhare. If we consider the measured values to be more accurate, the modeled wind speeds are found to be more uncertain in the complex highland site where wind flow turbulence is expected to be more. Further the effect of air density in power production in Dekemhare was analyzed and the results showed that as much as 12% difference in AEP was obtained between the corrected and un-corrected data sets. The capacity factor of the two turbines was determined using two model turbines (Enercon-E82 and Vestas V90). Though it has higher cut-in speed the Vestas turbine was found to have a better performance and capacity factor than the Enercon turbine in both sites which is expected and reasonable for larger turbines. It should be noted that the uncertainties that can incur on extrapolating the wind speed from 10-m to 100-m and the semi-virtual estimation of the roughness length z_0 in the complex terrain.

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Conflicts of Interest: The authors declare no conflict of interest.

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Session 7:

Sustainable Buildings and User Experience

Re-examining the Efficacy of Radon Mitigation Systems in Single-Family Dwellings: A Pilot Study

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Abstract: Indoor radon has been recognized as a health hazard since radon was correlated with lung cancer in miners in the previous century. In 2009 Radon gas has been classified by the International Agency for Research on Cancer as being carcinogenic to humans. According to the US Environmental Protection Agency (EPA), indoor radon is the second leading cause of lung cancer after smoking in the United States. EPA recommends homeowners to mitigate their houses against radon if the indoor radon concentration exceeds 4 pCi/L. The current mitigation systems are based on a concept of collecting the radon gas from the soil underneath buildings to flush it out to the outdoor air where it dilutes to a lower and harmless concentration. However, there are still many unanswered questions regarding the current mitigation systems; Do mitigation systems work effectively over time? If so, how efficient are they? Do homeowners maintain the radon mitigation systems? What kind of maintenance do homeowners do to keep these systems effective? In the present study, 6 digital radon monitors were installed in 6 mitigated houses in Bowling Green, Kentucky, an area categorized as zone 1 where predicted indoor radon average is greater than 4 pCi/L. The radon monitors were set to logging data around the clock for four months. The data includes Radon pCi/L, Temperature °F, Humidity %rH, and Pressure kPa. Also, a questionnaire was launched to gather information about the occupant's behavior towards the indoor air quality in their houses**.** The article reports the results of this pilot study. It sheds the light on an important issue that negatively impacts the indoor air quality of residential buildings in the United States. The study is part of larger research to improve the indoor air quality in single-family dwellings through building design and construction.

Keywords: Indoor environmental quality; Radon; Mitigation; Single-family dwellings; Mitigation systems; Maintenance.

1. Introduction

Radon is an odorless radioactive gas in the soil in areas rich in radium and uranium [1]. Radon is the second cause of lung cancer after smoking tobacco in the United States [2]. Testing one's home for Radon is necessary to determine exposure risk. However, despite Radon's public awareness, the proportion of people in the United States who have tested their homes remains low, ranging from 3% to 15% in different states [2-4]. There is a level of uncertainty regarding the classification of areas with potential indoor Radon hazards [5]. The doubt is originated from the inconsistency of Radon concentration and its progeny in the indoor environment [6]. the indeterminate time of exposure to Radon and its progeny that can potentially harm the human body [7], and lack of evidence in the literature regarding the impact of current mitigation systems on avoiding the health hazards of Radon. However, a cohort of researchers proved a dose-response correlation between residential exposure to Radon and risk of lung cancer [8-10]. This research is aligned with the past three decades' efforts towards developing mitigation systems to reduce Radon's concentration in the indoor environment. Researchers consider radon as one of the major indoor air pollutants in vast areas of North America. The primary source of radon in single-family dwellings is the infiltration from soil underneath the buildings and drinking water [11]. However, radon gas's infiltration from the soil is prioritized as the main reason for elevated radon indoors.

There are two practical approaches to improve indoor air quality [12]. The first one is source control, which reduces the amount of certain pollutant coming from a specific source by altering the source or leaving it out of the indoor environment. For instance, to overcome the harmful impact of inhaling volatile organic compounds (VOC), building designers use materials that have low VOC emissions [13]. The second approach is based on improving indoor air quality by increasing the ventilation rate to dilute the unwanted indoor air pollutants with fresh air to lower its concentration to a safer level. Also, this approach includes air filtration to minimize the outdoor air pollutants introduced to the indoor environment [14].

The indoor radon concentration is increased by either high source magnitudes under buildings or low ventilation rates [15]. Current radon mitigation systems take the source control approach. They are built on the concept of making a depressurization system underneath the building being mitigated. This system collects the gas in a depressurized chamber and flush it out to the air using a fan and pipe connected to the depressurized chamber. This mitigation system is branched into two types based on how the fan operates; Active system, in which the fan is running mechanically using electricity to keep the system working, passive system, in which the same components of the depressurization system are used. However, the system operates passively; the fan is powered by the wind movement above the house [16]. Active and passive depressurization Mitigation systems are commonly used across North America and Europe. It costs an average of 2000 USD in the United States and requires an invasive installation process to cut a hole in the foundation, install a pipe and a fan inside or outside the building to get the radon gas from the soil to the outdoor air.

In a study of indoor radon concentration in residential buildings in Spain, factors such as building materials, age of the building were found to influence radon concentration in bivariate analysis [6]. Also, ventilating buildings with fresh air can significantly reduce indoor Radon [17]. An experiment that examined the influence of air filtration on radon's concentration in houses found that air cleaners significantly decrease Radon's decay products [18]. In areas with a high Radon level, natural ventilation can reduce radon concentration significantly than forced ventilation [19]. Moreover, indoor Radon and its progeny in a Japanese dwelling changed based on changing air conditioning system and lifestyle of inhabitants [20]. The present pilot study investigates the efficacy of radon mitigation systems in 6 houses in Warren County in the Commonwealth of Kentucky. Warren County is one of the areas classified by EPA as zone 1 where predicted average levels of indoor Radon exceed 4PCi/L.

1.1 Radon Testing and Initial Investigation:

Radon gas is naturally changing every day based on various factors. Air pressure, temperature, humidity, wind, and precipitation can significantly affect the radon concentration indoors [21, 22]. The highest indoor levels are often found during the heating season. Weather conditions, operation of furnaces and fireplaces, and opening/closing of windows and doors are among the factors that cause these patterns.

Most of the research into indoor Radon's behavior involves measurements of radon averages in the indoor environment using one of two ways [22]. Short-term testing using passive devices or active devices that usually take between 2 and 90 days. The passive devices include alpha track detectors, charcoal canisters, or charcoal liquid scintillation detectors. After using passive devices for testing, they are usually sent to a laboratory for analysis. On the other hand, active devices require power to operate. Continuous monitors and Alpha trackers are commonly used for long-term testing [23]. A long-term test gives a reading that is more likely to reflect the building's year-round average radon level than a short-term test [24]. In the present study, long-term testing was taken to offer greater potential for generalization.

2. Materials and Methods

First, the Institutional Research Board (IRB) approval at Western Kentucky University was obtained to conduct this research. All participants (homeowners) signed informed consents ahead of installing the radon monitors in their houses and responding to the questionnaire. Professional Radon detectors were used to measure and record the radon concentrations around the clock in six houses for four months. Each detector sampled indoor air through a passive diffusion chamber using alpha spectrometry to calculate the radon level precisely. The detector took hourly readings throughout the testing period. By the end of the four months, one mitigation systems in one of the houses was found inactive due to disconnection from the electricity source. This house was excluded from the study because it was considered as unmitigated at the time of the study. Table 1. shows the houses' characteristics such as the structure description, the year it was built, the gross area, and the year the mitigation system was installed.

Table 1. The characteristics of the houses included in the pilot study.

House #	Gross Area sq ft	Year the House Built	Mitigation System	Year Mitigation System Installed	HVAC System
1	1900	1970	Active Sub-membrane depressurization	2017	A combination of furnace and heat pump
2	2170	1999	Active Sub-membrane depressurization	2017	A combination of furnace and heat pump
3	2150	1920	Active Sub-slab depressurization	2013	A combination of furnace and heat pump
4	3050	2006	Active Sub-membrane depressurization	2019	A combination of furnace and heat pump
5	2520	1924	Active Sub-slab depressurization	2014	A combination of furnace and heat pump

House 1 was built in 1970, the radon mitigation system was installed in less than five years, specifically in 2017. It is a one-floor with additional room upstairs. The structure is a wood frame built on a crawl space. The exterior walls covered with brick veneer.

The radon system is an active sub-membrane depressurization system. It collects the radon gas from underneath the crawl space and flush it to the outdoor air above the building.

House 2 was built in 1999, the radon mitigation system was installed in less than five years, specifically in 2017. It is a two-floor building. The structure is a wood frame built on a crawl space. The exterior walls covered with brick veneer. The radon system is an active sub-membrane depressurization system. It collects the radon gas from underneath the crawl space and flush it to the outdoor air above the building.

House 3 was built in 1920, the radon mitigation system was installed in 2013. It is a two-floor building with a basement. The structure is a wood frame built on a crawl space. The exterior walls covered with brick veneer. The radon system is an active sub-slab depressurization system. It collects the radon gas from underneath the crawl space and flush it to the outdoor air above the building.

House 4 was built in 2006, the radon mitigation system was installed last in 2019. It is a two-floor building. The structure is a wood frame built on a crawl space. The exterior walls covered with brick veneer. The radon system is an active sub-membrane depressurization system. It collects the radon gas from underneath the crawl space and flush it to the outdoor air above the building.

House 5 was built in 1924, the radon mitigation system was installed last year in 2024. It is a two-floor building. The structure is a wood frame built on a crawl space. The exterior walls covered with brick veneer. The radon system is an active sub-slab depressurization system. It collects the radon gas from underneath the crawl space and flush it to the outdoor air above the building.

The houses were selected based on specific criteria: 1) to be similar in the physical characteristics such as structure system, ventilation system, and wall design, see table 1 and fig. 1; 2) to be varied in the size; 3) to be built in different years; 4). The selection criteria were set to include the effects of factors such as materials, building systems, airtightness, and operation and maintenance practices on the results. The gathered data comprised the following two datasets:

1. Data measured by digital radon monitors. The monitors sample indoor air through a passive diffusion chamber using alpha spectrometry to precisely calculate the radon concentration in the air. The monitors were set to logging data around the clock for four months during the winter (heating season), usually characterized by high averages of indoor Radon. The collected data includes Radon pCi/L, Temperature °F, Humidity %rH, and Pressure kPa.
2. Homeowners' responses to a survey, the questionnaire was used to gather information about the occupant's behavior towards the indoor air quality in their houses during the test period.

In addition to the demographic data, the questionnaire included the following questions:

- What kind of maintenance do to maintain the radon mitigation system?
- When was the last time you checked the efficiency of the radon mitigation system?
- How often do you open the windows for natural ventilation? And in which time of the day/year?
- How often do you use the ceiling fans? And in which time of the day/year?
- What type of heating and cooling system is in your house? How long has it been installed?
- How often do you replace the HVAC system air filters?
- What temperature do you set your thermostat on during the winter?
- What temperature do you set your thermostat on during the summer?
- Do you have any issues or complaints for the indoor air quality in your house?
- How did you resolve this issue?

The radon measurements and questionnaire responses were analyzed to explore the efficacy of the radon mitigation systems in the five different structures.

3. Results

3.1. Radon measurements

House #1

The indoor radon concentration ranges between 0 to 120 pCi/L with average of 5.3 pCi/L over 4 months from December 1st, 2020, to April 1st, 2021. The radon average exceeds the limit set by EPA 4 pCi/L. It means that this house needs to be mitigated to bring the average of indoor radon to be lower than 4 pCi/L. Figure 1. shows the radon readings over the 4-month period aligned with the indoor air temperature, relative humidity, and atmospheric pressure.

Figure 1. Indoor radon readings pCi/L aligned with indoor air temperature, relative humidity, and atmospheric pressure in house #1.

House #2

The indoor radon concentration ranges between 0 to 29 pCi/L with average of 5.1 pCi/L over 4 months from December 1st, 2020, to April 1st, 2021. The radon average exceeds the limit set by EPA 4 pCi/L. It means that this house needs to be mitigated to bring the average of indoor radon to be lower than 4 pCi/L. Figure 2. shows the radon readings over the 4-month period aligned with the indoor air temperature, relative humidity, and atmospheric pressure.

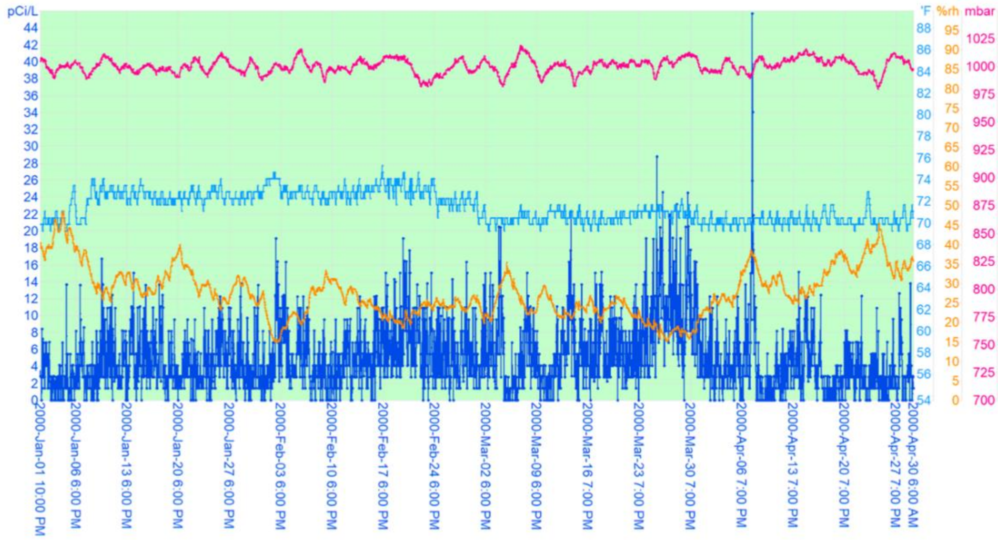

Figure 2. Indoor radon readings pCi/L aligned with indoor air temperature, relative humidity, and atmospheric pressure in house #2.

House #3

The indoor radon concentration ranges between 0 to 20 pCi/L with average of 8.9 pCi/L over 4 months from December 1st, 2020, to April 1st, 2021. The radon average exceeds the limit set by EPA 4 pCi/L. It means that this house needs to be mitigated to bring the average of indoor radon to be lower than 4 pCi/L. Figure 3. shows the radon readings over the 4-month period aligned with the indoor air temperature, relative humidity, and atmospheric pressure.

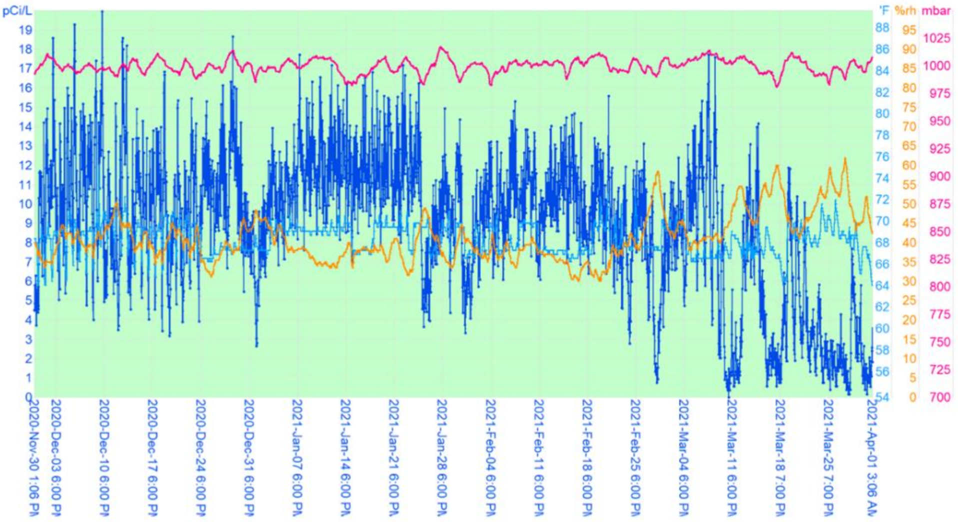

Figure 3. Indoor radon readings pCi/L aligned with indoor air temperature, relative humidity, and atmospheric pressure in house #3.

House #4

The indoor radon concentration ranges between 0 to 9.3 pCi/L with average of 2.5 pCi/L over 4 months from December 1st, 2020, to April 1st, 2021. The radon average exceeds the limit set by EPA 4 pCi/L. It means that this house needs to be mitigated to bring the average of indoor radon to be lower than 4 pCi/L. Figure 4. shows the radon readings over the 4-month period aligned with the indoor air temperature, relative humidity, and atmospheric pressure.

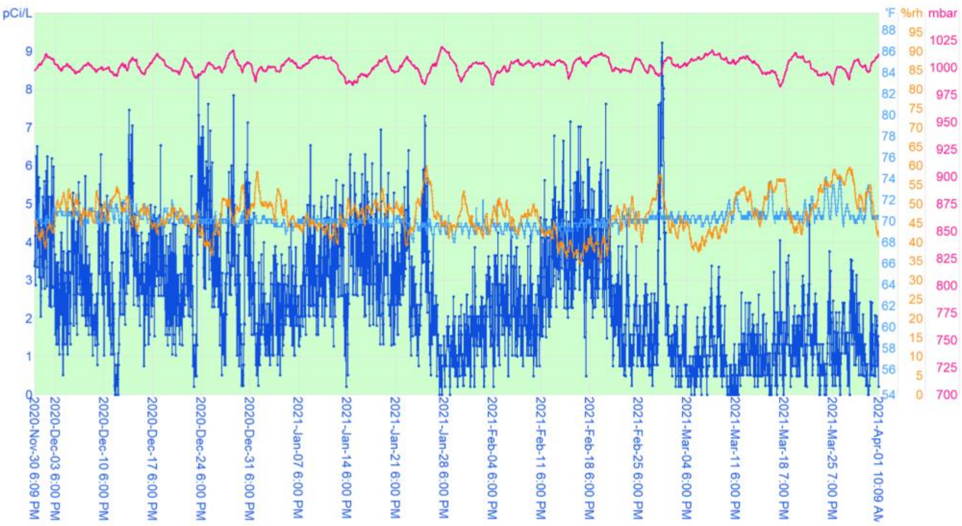

Figure 4. Indoor radon readings pCi/L aligned with indoor air temperature, relative humidity, and atmospheric pressure in house #4.

House #5

The indoor radon concentration ranges between 0 to 14.5 pCi/L with average of 6.4 pCi/L over 4 months from December 1st, 2020, to April 1st, 2021. The radon average exceeds the limit set by EPA 4 pCi/L. It means that this house needs to be mitigated to bring the average of indoor radon to be lower than 4 pCi/L. Figure 5. shows the radon readings over the 4-month period aligned with the indoor air temperature, relative humidity, and atmospheric pressure.

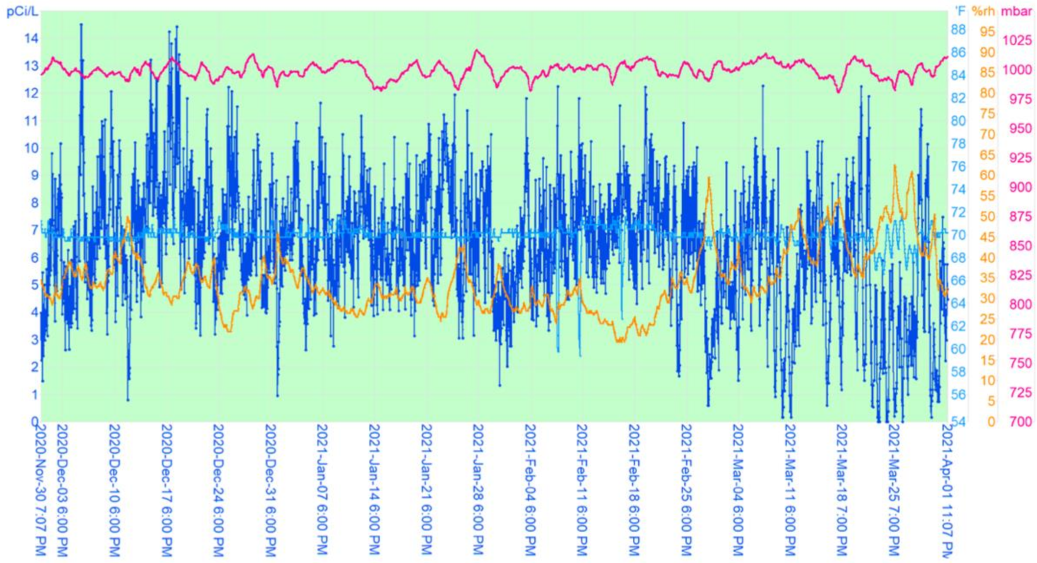

Figure 5. Indoor radon readings pCi/L aligned with indoor air temperature, relative humidity, and atmospheric pressure in house #5.

Table 2. shows the age of the houses aligned with the age of the installed mitigation systems, and the averages of indoor radon over the 4-month period of test. It has been found that there is a strong positive correlation between the building age and radon averages in the five houses. The correlation coefficient is 0.8322. it indicates that older buildings have higher indoor radon averages, Figure 6. Also, there is a stronger correlation between the mitigation system age and radon averages, the correlation coefficient is 0.9515. It indicates that buildings with older mitigation systems have higher averages of indoor radon, Figure 7.

Table 2. The indoor radon averages.

House #	Mitigation System	House Age (years)	Mitigation system age (years)	4-month indoor radon average
1	Active Sub-membrane depressurization	31	4	5.3
2	Active Sub-membrane depressurization	22	4	5.1
3	Active Sub-slab depressurization	101	8	8.9
4	Active Sub-membrane depressurization	15	2	2.5
5	Active Sub-slab depressurization	103	7	6.4

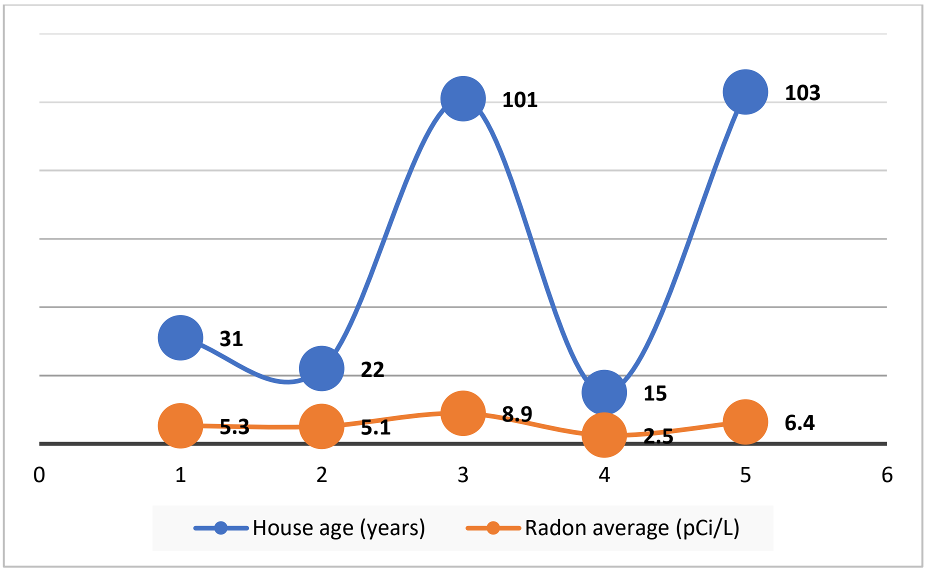

Figure 6. The correlation between house age and radon averages.

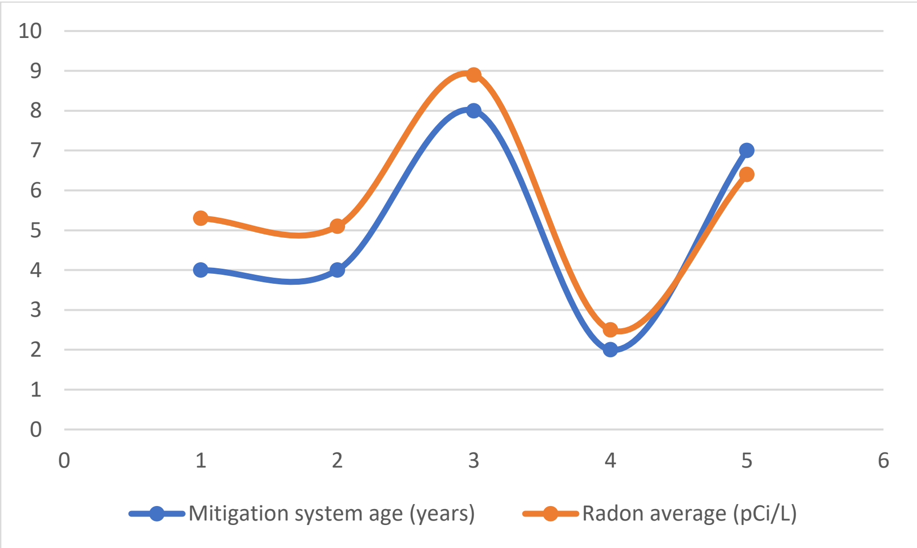

Figure 7. The correlation between the mitigation system age and radon averages.

3.2. Response to the questionnaire

100% of the respondents dealt with indoor air in the same manner; they have never maintained or checked the efficiency of the radon mitigation system since it was installed, they open the windows only in the Spring and early Fall, they use the ceiling fans only in the summer, they have almost similar HVAC system (a combination of heat pump and furnace), they replace the air filters regularly every 2-3 months, they set the thermostat around 67 F in the winter and 74F in the summer, and all of them did not have any issues with the indoor air quality. The similarity of homeowner's practices towards the indoor air quality minimizes the influence of building occupants' behavior on the indoor radon averages detected in the present study.

4. Discussion and Conclusion

According to the US Environmental Protection Agency (EPA), indoor radon is the second leading cause of lung cancer after smoking in the United States. EPA recommends a mitigation threshold for indoor radon, buildings that have indoor radon averages higher than 4 pCi/L should be mitigated. The mitigation systems available for single-family dwellings are based on making a depressurization chamber under the foundation to collect radon gas from the soil underneath the building, then flush out to outdoor air to be diluted to a safer level. In the present study, five mitigated houses were investigated by measuring the indoor radon around the clock for four months. At the same time, a questionnaire was used to collect information about how building occupants behave towards the indoor air quality in their houses.

The measurements indicated a success rate of 20% for the mitigation systems. One out of the five houses had indoor radon average less than the threshold set by EPA. The indoor radon concentration was 2.5 pCi/L over 4 months of monitoring. The lowest indoor radon average in the other four houses was 5.1 pCi/L, and the highest was 8.9 pCi/L. The age of the building, the age of mitigation system, the maintenance of the mitigation system, the magnitude of radon sources under each structure, and building occupants' behavior are all influential factors in the results. In the present study, the buildings had various ages ranging between 15 and 103 years. The occupants behaved towards the indoor air quality in the five houses in the same manner. The age of radon mitigation systems ranges between 2 and 8 years. The only unknown in these factors was the magnitude of radon sources under each building.

The data analysis shows that homeowners never maintained or checked the radon mitigation systems. There is a strong positive correlation between the building age, the mitigation system age, and indoor averages in the five houses. The author suggests that the currently available radon mitigation systems are not enough to reduce the indoor radon averages in areas classified as zone 1 by EPA. In addition to the radon mitigation systems, a change in occupant's behavior, regular maintenance, and check of indoor radon yearly should be considered as an integrative approach to lower indoor radon in areas classified as zone 1 by EPA. An example of an occupant's behavior is to naturally ventilate their buildings for 1-2 hours every day all year-round. A limitation of this study is that it was carried out on only five houses. A survey of a bigger sample of houses is currently underway for the results to be generalizable.

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Conflicts of Interest: The research obtained the Institutional Research Board (IRB) approval at Western Kentucky University. The author declares no conflict of interest.

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Advancing the Use of the Repertory Grid Technique in the Built Environment: A Scoping Review

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Abstract: Personal Construct Theory (PCT) is a theory of personality and cognition developed by George Kelly in the 1950s. Since its development, the Repertory Grid Technique (RGT) has been the most recognized analytical instrument used to elicit personal constructs. Using RGT was not limited to researchers and practitioners within the field of psychology, but also common across a variety of disciplines and approaches. Although RGT was found to be a viable scientific and practical method, its utilization was very limited in the field of the built environment. The purpose of this scoping review was to provide an informed summary on the use of RGT and explore its potential in the built environment. This study followed the PRISMA-ScR guidelines for scoping reviews. A structured literature search was conducted to identify relevant studies between 1965-2020 on Scopus. The findings were charted according to subject area, location, year of publication, and scope. 782 studies using RGT as a research method were identified to contribute to more than twenty-four different subject areas, widely published in the United Kingdom, the United States, and Australia, and show an increase in publication since 1965. Among these studies, only 35 studies were within the scope of the built environment and can be grouped into few main topics according to their aim and keywords. Results indicated the validity of RGT as a scientific research method and implied the extended efforts in the development of Kelly's PCT and its associated tools in different research fields. However, RGT was still an underused scientific method in the built environment and only few researchers were advantaging from RGT's potential. Hence, this review strongly recommended advancing the use of RGT in the built environment and developing future innovations in this fast-paced field.

Keywords: Personal Construct Theory (PCT); Repertory Grid Technique (RGT); Built environment; Research method; Scoping review; PRISMA-ScR

1. Introduction

Personal Construct Theory (PCT) is a theory of personality and cognition developed by the American psychologist George Kelly in the 1950s. The theory is concerned with the psychological reasons for actions. This theory suggests that the variations between individuals arise from the various ways in which they predict and experience events in the world around them. This theory has had a significant impact on the history of the human sciences movements of constructivism [1] Kelly found that anticipation and prediction are the main drivers of our minds. Walker and Winter construed that people create personal constructs of how the environment works to make sense of their observations and perceptions [2]. As Kelly explained in his book [3], personal constructs are the methods that each person uses to gather information, evaluate it, and develop interpretations.

Since the development of the personal construct theory, the repertory grid technique (RGT) has been the most recognized instrument used to elicit personal constructs. This technique was originally designed by Kelly in 1955 to combine elements, constructs, and rating scales in order to determine an idiographic measure of one's personality. It deals with reducing human thoughts into basic understandable elements while perceiving any stimuli. Unlike other research approaches, the repertory grid enables structured conversations by assigning mathematical values to the constructs and elements associated with the investigated issue. The repertory grid is a matrix that was manually constructed at its early stages and then developed into digital forms to make it easier and more accessible. Among these forms are DOS-based software including CIRCUMGRIDS, GRIDSTAT, GRIDSCAL, FLEXIGRID, and OMNIGRID. However, these were later replaced with Windows/Web-based software including Gridcor, GridSuite, Idiogrid, OpenRepGrid, Rep Plus, rep:grid, and Sci:vesco.

Using RGT was not limited to researchers and practitioners within the field of psychology, but also common across a variety of disciplines and approaches which was evident in the several systematic and bibliographic reviews. The latest bibliographic review of the repertory grid technique in 2012 covered the scientific production with or about RGT between 1998 and 2007 [4]. It evaluates the types of documents found, the evolution of the number of publications, the fields of application, and the degree of openness to other disciplines. However, there was no recent systematic review on the use of RGT as a scientific research method discovered.

On the other hand, research on the built environment shares the concerns of PCT with human behavior, needs, actions, interactions, experiences, social and cultural occurrences. Psychologists argue that experiences of places and people's intentions of acting towards them are determined by how they 'construe' place [3]. Safiullah et al. defines the built environment as "everything humanly made, arranged, or maintained; to fulfil human purposes (needs, wants, and values); to mediate the overall environment; and with result that affect the environmental context" [5] (p. 504). As a result, every aspect of the built environment has some psychological effect, creating contact with the user and influencing cognition, which in turn influences human behavior. The lack of knowledge about human behaviors, attitudes, and values observed is an important problem in the design of built environments.

Personal construct theory and repertory grids are theoretical and methodological approaches with successful application in the area of the built environment. In the 1970's, Honikman [6], [7], [8] studied the relation between the personal construct theory approach and the built environmental evaluation. He concluded with a discussion about the potential of this approach and its possible applications in developing human's understanding of how people use and interpret the environment. In succeeding research, Harrison and Sarre [9] assess and highlight the effectiveness of the repertory grid in measuring environmental images by urban residents. Their findings suggest there may be significant links between the image and behavior in the urban environment.

Building on Honikman's work on the potential and application of PCT in environmental evaluation, Agiel et al. [10] used the personal construct methodology to assess perceptions of traditional architectural images and contribute to the field of meaning in architecture. Results of this dissertation demonstrated the existence of architectural "brand images", "inherent images", and "ideal images" of the built environment in the perceptions of its inhabitants. In 2019, Agiel and Kutty [11] analyze and evaluate the visual aesthetics of contemporary architectural images of mosque designs and the influence of emotional, symbolic, and formal building qualities applied to them based on the PCT. Although RGT was found to be a viable scientific and practical method in determining cognitive features of participants and processes and evaluating the assessment of individuals' response to their environment, the utilization of this technique is very limited.

Since the last bibliometric review of RGT dates to 2007, as well as the evident limitations of RGT's use in the built environment, this paper aims to provide an informed summary on the use of RGT and explore its potential in the built environment. That is achieved through systematically mapping the use of RGT as a scientific research method in terms of subject area, location, and year of publication. This research intends to answer the following question:

1. What is the current state of scientific research utilizing RGT as a method in terms of subject area, location, and year of publication?

2. Methods

2.1. Protocol and registration

This study has been conducted as a scoping review. The "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" Extension for Scoping Reviews (PRISMA-ScR) was followed [12].

2.2. Eligibility Criteria

For the studies to be eligible for inclusion in this scoping review, records needed to be peer-reviewed articles that were published in the period of 1965-2020. Records of books, book chapters, conference papers, conference reviews, letters, and review articles (such as scoping reviews, systematic reviews and bibliographic reviews, meta-analyses, etc.) were excluded. Only articles written in English or those with available English translation were included.

Articles were required to use repertory grid technique as a research method or any of its derived tools or extensions to be eligible. Studies were included when the technique was used solely or in conjunction with other methods. Studies were excluded if RGT was not used as a research method or if the full text was not accessible.

2.3. Information Source

A structured literature search during the first quarter of year 2021 was conducted to identify relevant studies found in the bibliographic database Scopus, Elsevier's abstract and citation database. The final search results were exported into CSV format on April 16th, 2021 (available in appendix A). This feature allowed Scopus to be an effective search tool for the purpose of this study, unlike other databases, such as Google Scholar, ResearchGate, or JSTOR where data exportation was not possible. Given that the content on Scopus was checked and revised by an independent Content Selection and Advisory Board (CSAB), publications on this database were considered reputable to use. The exported database was comprised of citation information, bibliographical information, abstracts, keywords, funding details, and other information. In further stages of this research, where the full text of the records was required, the United Arab Emirates University (UAEU) online library and open access databases were used to retrieve the full text.

2.4. Search

Search terms considered in this review were selected based on the main concepts of the research question: repertory grid technique and method. To find records in Scopus database, Boolean operators were used to develop the following search string: "TITLE-ABS-KEY ("RepGrid" OR "repgrid technique" OR "repertory grid technique" OR "repertory grid method" OR "repertory grid") AND PUBYEAR < 2021" (without quotation marks). All records from such search had to comply with the condition expressed and at least one of the keywords from each OR operator was required in the title, abstract, or keywords.

2.5. Selection of Sources and Data Charting

In order to define the current state of scientific research utilizing RGT, the final database search results identified a number of records and the screening process was performed in two stages. In the first exclusion stage, all non-peer-reviewed articles, non-English articles, and articles with no abstracts available were removed in the respective order. Duplicates were later removed through an excel command that highlights cells with identical values. To decide whether highlighted publications were duplicates, the titles, document types, years of publication, and abstracts had to be the same as well. An additional free online tool was used to compare the abstracts of the duplicated records for further verification. Before starting any of the screening processes for this review, two reviewers screened 33 random publications and discussed the results in order to develop and amend a standardized validation process illustrated in Figure 1. Disagreement on study selection and data validation was resolved by discussion and consensus among other reviewers if needed. The aim of this stage was to prepare the data for validation.

In the second exclusion stage, the validation process started by identifying the Repertory Grid Technique in the abstract alone. If cited, the technique had to relate to Kelly's Personal Construct Theory and used as a scientific research method. Whether used solely as the main method of the research or in conjunction with other methods, the record was defined as relevant. If the purpose of using RGT was for description or comparison purposes, literature review, or part of a case study, the record was defined to be irrelevant. In case RGT or any of the terms used in the search string were not cited in the abstract, the full text was retrieved, screened, and validated. When the full text was inaccessible to the reviewers, the record was excluded. Excluded records at this stage had to comply with both conditions, in which key terms were not cited in the abstract and the full text was not accessible for screening. The aim of this stage was to exclude inaccessible records, irrelevant records, categorize records with accessible text into direct and indirect, and identify the use of RGT.

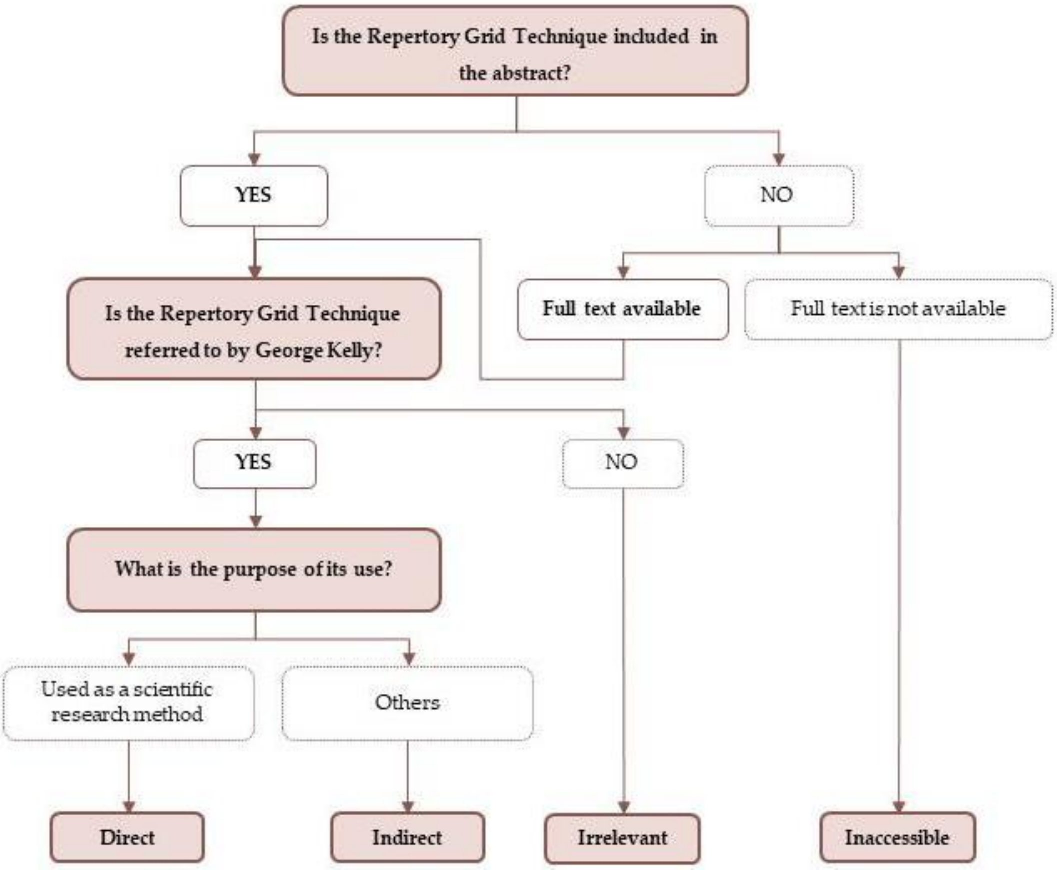

Figure 1. Second exclusion stage and validation process.

A data-charting Excel form was developed to determine which variables to extract and store the records obtained from the reviewed studies. Reviewers independently charted the data, discussed the results, and continuously updated the data-charting form in an iterative process. To increase consistency among reviewers, reviewers sequentially validated titles, abstracts, and keywords of the eligible publications. Using the same preceding validation process, each study was classified according to its purpose into one of the categories: (1) Direct; (2) Indirect; (3) Inaccessible; (4) Irrelevant. Table 1 summarizes the category description.

Table 1. Descriptions of the validation process categories.

Category	Description
Direct	Studies that used RGT as a scientific research method solely or in conjunction with other methods.
Indirect	Studies that investigate the potential of RGT as a tool without using it as a scientific research method; studies that describe or explain RGT; studies that compare RGT to other methods without using it as a scientific research method.
Inaccessible	Studies in which RGT is not cited in the abstract and full text is not available on UAEU's online library or open access databases.
Irrelevant	Studies in which RGT referred is not by George Kelly

In order to report on and explore the use of RGT in the built environment, relevant studies in the previous stage were further screened in two stages. In the first stage, titles and abstracts were screened to categorize studies (1) within the scope of the built environment or (2) out of the scope of the built environment. Studies were categorized within or out of scope according to the definition of the built environment stated earlier in this paper. In the second stage, the full texts of the studies classified within scope were retrieved, carefully reviewed, and listed with their use of RGT.

2.6. Data Items

The elements of data charting that were considered were as follow:

- Author(s): First author's last name, first author's first name et. al.
- Document title: as specified in the data-charting Excel form.
- Publication year: as specified in the data-charting Excel form.
- Document type: as specified in the data-charting Excel form.
- Country: manually extracted from the first author's affiliation.
- Subject area: manually extracted from Scopus.
- Use of RGT: manually extracted from research papers.

2.7 Synthesis of Results

The figures and tables presented in this study were created using both automated and manual processes. The data-charting Excel form included the author(s), document title, publication year, and document type. However, the publication country was manually extracted by the reviewers from the first author's affiliation. The study's subject area was exported from Scopus into a CSV format sheet and merged back into the original form.

3. Results

3.1. Selection of Sources of Evidence

Figure 2 illustrates the PRISMA-ScR flowchart to answer the two research questions. In order to define the current state of scientific research utilizing RGT, the reviewing team started with a total of 1,719 records to screen. In the first exclusion stage, books, book chapters, conference papers, conference reviews, letters, and review articles (n=356), non-English articles (n=67), and duplicates (n=2) were removed in the respective order. After the first exclusion stage, 4.7% (425 out of 1,719) of the studies were eliminated and as a result, 1,294 publications were eligible for validation in the second exclusion stage.

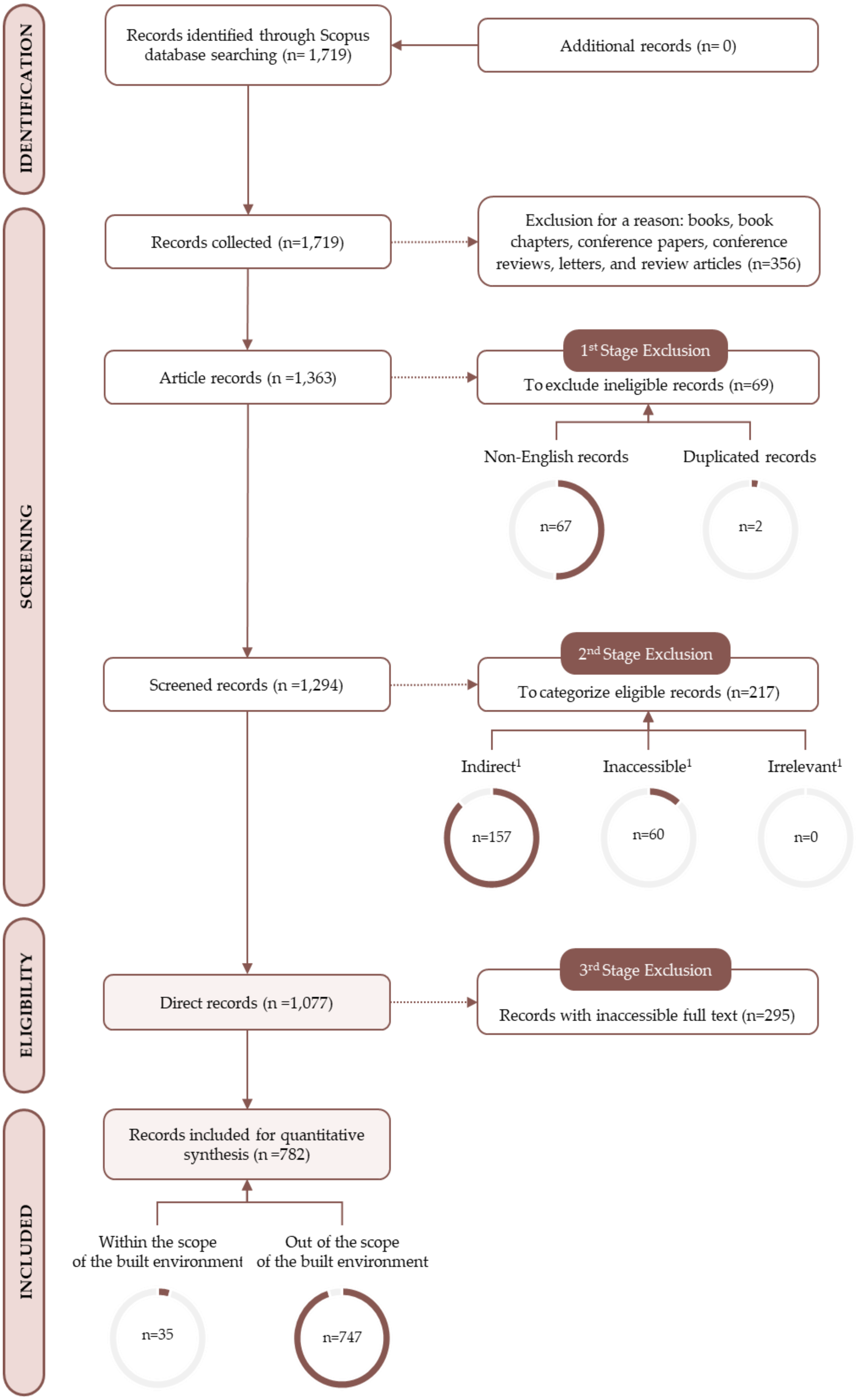

Figure 2. Flowchart indicating the process of literature search developed in accordance with PRISMA.
[1] Refer to Table 1.

In the second exclusion stage, studies that cite the terms “RepGrid”, "repgrid technique", “repertory grid technique”, "repertory grid method", or "repertory grid" in their abstract and in which refers to the technique by Kelly were screened and categorized. If RGT or any of these terms were not cited in the abstract, the full text was retrieved, screened, and categorized. As a result, 3.2% (1,077 out of 1,294) of the studies were categorized as “direct” using the repertory grid technique as a scientific research method. 12.1% (157 out of 1,294) of the studies were categorized as “indirect” as they describe, explain, compare, cite, or study the grid without using it as a scientific research method. 4.6% (60 out of 1,294) of the studies were inaccessible. No records were identified as irrelevant.

In the final exclusion stage, the full text of 27.4% (295 out of 1,077) of the “direct” studies were inaccessible, and consequently, 782 studies were included for quantitative synthesis. Among these papers, reviewers were able to identify 4.5% (35 out of 782) of the records within the scope of the built environment and 95.5% (747 out of 782) out of scope.

3.2. Characteristics of Sources of Evidence

Figures 3-5 present the characteristics of the 782 studies using repertory grid technique as a scientific research method and simultaneously highlight the characteristics of the 35 studies within the field of the built environment.

3.2.1. Subject Area

According to Scopus, more than half (432 out of 782) of the studies in our sample were published in more than one subject area. One record was contributing to six different subject areas including Social Sciences, Health Professions, Agriculture and Biological Sciences, Arts and Humanities, Psychology, and Nursing. Another was contributing to five different subject areas. Fourteen (14 out of 432) other records were contributing to four subject areas, while thirty-six records (36 out of 432) were contributing to three subject areas, and three-hundred-fifteen records (315 out of 432) were contributing to two subject areas. Almost half (350 out of 782) of the other records were contributing only to one subject area in which the subject areas of 72 studies were classified as “others”. Figure 3 illustrates the distribution of these studies among the subject areas defined by Scopus.

As highlighted in Figure 3, 35 records identified within the scope of the built environment were also contributing to one or more subject areas such as Social Sciences (n=23), Environmental Science (n=6), Engineering (n=4), Agricultural and Biological Sciences, Chemical Engineering, Decision Sciences, Earth and Planetary Sciences, Health Professions, Psychology (n=1) each. The subject areas of 5 studies were classified as “others”.

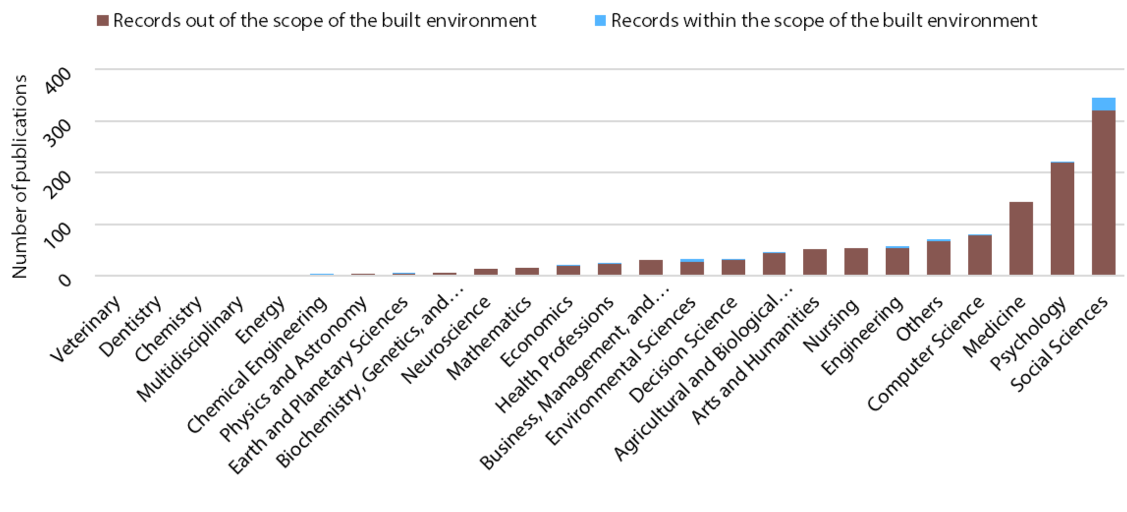

Figure 3. Second exclusion stage and validation process.

3.2.2. Location

Included records have been published in several parts of the world as indicated in Figure 4. To a greater extent, and since 1967, research has been conducted in United Kingdom (37.1%, n=290), United States (9.8%, n=77), Australia (8.6%, n=67), Spain (4.6%, n=36), Canada and Germany (4.5%, n=35) each, Taiwan (3.6%, n=28), Italy (2.9%, n=21), Sweden (2.5%, n=20), Philippines (1.8%, n=14), New Zealand and Turkey (1.5%, n=12) each, China and Netherlands (1.4%, n=11) each, Hong Kong and Switzerland (1.3%, n=10) each.

On a smaller scale, research has been published in Belgium (1.2%, n=9), Denmark, Ireland, and Japan (0.78%, n=6) each, India, and South Africa (0.6%, n=5) each, France, Malaysia and Russian Federation (0.5%, n=4) each, Norway (0.4%, n=3), Argentina, Brazil, Czech Republic, Finland, Greece, Pakistan, Portugal, and other countries (0.25%, n=2) each, Bahrain, Bangladesh, Chile, Cyprus, Iceland, Indonesia, Iran, Luxembourg, Mexico, Namibia, Singapore, South Korea, Thailand, and United Arab Emirates (0.1%, n=1) each.

As for the records within the field of the built environment, research has been conducted in United Kingdom (28.6%, n=10), Australia (20.0%, n=7), Malaysia (8.6%, n=3), Japan, Switzerland, Taiwan, and Turkey (5.7%, n=2) each, Bahrain, Greece, Hong Kong, Luxembourg, Spain, and United States (2.9%, n=1) each.

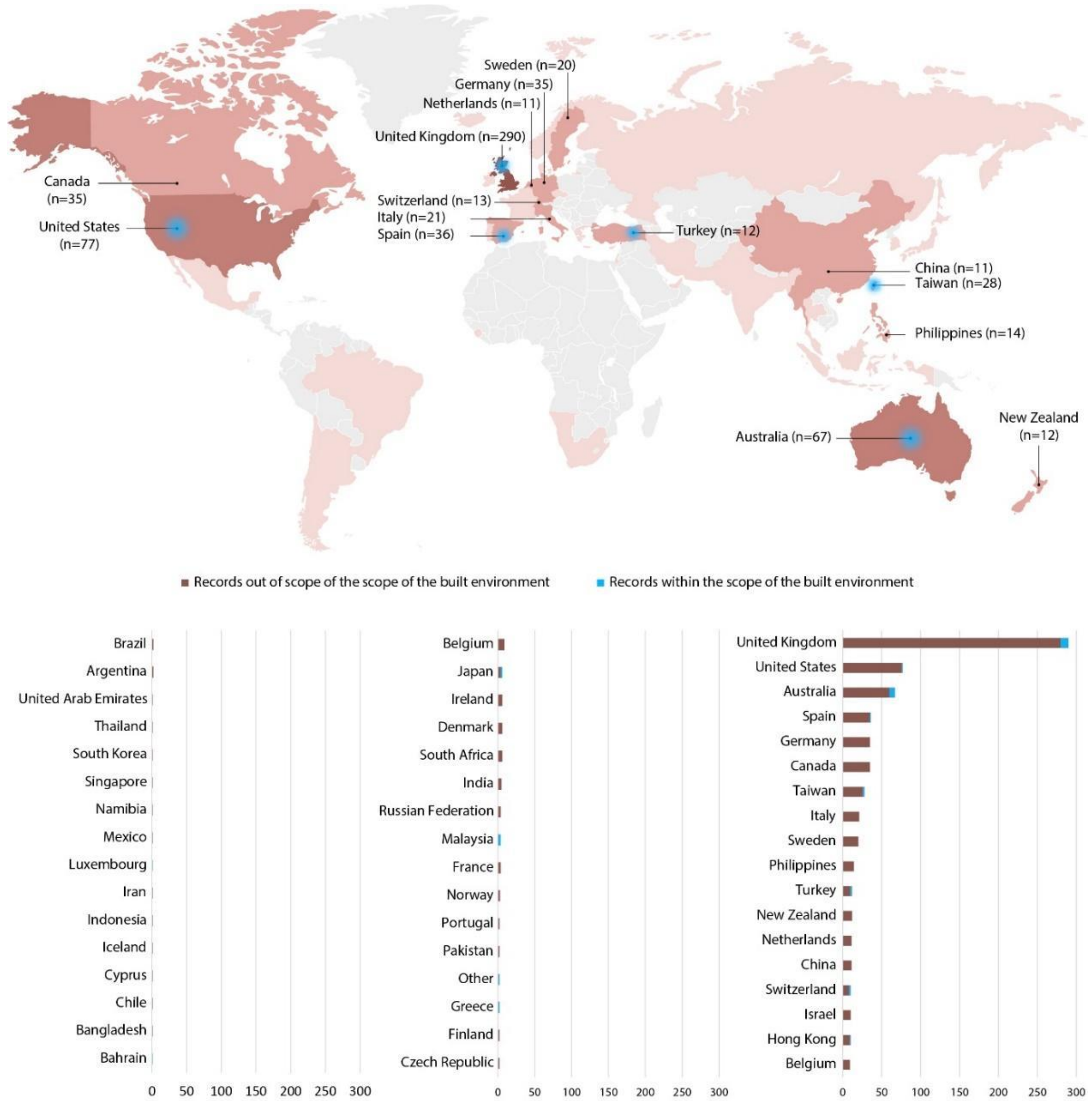

Figure 4. Number of publications according to authors' affiliation countries in the included studies.

3.2.3. Year of Publication

Figure 5 demonstrates the 782 studies published between 1967 and 2020 as a line graph. Overall, the rate of publication improved over the given time period. From 1967 to 1994, the rate of publication remained consistent, ranging from (n=1) to (n=7) publications per year. Following that, the rate increased dramatically, peaking at (4.6%, n=36) publications in 1997 and again in 2000. Between 2001 and 2015, the publication rate fluctuated, reaching a low of (2.2%, n=17) studies published in 2003 and 2008 and a high of (4%, n=31) studies published in 2012 and 2014. Later, the number of publications increased to (5.6%, n=44) studies in 2017 but slightly fell to (4.8%, n=38) publications in 2020. On the other hand, studies within the field of the built environment started emerging in year 1978. Studies reached a high of (11.4%, n=4 out of 35) studies published in 2012 and 2014.

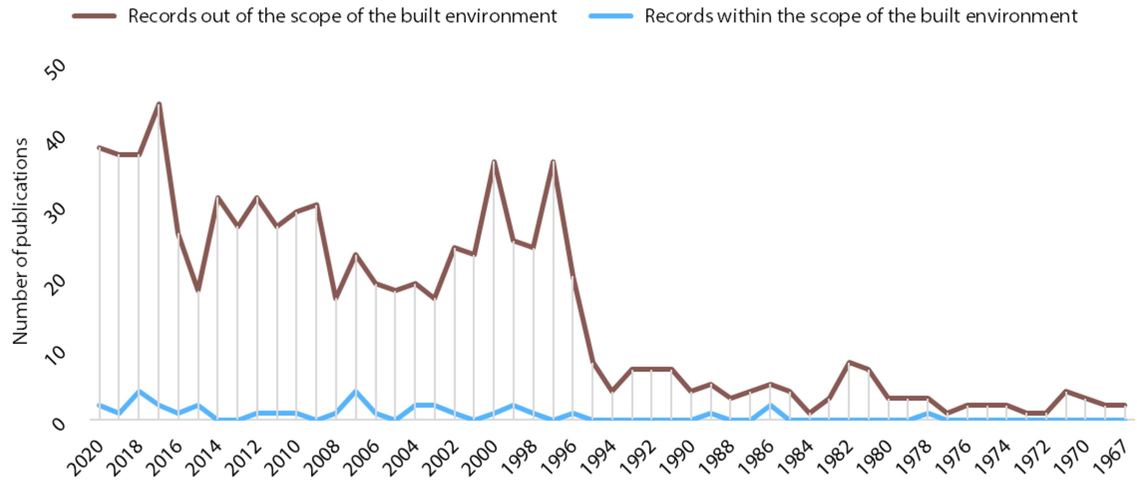

Figure 5. Number of publications according to authors' affiliation countries in the included studies.

4. Discussion

4.1. Summary of Evidence

This scoping review has identified a total of 782 studies using the repertory grid technique as a scientific research method in terms of subject area, location, and year of publication. According to Scopus, these studies were contributing to more than twenty-four subject areas and more than half of them were listed under two or more areas together. Higher contribution rates were identified in the three main areas of Social Sciences, Psychology, and Medicine in which the personal construct theory was initially introduced. Areas of Computer Science, Engineering, Nursing, Arts and Humanities, Agricultural and Biological Sciences, and Decision Sciences received relatively equal amounts of contribution following the main three areas such as Veterinary, Dentistry, Chemistry, Multidisciplinary, and Energy received the least amount of contribution.

In terms of location, the highest number of publications was 290 articles in the United Kingdom, followed by the United States, Australia, Spain, Germany, and Canada, respectively. The higher publication rate in these particular countries is expected because of the international congresses and conferences taking place in those regions. The United Kingdom alone houses several regional "interest groups" working in Personal Construct Psychology. Nevertheless, publications were not limited to these countries, but were also spread throughout more than forty-three other countries.

In terms of year, the rate of publications has increased over the period 1967 and 2020. From 1967 to 1994, the rate of publication almost remained consistent especially during the evolution of PCT and RGT as its tool. Following that, rates have increased dramatically, peaking in 1997 and again in 2000. Rates fluctuate between 2001 and 2015, increase again in 2017, and fall slightly in 2020. These rates do not necessarily reflect publications on the repertory grid technique as a tool, instead, they serve as a reflection of its use as a scientific method in the field of research.

Among the included 782 studies, this review identified only 35 studies within the scope of the built environment. According to Scopus, these records were also contributing to one or more subject areas such as Social Sciences, Environmental Science, Engineering, Agricultural and Biological Sciences, Chemical Engineering, Decision Sciences, Earth and Planetary Sciences, Health Professions, and Psychology. In terms of location, the highest number of publications was 10 articles in the United Kingdom, followed by Australia, Malaysia, Japan, Switzerland, Taiwan, Turkey, Bahrain, Greece, Hong Kong, Luxembourg, Spain, and the United States, respectively. While studies using RGT had a high rate of publication over the period 1967 and 2020, RGT in the built environment was noticeably absent. Studies started emerging in the year 1978 and increased to a maximum of four publications during 2007 and 2018.

As a result, the wide variety of subject areas and locations, in addition to the increase in the number of publications, indicate the validity and value of the repertory grid technique as a scientific research method. Furthermore, findings imply the extended efforts in the development of George Kelly's personal construct theory and its associated tools in the different research fields. However, it is observed that RGT is still an underused scientific method in the field of the built environment and few researchers only are advantaging from RGT's potential.

4.2. Limitations

The most important limitation to this study is the time limit. To make this review more feasible, only the bibliographic database Scopus was used for the initial identification of records. Further adding to this issue, only UAEU online library and open access databases were used to retrieve the full text of the records. Absence of grey literature.

5. Conclusion

The purpose of this scoping review was to provide an informed summary on the use of the repertory grid technique and explore its potential in the field of the built environment. That was achieved through systematically mapping the use of RGT as a scientific research method.

Seventy years after RGT's creation, this review is an evidence that the current state of scientific research utilizing RGT as a method is solid despite the large number of other existing evaluation tools. Although there is a growing interest in the scientific community for the potential that RGT has in the field of Social Sciences, Arts and Humanities; RGT in the field of the built environment is still underused. Especially that the field of the built environment shares several attributes with the fields of social sciences and arts and humanities in terms of user experience.

The limited number of publications in the Middle East suggests the need of further investigation into the repertory grid technique. With the growing interest of the MENA region towards sustainability and user-centered design, a promising direction for future research could focus on embedding RGT into the designing process.

Finally, the review recommends advancing the use of RGT in the built environment and developing future innovations in this fast-paced field.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "conceptualization, A.A., R.R. and D.B.; methodology, D.B., R.R. and A.A.; software, R.R. and D.B.; validation, D.B. and R.R.; formal analysis, R.R. and D.B.; investigation, D.B. and R.R.; resources, D.B., R.R. and A.A.; data curation, R.R. and D.B.; writing—original draft preparation, D.B. and R.R.; writing—review and editing, R.R., D.B., and A.A; visualization, D.B and R.R; supervision, A.A.; project administration, A.A., D.B. and R.R.; funding acquisition, A.A."

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Supplementary data to this article can be found online at: Supporting Material.csv

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Paradigm Shift of Work and the Workplace amid the Pandemic: an Exploratory Study in the UAE

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Abstract: The conventional and long-established workplace, with its working modalities may be drastically challenged, more than any other building type, following the disruptive and instant changes imposed by the recent global pandemic. The subsequent measures taken resulted in a complete disruption to the office employee experience. All indicators show that the pandemic is likely to change or accelerate the new working models, but it may also inspire technological advances related to the health and satisfaction of building occupants. This research aims to explore and identify the impacts of the pandemic on the workplace with a focus on the users' concerns, experiences, satisfaction, and expectations. The main purpose is to investigate how the pandemic may be shifting the working model and what may be its implications on workplace design. A survey was designed to explore three main aspects. First, the employees' concerns and fears about returning to the workplace, second, the impact of the pandemic on the work model, and third, the participants' expectations for the future of office design and layout. The survey was carried in November 2020 with 68 employees of a UAE government ministry in Abu Dhabi. The results showed that the main concerns of the participants were related to the health implications on their families and themselves. Over half of the survey respondents preferred a mixed working mode (57%), or even working fully from home (26%). The respondents indicated that they remained more or equally productive while working from home. Interaction and socializing with peers were the most missed workplace activities. In terms of office layout, an increased distance between workstations was preferred by over 57%, while 38% favored work in individual offices. The outcomes indicate a critical need to revise the current work models and explore the possible shift to a hybrid home-office work that ultimately will incite drawing new guidelines for office design.

Keywords: Workplace, Pandemic, Employee, Concerns, User satisfaction, Work model, Office, UAE.

1. Introduction

It is a well-established fact that most people spend a substantial part of their life working, and that work satisfaction is an essential feature of the wellbeing which contributes to meet the required productivity levels. For a multitude of reasons, office design has gone through different developments starting from the 18th century till today, with often a focus on efficiency and productivity that has since moved to a more human centric design. Since early 2020, the whole world has faced a global pandemic that is affecting all countries and all sectors, with the workplace being a prime example of this disruption. In context, since March 2020, and in order to achieve social distancing, the United Arab Emirates (UAE) government, in line with the global reaction, instructed that all workplaces be closed and all work to be conducted remotely. Although working remotely maybe familiar in other countries, it is a novelty in the UAE and likely in many other part of the world. The employees had to manage the situation and create their own work environment at home. By early July 2020, the UAE government instructed a return to work in offices for all federal entities in partial or full capacity in different cities of the country. Other entities continued to work remotely

[2]. There is a general hope that life will return to normal with the vaccination campaign, but it seems that familiar ways will be part of the past, as some of the necessary changes may remain in verve.

All around the world, work modalities changed and the employees had to adapt to the changes during and will have to adjust post pandemic. To forecast any changes is very crucial for the adaptation process. Therefore, it is critical to explore the statutes of the workplace under the current situation, to review and maybe revise the work modalities and to rethink the office space layout. There is an urgent need to know what people feel about working from home, what they like and do not like about working remotely, assess their satisfaction, comfort, productivity and performance levels, etc. If any adjustment is required, such as shifting to a new work format, it will challenge the whole existence of the office, its structural management. And in return, it may well also call for revisiting office design in order to meet the requirements of the proposed work formats.

Hence, this research attempts to fill part of this gap and will; therefore, be driven by a main research question that looks into "How the pandemic is shifting the working mode and its implications on the workplace design and layout?" This main research question can be further articulated into two specific sub-questions:

1. "What are the currently preferred work modes? " (in office, hybrid or remotely)
2. "What are the implications of the pandemic on the office space design and layout?"

These questions may well be assessed and addressed, through the following research objectives:

- Assess the concern and fears of the employees in relation to the pandemic and returning to work under the same conditions,
- Assessing work mode preferences based on the current experiences of remote work versus conventional,
- Identify advantages and disadvantages of each work mode,
- Investigating of how the productivity and satisfaction have been affected, and
- Expectations of how the design of workplaces will change.

2. Methodology and Case Study

This research aims to have an overall look at the current status and impact of the pandemic on work and the workplace in order to attain the research's objectives. Since this pandemic and its impacts are recent phenomenon, with only few recently published papers, and due to the social distancing regulations and the lock down instruction, this research was best investigated using a survey as the methodological approach. The survey has been designed in three main sections exploring the main objectives of this research:

1. Employees' fears and concerns going back to offices,
2. Work modality preferences.
3. Exploring the expected future of the workplaces design and layout.

The survey was carried among the employees of the Ministry of foreign affairs and international cooperation headquarters (MOFAAIC) in Abu Dhabi (Figure 1), where the first author works and access and ethical approval were sought and granted.

Figure 1. Ministry of foreign affairs and international cooperation building [1]

This specific sample is chosen for the following reasons:

1. Obtain more accurate and reliable results since all the employees have gone through the same circumstances and working in the same building and under the same employer.
2. Facilitated access to the participants.
3. Engage the management with the employees' concerns.

The survey had 24 questions including multi-selection and open-ended questions and they are categorized into three main sections to measure qualitatively the needed aspects mentioned in the themes below:

1. Theme 1: Employees' fears and concerns going back to offices.
2. Theme 2: Work modality preferences.
3. Theme 3: Exploring the expected future of the workplaces design and layout.

The survey was conducted over the first 3 weeks of November 2020 with a total of sixty-eight (68) participants.

The case study as mentioned was the Ministry of Foreign affairs (Figure 1) where a range of offices exist ranging from private offices to separate workstations and share open plan workstations. Figure 2 illustrates a typical floor plan layout.

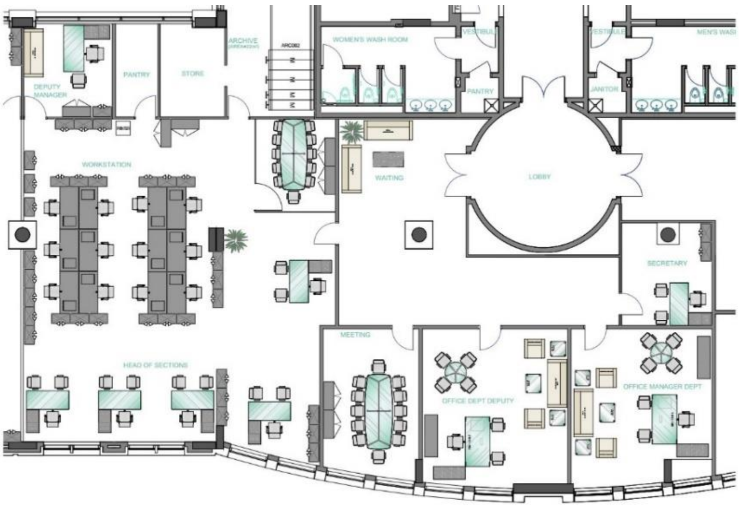


Figure 2. Typical floor plan inclusive of various workplaces layout and furnishing

3. Results and Discussion

3.1. Characteristics of respondents and their workplace.

A total of 68 participants responded to the survey, including 40 female and 28 male employees, Figure 3 illustrates the representative ratio of the contextual workforce. The results are assuming that there is no existence of gender bias since the responses rate between female and male are close (41.2% Male, 58.8% Female) .

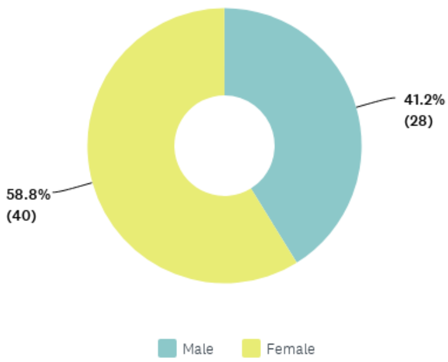


Figure 3. The survey respondent's gender ratio

The MOFAAIC work place has different types of offices including private offices, individual workstations within the open plan office and shared workstations located within the open office area, as shown in the space layout of Figure 2. The distribution of respondents are almost equally split among the three different types of offices. This fact is assumed to contribute to the results by having equal responses to each question (Figure 4).

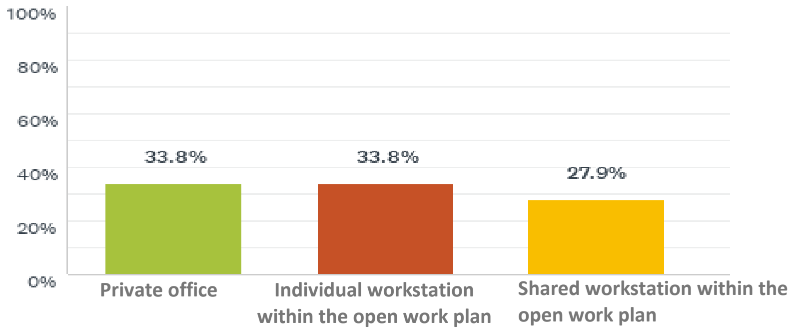


Figure 4. The type of offices that the survey respondents occupy

3.2. Concerns and fears of the employees going back to the offices during the pandemic

Since the beginning of the pandemic, employees have been carrying unusual levels of constant stress. This section presents the survey results related to concerns and fears that employees experienced while going back to the offices during the pandemic with implications on their work life. The results showed that participants most important concerns about returning to work in the office were strongly related to the health implications on their families and themselves, while concerns related to work life came second (Figure 5). This type of concerns makes employees carry feelings of fear, uncertainty, and a sense of loss of control and the "homification" of work, which has had employees work, for instance, outside of normal hours to accommodate disrupted family routines. This unknown situation in contemporary times may have an impact on the employees such as decreased performance, productivity, motivation, mental health and increased stress rate.

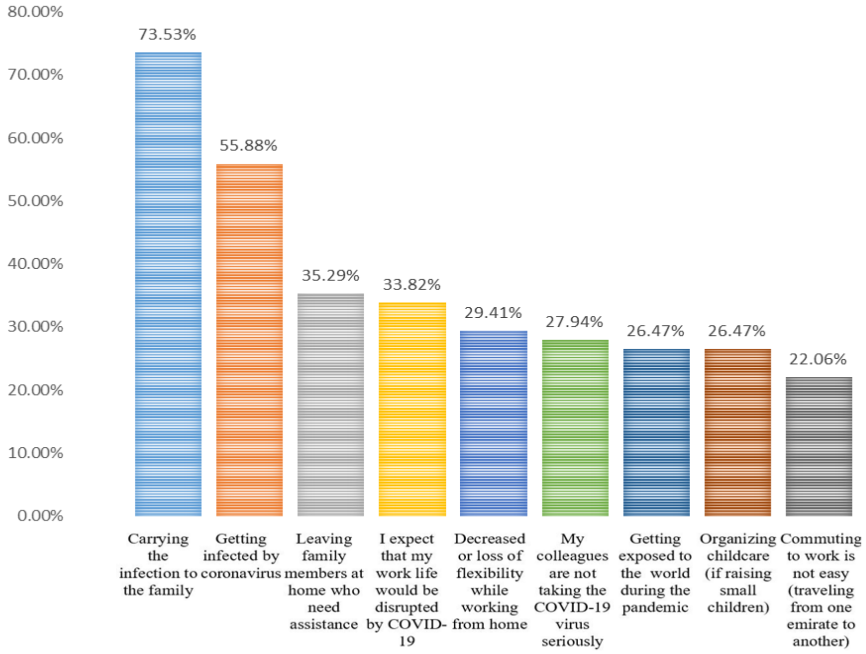
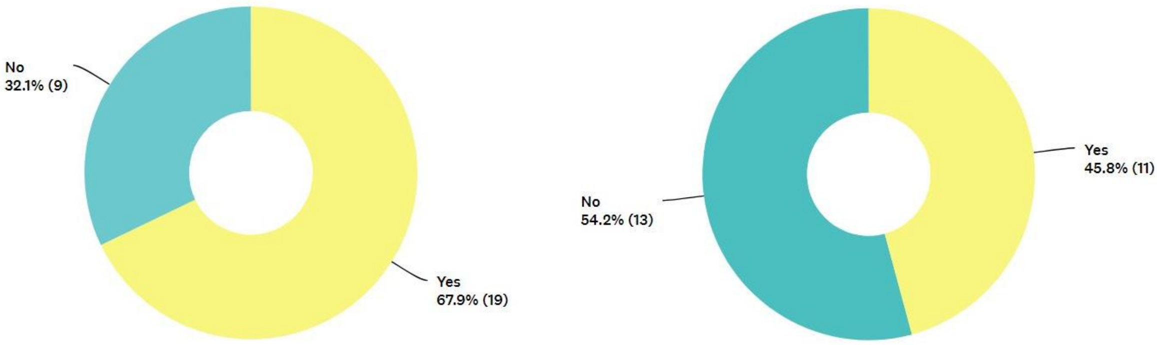


Figure 5. Participants' concerns and fears about returning to work in the office during the pandemic.

Well over two third (67.9%) of the female participants have personal issues and concerns that require special accommodation upon returning to work; for example, the challenges of managing work with childcare, social life, household chores, and family responsibilities (Figure 6a). On the other hand, with a percentage of 45.8%, the male participants reflected the fact that working women are usually more concerned and carry the load of the family care than men while working from home (WFH) (Figure 6b).



(a)

(a) Female respondents, **(b)** Male respondents

Figure 6. Fears and Concerns while working from home

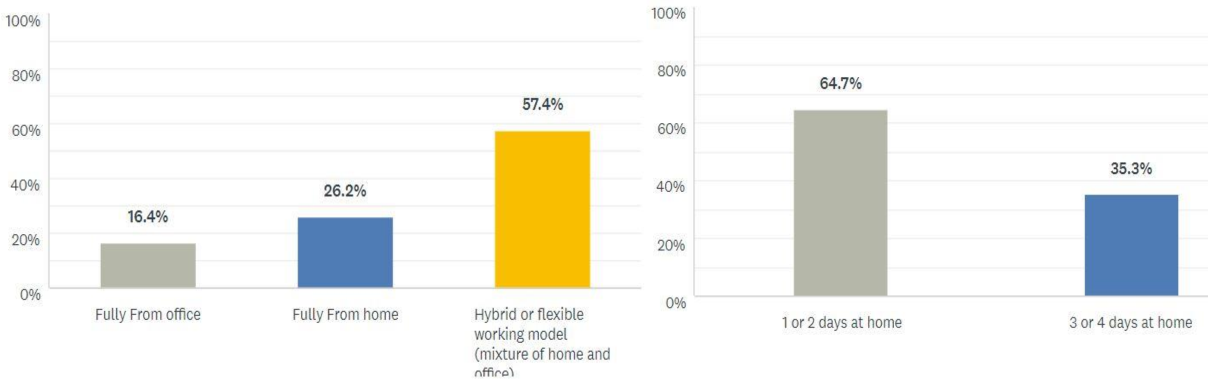
3.3. Work mode preferences

Respondents were asked several behavioural questions in order to gain insights into their work mode preferences, satisfaction and comfortability with WFH arrangement, challenges they faced while working from home and to measure their productivity levels while working from home.

3.3.1 Work mode preferences

The most striking result, despite the non-preparation for such a rapid shift, was the overwhelming preference for a full switch to work from home (26.2%), or a hybrid working model, where well over half (57.4%) of the overall respondents preferred to work in a mixed mode (Figure 7a).

The respondents showed different preferences (in a ratio of two-thirds to one-third) with the number of days that they would like to work remotely per week; 64.7% of the sample preferred to work 1 to 2 days and 35.3% preferred to work 3 to 4 days at home and the remaining in office (Figure 7b).



(a) *(b)*

Figure 7. (a) Work mode preferences; **(b)** Preferences with the number of days per week in remote work.

3.3.2 Working from home office arrangement

There are significant levels of agreement with respondents finding the work from home experience to be mostly satisfying, and that they have an appropriate space arrangement from which work can be completed (Figure 8). Arrangement of workplace is significant, and it should be highlighted that arrangements for working from home were initially random as the pandemic forced itself upon the many very suddenly. Employees had to update their home furniture to be used as desks or using the family dining or living rooms as shared workplace. Despite the above-mentioned circumstances that made the employees adapt to the fast changes, well over –half, or 62% of the sample said that they were extremely or slightly more comfortable with their home workplace arrangement (Figure 9). In the future, the overall WFH arrangements experience may become more satisfying and positive, when workers would have had more time to prepare for it and reduce or eliminate inconveniences.

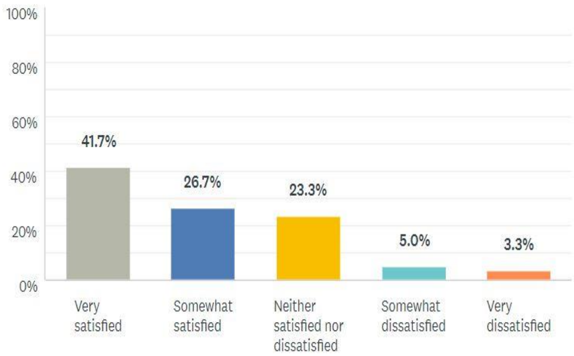


Figure 8. Respondents' satisfaction of workplace arrangement while working from home.

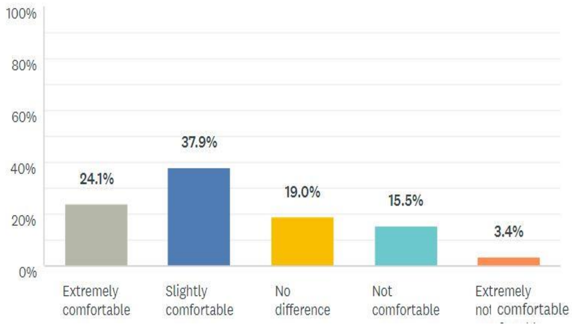


Figure 9. Respondents' comfort of workplace arrangement while working from home.

3.3.3 Challenges of working from home: The WFH model

The biggest challenges that have been faced while working from home was the inability or challenges in adequate and productive communication with co-workers (54%). This means that, if the organizations decided to implement the mixed working mode, the workers could be provided with enhanced communications technology to achieve satisfaction [3]. The other challenges came nearly equally, but not less important, such as the physical workspace (41%), keeping a regular schedule (39%) and social isolation (38%) (Figure 10). While working remotely, most of the participants agreed that they had access to all what they needed to succeed at work, the materials and equipment needed to perform effectively, and the technology needed to help them to stay connected with their team.

On the other hand, working from home resulted on a quite high satisfaction rating by the participants, where 72.1% of the participants showed that they had healthy work - life balance when working from home, which highlights one of the main benefits encountered, i.e. people need to spend more time with families at the same time workers are more able to achieve their tasks (Figure 11).

On the other hand the open ended question was asking the participants to select five of the biggest challenges they faced while working from home and the question was open ended to allow participants to share their own experience in their own words. As such, the participants stated:

"The biggest challenges I have faced while working from home is overworking".

This clearly shows that they experienced discomfort with overtime and that the pandemic blurred the lines between work and personal life. This gives a great benefit for the workplaces that is underestimated, where it helps employees physically differentiate between home and work life, starting from the moment where they commute to get to the workplace till the moment they leave it [14]. This may call for organizations to set a clear role to regulate and control the working hours from home, it is expected that the issue of overworking will become manageable.

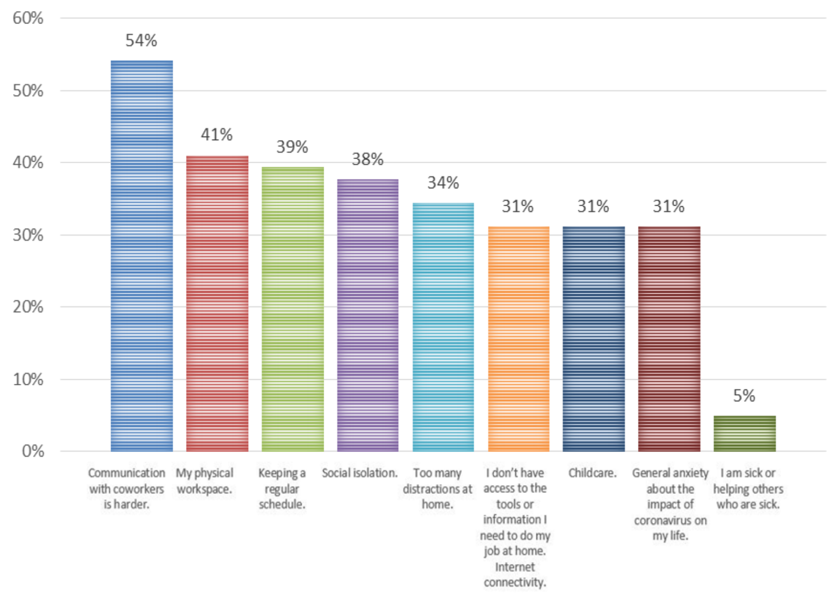


Figure 10. Challenges faced by the respondents while working from home

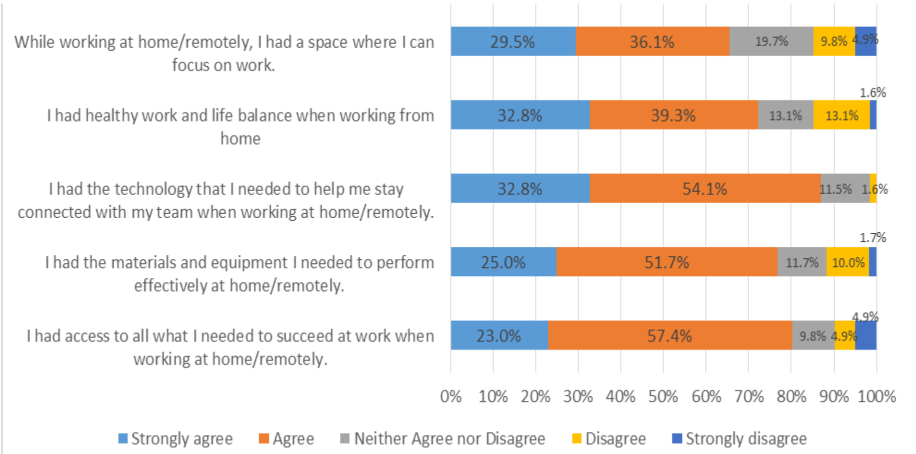


Figure 11. Level of agreement regarding the overall WFH environment.

3.3.4 Productivity levels of the participants in the WFH model

Survey participants were also asked to evaluate their level of productivity at home compared to the office. Overall, 43.1% of respondents rated their productivity as higher or that they are more productive than being at the workplace and (48.3%) showed that they had the same productivity level as being at the workplace. At the end of the day and while working remotely from home, 44.3% of the respondents found themselves delivering and completing the work assignment, while 32.8% were more satisfied and felt like they have made a difference. Since productivity is the same or higher than usual, this clearly states that working from home does not seem to affect productivity of the sense of performance.

3.4. The future of the workplace design and work model

During the last decades and prior to the pandemic, the workplace was in constant development and improvement, and the conventional wisdom had been that offices were critical to productivity, culture, and winning the competition for talent. Companies competed strongly to get prime office space in major urban centres around the world and focused on solutions that were realized to promote collaboration, satisfaction, productivity and wellbeing [3].

The last theme explored was the future expectation of the workplace and work model after the pandemic and questioned the need for the real office spaces and the next transition in work mode.

3.4.1 The need of the workplace as we know it

Collaboration and social connection are the most needed factors in offices as stressed by employees. Survey results indicated them as the most important reasons for going to the workplace, or even the desire to return to it. People still clearly value face-to-face interactions over virtual contacts despite the rapid adoption of virtual collaboration technologies, stating they missed socializing with their co-workers and being part of the community (Figure 12).

When asked about the top reasons for wanting to go to the office, 50.8% of the respondents related their selection to connecting to "people". Participants also reported certain office activities, such as access to technology, professional development/coaching and access to amenities as desire for return reasons (Figure 13). A recent report that revealed the survey results about work from home 2020 in U.S.A published by the Gensler Institute showed nearly the same data. When asked what they missed most about working from the office, three out of four survey respondents said "the people". In the same report. Interviewees also reported that certain activities, such as collaborating and staying informed about what other colleagues' work are harder to do from home, underscoring the value of physical presence [15]. After the pandemic, it has been widely demonstrated by health care specialists that it is completely normal to feel stressful about returning to office life, the benefits, from improved mental health to increased creativity, are not to be underestimated. Working at home limits the interactions gained from workplace, from overhearing conversations that may enhance the understanding work processes to missing important verbal information. It is not only about what can be discussed or heard. Body language plays a significant role, as human communication is expressed by body movements. It would help to improve and expand the relationships, encourage others and enhance productivity. The absence of face-to-face contact eliminates the important role of body language [14].

In an experiment by Stanford University economics professor Nicolas Bloom on remote working, half of remote workers wanted to return to the office after the experiment, saying they missed the social connection. Offices have always been a physical manifestation of a corporate ethos, and they are still needed to embody their brand and culture. For that same reason, it is almost impossible to create a company culture when everyone is virtual and human contact cannot be replaced by technology [14].

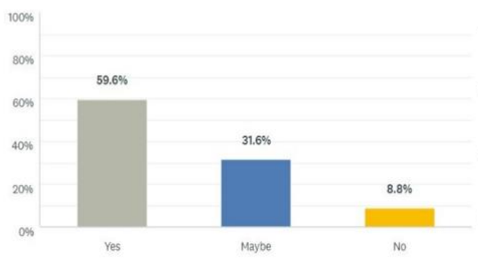


Figure 12. Respondents' opinions about the future need of the offices as known today.

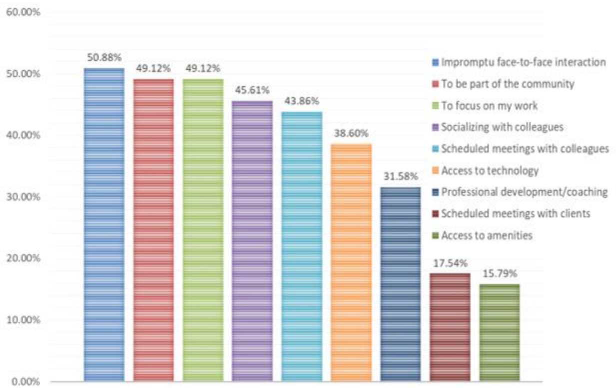


Figure 13. Most important things that have been missed about the offices while in the WFH mode. model.

3.4.2 Readiness to work remotely and the need of advanced technology

Before the pandemic, a year was the typical duration to implement the level of remote working that took place during the crisis. In reality, it took an average of eleven days to implement a practical move, which means that the transition of the work model from the existing work places to work remotely was done nearly 40 times faster than what was expected [8].

This shift was achieved thanks to the existence of the adequate technology infrastructure, visible with the fast adoption of online conferencing and meeting platform technologies at the beginning of the pandemic such as Zoom, WebEx and Microsoft Teams [8]. This alignment is critical in the post-pandemic environment, where the participants, who showed willingness to consider hybrid working model in future, that their remote work environment would be improved if advanced communication programs and portable computers are provided (Figures 14).

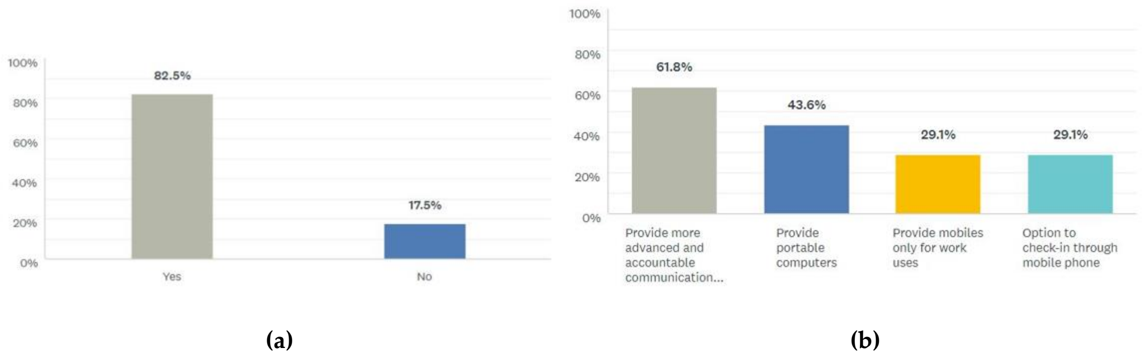


Figure 14. (a) Respondents' willingness to consider hybrid working model in the future**; (b)** The required features to enhance the hybrid working model.

3.4.3 Potential needs to be considered in the workplace after the pandemic

It is commonly believed that the only solution to return to normal life is to cope with the pandemic and live with it. Today, many countries are cautiously trying to relax quarantine and lower lockdown restrictions in order to at least return to their position before Covid-19. Yet, in the absence of a global immunization, characteristics of modern workplaces will have to change to ensure a maximum safety to the returning employees. Making basic changes to keep employees safe and allay fears is the first stage resuming office life will involve. The changes needed as stated by the respondents are indicated in Figure 15 and include:

- **Increase office sanitization**

To perform the necessary routine of cleaning and disinfection is important to keep all surfaces and materials virus-free. Also, it is very important to make a list of all main areas that employees are most frequently in contact with, such as door handles and elevator push buttons. This sanitization effort should be carried out routinely throughout the day and once the working day is finished to ensure a clean and safe environment for the workers in the next day [5].

- **Increase social distancing**

Employees insist on enforcing social distancing, though most of the precautions were already taken by MOFAAIC, which leads to suggest that there is likely a lack of conformance.

- **Increase the distance between workstations.**

Although Covid-19 vaccination plan is well underway in the UAE for a high coverage, the local government stressed the need for continuing precautionary measures in conjunction with country-wide vaccination campaigns to lower the pandemic and for the success of the containment process [5]. This recommendation means that social distancing and guidelines in the workplaces and the installed 'sneeze guard' will remain until the risk of pandemic is lowered or well-controlled. Previously, arguments against workstations were about privacy and acoustics. Now, they represent a physical separation between colleagues. This opens a critical question about the end of the open-plan workplace and the return of small, individual offices with combination of more socializing areas since one of the reasons that makes the employees want to come back to their offices is to interact with their colleagues.

Figure 15. Respondents' potential needs to be considered in the workplace after the pandemic.

3.4.4 Imagining the future of the workplace design layout

For decades office design has encouraged open plans for its numerous benefits. The recent pandemic circumstances and its underlying changes made experts question the future of workplace design and layout. Experts are not suggesting a return to the cellular cubicles of the 1950s, but are expecting that the density in offices will change, a thought that forecasts again a move away from open-plan layouts [7]. These long-term design upgrades and changes will put hygiene at the heart of workplace space planning. Similarly, when the participants were asked about their expectation of the future of the workplaces, 73.5% of them stated that the work model will shift to work from home, 47% wanted more private offices and 37% suggested to eliminate the workstation altogether (Figure 16).

Overwhelmingly, participants preferred to work from home or in mixed mode, and as humans the need of the office space is mainly for meeting, collaboration, and interactions with others. Eventually working from home will continue, and office life in some form will remain as well. These drastic changes that are happening confirm the important role of the office spaces, and to satisfy the users' needs, the design has to accommodate these required changes. The section below will illustrate a general expectation of how the future of the workplaces design will look like:

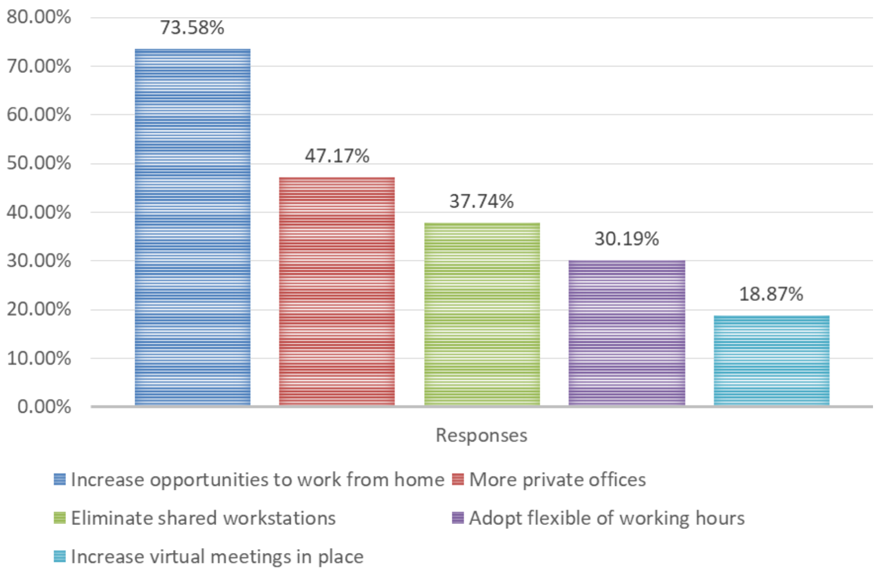


Figure 16. Imagining the future of the workplace design layout.

1. *Introducing biophilic design and human centric designs*

The next big move in the workplace world is going to come from taking elements of what we already have and combining them together to insure wellbeing and holistic health.

Figure 17: Living wall at the University of New

Figure 18: Highlighting the visual connection with the outdoors,[11].

Figure 19: Biophilic office building in Manhattan, New York equipped with three rooftop

Figure 20: Demonstration of the six-feet office design

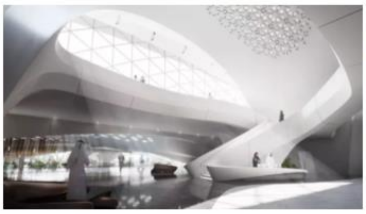


Figure 21: The Bee'ah headquarters in the UAE, [5].

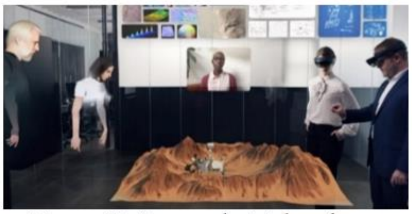


Figure 22: Screenshot taken from (spatial) platform that provides virtual work and meeting spaces

The key strategy to enhance healthiness in office buildings is to provide opportunities for employees to encounter the natural world. This can happen by introducing "biophilic design" which promotes productivity, physical health, and performance [11]. Rick Cook, the founder of CookFox, a Manhattan-based architecture firm that works on sustainability and green spaces in designing buildings said that *"the basic theory of biophilic design is to reduce stress by enjoying the richness and complexity of nature and using the amazing ecosystem"*. Biophilic concepts include integrating green walls with plants to clean the air instead of bland partitions; using natural materials like wood in the fit out; indoor water features like ponds and waterfalls; and circadian lights that provide different colour temperatures to keep the body's internal clock in line (Figures 17, 18).

2. *Natural light*

The photophilic design supports the design of spaces which introduces the natural light inside the building and eventually leads to better health and lower energy consumption.

Research published in the journal, Environmental Health Perspectives, shows that workers are inflicted more stress and impair decision-making abilities when they work in offices with artificial lighting, lack of windows and poor ventilation. In contrast, working in a room with natural light helps boost productivity and mental health. According to research published in the Journal of Clinical Sleep Medicine, workers who are exposed to natural light in offices sleep better because the light improves circadian rhythms [12].

3. *Natural ventilation.*

People spend over 90% of their lives inside buildings, and according to the U.S. Environmental Protection Agency, the indoor air pollution which comes from smoke, dust, mould and building materials is up to five times worse than outdoor pollution [12].

Increasing the volume of outside air that comes into buildings, is one of the easiest ways to avoid the indoor spread of any infectious respiratory virus, but it is nearly impossible to do that since modern office buildings typically have tightly sealed windows. The sealed windows play a positive role for the environment by increasing the energy efficiency, but on the other hand, it traps in and circulates airborne contaminants. Considering the pandemic, this sealed environment puts the experts in a challenge and increases the demand for high quality air filters incorporated within the ventilation systems.

Another easy way to introduce natural air is by designing outdoor workspace, such as terraces, (Figure 19) [11]. Covid-19 has steered the healthy buildings movement, and every sector is now highlighting the need of healthy building to overcome Covid-19, infectious disease transmission and beyond [13].

4. *Changing the furniture design and layout*

To ensure social distancing, the governments are mandating a minimum of 2 meters between each person. This is prompting a revisit of office layout. In this regard, Cushman & Wakefield (2020), the global real estate company, has risen to the challenge with a new office design proposal [4]. It is called the Six Feet Office, where existing offices are having different furniture layouts to fulfil the requirement (Figure 20). The concept aims to create safe spaces with elements like new and improved rules of conduct, unique routing for each office, adapted workstations and optimized shared facilities.

Arjun Kaicker, the head of analytics and insights at Zaha Hadid Architects (ZHA), is predicting that the pandemic will drastically reshape the design of office and its furniture layout. He stated, *"Office desks have shrunk over the years, from 1.8 metres to 1.6 metres, to the present 1.4 metres and less, but I think we will see a reversal of that, as people will not want to sit so close together,"* he told The Guardian [7].

When combining these thoughts with the Biophilic Design objectives and the need for the office as a meeting and interaction spaces, it leads to rethink the office design, where there will be larger areas dedicated for meeting and interaction spaces, with defined number of spaced offices, integrating different elements and ways of interaction with nature within the building to enhance satisfaction and wellbeing.

5. *Emergence of co-working offices*

Over the course of the pandemic lockdowns around the world, the demand for shared office spaces had dropped dramatically, as huge businesses have cancelled flexible office memberships to save on costs. While some co-working space operators remained in operation, they are presently required to apply all safety and social distancing requirements, which significantly affect the space allocated for occupants within a shared location.

Once the pandemic is over, it is predicted that businesses will aim to avoid financial commitments and rent expenditures. As a result, this phenomenon will drive the demand for pre-built flexible infrastructure of spaces and lease flexibility. In the process of reviving the market post-pandemic, where flexibility and collaboration are the top priorities, co-working space is expected to emerge stronger with quick growth rates comparing to pre-Covid-19 rates [9].

Providers of co-working spaces are in a unique position to grab the opportunity and make this real estate market segment more attractive for its demanders, since flexible workspaces can fit the bill and address the requirements of safety, sustainability, and cost optimization for any business.

6. *Contactless technology*

The new headquarters for the Bee'ah waste management company in Sharjah, UAE which was designed by Zaha Hadid Architects gives a glimpse of the future of workplace design. It aims to introduce a new era of smart workspaces which incorporate artificial intelligence system (AI). The AI technologies incorporated in the functions of the building include predictive facilities maintenance; smart security; and innovative digital twin technologies.

The main design concept is about what Zaha calls *'contactless pathways'*, where the chances of touching the building with free hands are minimized. Office doors open automatically using motion sensors and facial recognition, while lifts and coffee can be ordered using a smartphone (Figure 21) [5]. The building sits as a strong illustration of how smart building technologies and systems can overcome obstacles presented by the pandemic.

Technology could also be used to remind employees of social distancing. Cushman & Wakefield consultancy has installed beacons into its office to track employees' movements via their mobile phones, potentially sending alerts when six-foot rules are breached [4].

7. Augmented reality workstations

What exactly people have done to accomplish their tasks can be digitally traced. If the advanced technology is adopted in the workplace to create the networked office layouts, it will give the workers more opportunities to work fluidly and remotely. And many of the desks can be been replaced with a range of different spaces for activities such as brainstorming, focused teamwork, quiet concentration or confidential calls, in line with the survey results which showed that most of the participants preferred to eliminate the workstation and to have private offices (Figure 22) [12].

During the pandemic, Facebook has been testing a proposal of futuristic desk set-ups, where virtual screens float in the air and users can control their locations, arrangements and resize them. There is also a new technology using a new computing platform that combines augmented and virtual reality with new devices to create "infinite workspaces". The platform allows co-workers to collaborate in virtual meeting rooms. For example, "Spatial" is a startup that enables people experience virtual meetings. In order to enhance social interaction, it gives that level of presence and personification by using Codec Avatars that provide a rendition of the users. During the pandemic "spatial", had intense demand that reached up to 1,000 % increase, providing virtual collaboration and allowing people to work from different countries [4].

4. Conclusions

This research aimed to explore and identify the impacts of the current Covid-19 pandemic on the workplace and its users' concerns, experiences, satisfaction and expectations. The main purpose was to investigate how the pandemic may be shifting the work model and what may be its implications on the workplace design. The research was conducted during the pandemic time during which no studies were available. In order to obtain real answers against the assumptions and the general predictions, the research tested them through the survey. And due to the time limitation, the survey was aimed towards a specific group of employees from one single workplace to collect as many responses as possible.

The most important findings, independently from the abrupt time, government and businesses had to accommodate for such a rapid shift, was the vast preference for a full switch to work from home or to work in a mixed mode. Moreover, the survey showed that productivity levels were satisfactory. The employees were able to deliver their tasks, while enjoying more time with their families. These outcomes indicate a critical need to re-examine the current work models and explore the possibility to allow more opportunities for work in a mixed-mode with less restriction regarding defined working hours and the need to develop alternate systemized ways to track productivity.

The survey results showed that the respondents preferred to increase the distance between workstations or be in private offices. At the same time, what they expressed missing interacting and meeting with their co-workers. If the government intends to adopt working in a mixed-mode, employees would still need a place to gather, share information and collaborate. This fact cannot be marginalized and should be included in the new guidelines of workplaces design and office layout to satisfy the needs.

Generally as this research demonstrated, the pandemic had made the majority use the ultimate benefits from advanced technology, which was already available, but was underestimated. The rapid shift opened the doors to look for the possibilities to accommodate a new mode of working where personal life and work life can strike a better balance.

The future of the workplace however had an emphasis on favoring spaces for socializing, interaction with biophilic elements and the lessons learned from the experience of working from home during COVID-19 offer an unprecedented opportunity to rethink the future of work and the design of the workplace, it suggest to think of different forms , summarized below :

1. First, It will ultimately incite the need of drawing new guidelines of workplaces design and office layout to satisfy occupant's needs and address the requirements of safety and sustainability , for example :
    - Co-working or Shared office spaces.
    - to allocate more square footage per employee than existing buildings, with some offices potentially gravitating to more individual office space, rather than open floor plans
    - Prime focus on meeting places that calls for diversified layouts and furnishing
2. Secondly, it also calls for Innovative technologies for realistic virtual meetings and inspire technological advances related to the health and wellness of building occupants.
3. Thirdly, the need of the Integration of Biophilic design, incorporation of natural elements and materials, also using possibly outdoor such as patios and courtyards as work spaces.
4. Finally, the future of work and the workplace are challenged in an unprecedented way, calling for designers and researchers to explore, rethink, repurpose and re-create the workplace.

For future studies and to validate the survey results, it is recommended to conduct a similar approach but target larger samples of workers working in different environments. Post pandemic and if social distancing restriction are eased, different methodologies can be used to study and analyze the situation, for example carrying in-situ observations and/or interviews.

Also investigating the workplace post pandemic is crucial to determine its impact on productivity and comfort levels. Moreover, critiquing current technology and design approaches is important to develop a set of recommendations for research and practice methodologies.

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The Role of Heritage Tourism and its Implications for Urban Regeneration in Old Doha, Qatar.

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Abstract: Doha, the capital of Qatar is the largest city, with over 80% of the nation's population residing in Doha. It is also the administrative and economic centre of the country with a population of more than 2,900,000 persons in May 2021. Prior to 1950, Doha was a small fishing and pearling village stretching 5kms along the sea. Within six decades, it grew rapidly to become a main hub in the Gulf for mega sports competitions, international conferences and exhibition events. The Qatari rich cultural heritage is now being recognized as a valuable resource for sustainable development. This paper focused on the role of cultural heritage tourism and its implications for urban regeneration in the context of Qatar with a particular focus on old Doha. Therefore, in order to use heritage wisely, it was necessary to position cultural heritage tourism as an essential element of sustainable development. The research methodology was based on the case study approach. A thorough investigation of Souk Waqif as an important tourist destination for the local and global tourists was carried out. This analysis evaluated the experience and identified the weaknesses that needed to be reinforced. Moreover, the paper concluded with some recommendations for regenerating old Doha.

Keywords: historic cities; urban regeneration; resilience; cultural heritage tourism; identity, sustainability.

1. Introduction

Historic urban centres and districts echo the 'spirit' of a culture and remind people of their past. They express the collective attitudes and the common patterns of life, and as such, they are a source of identity and inspiration. What exactly distinguishes a historic district from other parts in the city are qualities linked to age, rarity, character, memory, sense of pride, a source of identity and authenticity. Historic centres present the past inheritance of buildings, quarters, streets and squares that resonate with memory and cultural traditions. The human scale of their buildings and urban elements reflect long chapters of history and events. The main historic landmarks in the city, such as ancient mosques, forts, palaces and souks are usually found in these central areas and form the main links with the past.

The main heritage landmarks in a historic centre provide reassuring reference points especially for the local inhabitants. They strengthen the cultural identity of the historic city, by reinforcing the relationship of people with them and thus creating a sense of place. Unlike museums - where the past is displayed but not touched - historic districts are places where life is bustling. Therefore, these old cores need a holistic approach to regenerate and revive them within the present city. Historic districts are the symbiosis of a complex system of forces; economic, cultural, and environmental. A well-conserved historic district provides many advantages for its citizens; it is intimate, human in scale and often rich in diverse activities. Compared with some recently planned cities, it can be extremely convenient for housing, commercial, entertainment activities and tourism.

In Qatar and since the 1950s the initial goal of the local government was to erase images of under-development and poverty. To do this, it embarked on large-scale re-development projects to catch up with the modernized world. In order to meet the increasing need for housing, education, health and shopping areas, large areas had to be prepared for these purposes. In Doha, the bulldozer cleared away several old districts, including significant heritage landmarks. These historic areas and buildings were replaced by concrete, steel and glass tower blocks, which are often alien to the local context.

Figure 1. Map of Qatar, showing the location of Doha on the eastern coast.

Most of the historic districts in Doha that escaped the ravages of demolition during the 1950s until early 1980s, suffer from neglect, lack of maintenance and deterioration. These surviving heritage areas are victims of crumbling infrastructure and real estate speculation. Economic decline and the original inhabitants' exodus from the historic cores, has led to further destruction and dilapidation. In addition, housing decay, decline of commercial activities, lack of appropriate city planning, changes in consumer tastes have worsened the situation to the level of transforming these historic centres into "urban slums". The task of bringing these historic areas back to life, through sustainable regeneration needs to be addressed urgently in order to prevent more cultural amnesia.

Case studies are important for providing knowledge about real-world examples that are critical, representative, revolutionary, unique or longitudinal and exemplify certain patterns and issues. This study adopts an exploratory case study approach to discover the key tourism challenges in the city of Doha. This paper takes advantage of a variety of data sources, including publicly available relevant documents, websites, promotional materials, business conference presentation reviews, field observations and follow-up communication by phone and email.

2. Historic Cities and Sustainability

What is sustainable development? The 1987 report "Our Common Future" from the United Nations World Commission on Environment and Development (WCED) set forth the most widely used definition of the concept: “Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs”. The Brundland Commission lists food, water, clothes, shelter, work, energy and hygiene as examples of what is termed ‘basic needs’ [1]. Sustainability is a key aspect of local development and planning discourse. Recent interest in the sustainability of historic cities reveals a more complex picture than that of a development process. Rather, what is being witnessed is the rise of development agendas related to the desire for local policy makers to make historic cities look different from each other. This will enhance their uniqueness and distinctiveness that can be used as a catalyst for the pursuit of economic growth through tourism, trade and other activities.

Reduce; reuse and recycle are the '3Rs' of non-renewable cultural heritage resources and form an essential part of the meeting point between conservation and sustainability. The sustainability discourse argues that historic urban centers should not just be perceived in terms of nostalgia, history and architectural dimensions only. The rationale for an appropriate conservation approach is to link the historic district and center into its environmental capital with a relation to other parts of the city as a whole. This does not mean that people should stop building new but try to re-orientate the building industry towards activities such as maintenance, reuse, adaptation and upgrading of the existing fabric. This should be undertaken within the principles that govern a sustainable city and holistic urban management approach [2].

There is a growing belief that most of the historic cities in the Arab world are facing multiple pressures. Competing demands for land use, introduction of new economic activities, and marketing of heritage resources place an important burden on the local heritage players. The latter strive to find appropriate ways to manage these surviving old cores. During recent years, new policy mechanisms have emerged to reconcile the conflicting demands of conservation and development by applying sustainable development policies to prevent further cultural amnesia [3]. Historic cities have unique characteristics that can guarantee their sustainability. On one hand this implies that development in these historic cores should be limited, while on the other hand the issue of maintaining local economic vitality is essential. Most of heritage players recognize that such places cannot reproduce themselves without some kind of intervention. These are meant to regulate and manage the physical and social fabric upon which their local identity and economic success is predicated [4].

Sustainable development can be seen today as a powerful motivation for urban regeneration. Basically, it would consist of a process of urban development based on the constant reuse of existing built resources, associated with a low input of energy for adaptation to new requirements conceived in society. It is also viewed as a process founded in the local culture, in an equitable distribution of urban services, the use of democratic principles of management, and the revival of traditional social values and practices. Urban regeneration is a phenomenon which has great significance, not only because a symbiotic functional usage in historic buildings steps up the maintenance of the structure and as such delays its decay, but also because the resultant monitoring prevents cases of vandalism and scavenging of material heritage as is seen in buildings that are deserted and disused. The importance of integrating economic and cultural activity in historical areas cannot be overemphasized.

For a historic city to be sustainable, it must allow adjustment as circumstances change. This will enable historic centres to stay alive and not become fossilized "museums". In this way there is no choice, and according to Dix "when talking about true conservation, it is the wise use of the resources of our environment, respecting but not copying the past: incorporating new and old to the best advantage" [5]. Historic urban centres represent a great economic, social and cultural investment that it would be unwise for the community to waste. In old cities and centers, history and heritage have become the dynamic assets that combine the local and the global. They establish the local specificity and distinctiveness so attractive to a global tourist market. This local-global dimension of exchange contributes to explain why the local heritage players seek a competitive advantage over similarly historic areas. Cities that demonstrate through promotion and marketing their historical richness are more appealing to those with capital seeking attractive locations, especially for visitors and tourists [6].

3. Cultural Heritage Tourism in the Arab World

The term 'sustainable tourism' usually denotes the application of the more general concept of sustainable development to tourism as a specific economic sector. Emergence of the sustainable development concept has focused attention on the need to safeguard tourist attractions from the negative impacts of tourism. Resource-based attractions such as heritage sites in particular, require the development of efficient management systems and planning processes. There is a growing global consensus that tourism development in any region must stand upon three main pillars to remain sustainable: economic, environmental and community considerations. Arguably, to achieve such sustainable tourism development, tourism should be approached as part of the development framework of each state and must be related to other economic and social activities, whilst also benefiting local citizens, safeguarding the natural and cultural environment and satisfying political objectives. This goal requires highly sophisticated planning approaches as a key factor in implementing sustainability [7].

Since the first Earth Summit, held in Rio de Janeiro in 1992, sustainability has become a central issue in tourism development policies throughout the world. It has become the organizing framework for tourism planning and research [8]. In tourism planning there are two key issues. The first emphasizes that tourism has environmental implications, both positive and negative, and that they can be controlled through the systematic implementation of planning and monitoring techniques. The second implies that the social impacts of tourism also need to be mastered, in order to avoid destroying the social fabric and values of traditional societies [9]. Sustainable tourism must meet the needs of both the tourist and host community, without diminishing opportunities for the future. Sustainable tourism also implies optimum use of resources and maximization of benefits to conservation and local communities. There are certain preconditions for achieving a sustainable approach to tourism planning. These are co-operation, industry co-ordination, strategic planning and commitment to sustainable objectives.

Arguably, policy acceptance of the principles of sustainable tourism development is only the first step [10]. The next and most significant step is the demonstration of commitment through action rather than words, by establishing an appropriate framework for planning and management, which takes into account the spatial, political and temporal parameters of the implementation process [11]. [12] suggests that the most effective level at which to implement strategies for sustainable tourism development planning is the local, because it is at this level that the problems are most apparent and policies are likely to receive most political support.

Under the umbrella of sustainable tourism, the concept of 'cultural heritage tourism' integrates 'culture', 'heritage' and 'tourism'. ATLAS outlines two definitions for 'cultural heritage tourism'; first "All movements of persons to specific cultural attractions, such as heritage sites, artistic and cultural manifestations, arts and drama outside their normal place of residence". Secondly; "the movement of persons to cultural attractions away from their normal place of residence, with the intention to gather new information and experiences to satisfy their cultural needs" [13]. Cultural heritage tourism is about the exploration and enjoyment of cultures as forms of tourism. Cultural heritage tourism is a much larger concept than an interest about palaces, forts and mosques might imply. Its resources expand to include historical geography, archaeology, literature and environmental management. Essentially, cultural and landscape tourism is about what a geographer would term *place*, the understanding of places as they really are and about *heritage*, things used as tourism *place-products*, 'which are literally or metaphorically passed on from one generation to another [14].

Tourism resources may be classified in two types; primary and secondary elements. Primary assets are those, which attract people and consist of museums, art galleries, sports facilities, historic districts, buildings, landscapes and special events. Secondary elements enhance these attractions or assist in the process of attracting tourists through shopping centers, hotels, and transport and tourism agencies. Once the primary and secondary tourism resources are defined; the factors, which play a role in the development of a cultural heritage tourist opportunity spectrum, are:

- "Accessibility to and within the destination area;
- The possibility of choosing from a wide range of activities and meeting a diversity of preferences;
- The combination of activities within a specific time-space budget;
- The spatial arrangement of interesting places (networks, trails);
- The functional synergy between urban facilities;
- Interaction between activities" [15].

Cultural Heritage Tourist Opportunity Spectrum

Core elements of the cultural heritage tourism product

=

Main pull factors for cultural tourists

High marker value

Heritage buildings and complexes, museums, monuments, events, theatres, etc.

+

Secondary elements

(Added value to the tourist experience and image)

Hotels, restaurants, street markets and shops, etc.

Diagram 01. Adapted from Urban tourist opportunity spectrum: the concept [16].

The potential of heritage tourism in urban regeneration depends on the availability of built heritage resources, which can be commodified into tourist attractions, on the financial capacity of public and private institutions to do so and before all on the political will. Policies for urban regeneration are mainly inspired by the possibilities of reusing the cultural resources of historic districts. The central issue in this approach of developing tourism as a catalyst of urban regeneration and the ways heritage resources are being converted as tourist attractions. The main concern is to conserve the local cultural identity, while commodifying cultural heritage resources for tourism. Three main issues need to be considered while exploring heritage tourism for urban regeneration:

- Transformation of cultural heritage resources into tourism attractions;
- Consideration of cultural identity, sense of place, selection process and interpretation;
- Quality management; integration of tourism in the urban system, resource management and visitor management [17].

Recently, a new mode of development emerged in a way to reuse and develop historic cities and districts for tourism. To achieve this, there is a need to make funds available by developing heritage areas and buildings for tourism. Meanwhile and according to Orbasli “Tourism may become an important contributor to the economic realisation of a project, but there is the delicate balance between tourism being a support to conservation and tourism becoming a reason for conservation” [18]. While the former can be beneficial to conserve more historic sites, the latter may encourage the proliferation of inauthentic and fake heritage attractions. Many cultural sites are being compromised because local authorities are not aware of the value for conserving them. Developing historic areas for tourism and commerce requires the transformation of conservation from a political, cultural and social aspect to that of economic development. As Kuban points out: “Tourism is a twentieth century phenomenon. You cannot put it aside. One must accept it as a phenomenon that exists, good or not so good. Millions of people travel. One cannot stop them. They will come, so let them be used as a source of development” [19].

Adaptive reuse of existing heritage buildings; residential, workshops, or public amenities for tourism may attract a large number of tourists which can strain existing systems of sewage, water and power services. The flow of visitors, if not well regulated can eventually disrupt local lifestyles. Moreover, there are cases where the tourists' tastes and habits have proved offensive to local population. In fear of such problems, the influx of tourists may not be welcomed by local residents and the facilities favoured by them may be different from those needed by the host community [20]. Therefore, there is a need to apply a cautious approach, which does not undermine the local inhabitants' needs when developing tourism in historic areas.

The responsible visitor may be aware of many nuances of management, function and interpretation and be able to take them into account in seeking what he or she came for. The mass-tourist, however, does not have the time, and often not the inclination, to react through discerning and judgmental filters (Boniface and Fowler, 2003). Large visitor numbers, poor interpretation and information, crowds, congestion and pollution, seem to be the main threats affecting the quality of both the tourist experience and resource preservation, resulting in a complex relationship between visitation and regeneration [22].

There is now a consensus that the way forward is to manage heritage sites to maximize the quality of the visitor experience, whilst minimizing the impact on the heritage resource. However, this is not simple and a number of issues come to the fore in terms of the approaches to heritage management and sustainability. Many of the debates relate to the dilemmas that confront heritage sites, particularly in terms of maintaining the sensitive balance between conservation, visitor management and community involvement. Other issues relate to the problems of funding and the extent to which the commercialization of heritage and museums compromise their core function [23].

In many historic cities, a 'local fatigue' may result when over-consuming local infrastructure, historic buildings versus a demand on land, growing social conflict between visitors and local inhabitants, as well as the environmental impact of tourism. These tensions between the demands for development and conservation in historic cities have raised the issue of introducing sustainable development policies to counter the consequences of diminishing resources. Such an interpretation implies that there are limits to growth that must not be breached within a historic city as stated by Jacobs: "A limit to the amount of development which an area can take over time, determined by its environmental characteristics… [And]…that if development exceeds a particular level, the loss of or damage to these features [environmental characteristics] will be unsustainable or otherwise unacceptable, and should therefore not be permitted" [24].

Trade patterns in historic towns are changing quickly; small workshops and crafts are being displaced because they are seen as too noisy and unsanitary to be left in the heart of cities, which prepare to welcome tourists. In many historic cities, local crafts and activities are being replaced by "souvenirs" and "coffee" shops because these kinds of shops generate more income. Therefore, a strict management of heritage tourism should be established in order to avoid any economic gentrification of the historic city and centre. Besides housing and other activities, heritage tourism can be a major catalyst of urban regeneration, for historic centres like old Doha. Over-emphasis on the tourist function creates pressures for new services and associated development, sometimes to the detriment of the local population and can lead to damage significant cultural assets. It is therefore important for the tourism capacity to be carefully managed and controlled in a sustainable manner. Furthermore, a strong management is needed to avoid the expansion of inauthentic structures, which can further erode the character of the historic centre that visitors have come from long distances to explore.

4. Souk Waqif; Urban Regeneration Led Tourism

Old Doha lies on area of 250 hectares; it is a combination of traditional districts going back to the period (1850-1950). These surviving historic districts, such as Souk Waqif, Msheireb and Al Asmakh keep some traces of the past and thus form important chapters in preserving the city's history and identity. While a law was instituted in May 1980 to conserve cultural and archaeological heritage, however comprehensive actions to conserve the past did not follow until the beginning of 2000. Following this, a number of single monuments started to be restored. Mohamed Bin Jassim Palace was the first historic building to be rehabilitated just after independence and during 1972-75 to become the national museum of Qatar. However, the first large scale scheme action at the city level was the rehabilitation of Souk Waqif during the period 2004-2010.

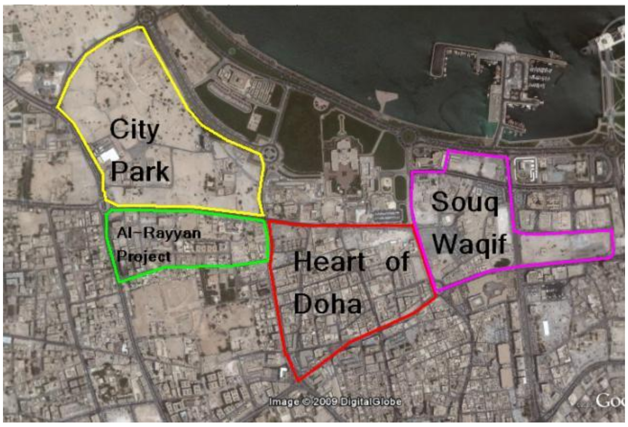

Figure 2. Location of Souk Waqif in old Doha.

After long years of dilapidation and neglect, during the beginning of the 21st century Souk Waqif fell into disrepair and decay. Due to a lack of any rational actions, unsympathetic buildings of dense shops frontage intruded the souk. All these actions resulted in a hybrid environment of new and old structures that dramatically transformed the unique identity and character of the souk. Due to advanced dereliction, in 2000, the former Emir of Qatar Sheikh Hamad Bin Khalifa decided to launch an urgent rescue for the souk before it disappears. This political support was crucial later in launching urban regeneration projects in historic areas, following the Souk Waqif rehabilitation project.

Figure 3. Showing the main areas in the Souk.

Since most of the shops were privately owned, the government had to purchase these shops from their owners. According to Mohamed Ali Abdulla the Project Manager of the rehabilitation project, after a detailed survey it has been found that two thirds of the buildings were still in their original state [25]. This is very significant as these structures can play a major role in rebuilding the damaged character of the souk. In this context, the rehabilitation project aimed to realize the following objectives:

- "Reconstruct the lost image of historic Doha through the rehabilitation of its authentic Souk Waqif;
- Protect the area of the souk and its surroundings from real estate development;
- Create an open-air public area totally pedestrianized;
- Establish a vibrant souk with its original layout and goods" [26].

Figure 4. Views showing the Souk state before the beginning of restoration in 2004.

To retrieve the original character of the souk, a number of modern buildings were demolished and replaced by new structures inspired from the local Qatari architecture. This was implemented to create a physical continuity with the 1/3 remaining of original historic buildings. During the restoration process, traditional building materials were recycled and re-used, such as; coral stones for walls, *Danjal* and *Bamboo* for the roofs and teak wood for doors and windows. New features and services to upgrade and enhance the living environment were added, such as a better lighting system. Souk Waqif is both a traditional open-air public space and most importantly a car free area for tourists, merchants and residents alike.

The 3Rs (reduce, recycle and reuse) actions were implemented in the case of Souk Waqif. "Reduce" aimed to limit further destruction and demolition of historic buildings and districts, whereas "recycle" worked towards utilizing the traditional building materials found from previous demolitions in the souk and its immediate surroundings. Adaptive "Reuse" was implemented to give a new heart to the souk. As part of the rational actions, the souk was completely revived. In addition, a number of shops, restaurants, an art center and boutique hotels were opened. Restaurants and cafes are taking place along Al Khrais Street on the southern part of the souk, with a wide variety of indoor and outdoor siting, public and semi-public spaces; it is called Al Najada area. The intermediate area between Souk Al Etem (the oldest part of the souk) and the restaurants area is characterized by the handcrafts, souvenirs, shops, Souk Waqif Art Centre and the traditional *majlis* settings.

While new activities have been injected in the souk, the cultural dimension was not neglected, as some of the original functions have been preserved to a certain extent. For instance, great efforts have been made to sustain the traditional crafts; there are still shops selling traditional clothes, dates and spices. Moreover, a traditional café 'Gudwe" still attracts many elderly Qataris to chat and gather. To remember and live moments of the past, during each evening, a large *baraha* (plaza) hosts and welcomes a great number of women who sit to prepare traditional food for visitors to taste and try. While efforts to keep the original activities of the souk remain insufficient, new activities to boost tourism have been added. While this is important to keep the souk alive, an integration between the economic and cultural forces is more than necessary. To avoid any radical transformation of the souk through over marketing tangible and intangible heritage resources for tourism.

As part of the rational actions, recently, two major underground parkings, which accommodate around 3,000 cars, have been established. These two parkings aim to reduce the pressure caused by the lack of parking slots especially during weekends, holidays and special events. While the underground parking created a big relief for the daily users of the souk, its roof offered a unique Baraha (plaza) facing the corniche, for public gatherings and recreation. This creates an interesting opportunity to integrate between the head and heart, the parking issue was solved while the *baraha* allows social interaction and integration between the users of the souk, which increases a sense of place and belonging. Adding to trade and recreational facilities, Souk Waqif has become home for cultural activities found in the art galleries and workshops, accommodating several exhibitions and local concerts especially during special festivals.

Figure 5. Souk Waqif; the restaurants area provides a bustling life day and night.

5. Discussion

Rehabilitation of the Souk was successful in conserving most of the historic buildings (physical features) despite some issues of authenticity in the restoration process. However, more efforts are still needed to preserve the original heritage activities and functions of the souk. This experience is helping to give the city of Doha a meaning based on its past, and Souk Waqif has become a main historic landmark in the city and a meeting point between the local and global tourists. An integration between the economic and cultural actions has contributed greatly in injecting a new heart to Souk Waqif. While the souk was rehabilitated to generate funds, the revival of memory and an increasing feeling of a sense of place and pride started to be felt by the local community. People in Qatar feel that the souk represents a great part of their past; it has increased their pride and has become a significant element in creating a continuity with the city’s past in a global environment.

One of the major drawbacks of the regeneration strategy in Souk Waqif is the absence of housing from the adaptive reuse program. However, a number of hotels have been established to attract many tourists. Souk Waqif is reinforcing its place as a major hub for shopping and entertainment, through a collection of nine boutique hotels in the market. These hotels are spread across the souk and were designed in a traditional Qatari architectural style. While tourism as an outcome of the rational actions is important, the original activities of the souk including housing should be re-introduced again. The reliance on one person in managing this very sensitive project was another major issue. Sustainable urban regeneration requires a multi-disciplinary work and thus cannot be conveyed to one person. To ensure a comprehensive, a multi-disciplinary team should include town planners; architects; structural engineers, roads and drainage, cost consultants; economists; landscape architects; urban designers; property managers; public health experts; transport managers; and, last but not least, dedicated administrators.

Cultural heritage tourism is an essential function of contemporary cities. A historic district is much more than merely a static physical structure or canvas of a place. It is also engaged with the perpetuation of social and cultural life. Thereby, it is continuously influenced by many internal and external forces. To start to fully understand the potential of historic cities for tourism, this study has demonstrated that we must approach this subject from a broader perspective. As medinas are in general part of much larger urban agglomerations, we argue that cultural heritage tourism is one of the key research domains to start with.

6. Conclusions

Historic urban cores in the Arab world and worldwide should be places in which people live, pursue their work, and enjoy their leisure time; they are not museums. They are primarily a setting for social interaction and cultural expressions. Functional variety should be maintained, through the permitting of mixed uses within individual and group buildings. For example, souks and bazaars can be promoted for local trade, crafts and tourism. While tourism can be promoted, consuming and marketing heritage resources should be kept to the level of not threatening the identity and authenticity of the historic environment.

The financial input that tourism can deliver to host communities can be the incentive for launching more urban regeneration actions. In resilient historic centers, over-emphasis on the tourist function creates pressures for new services and associated development, sometimes at the detriment of the local population and can damage significant cultural assets. It is therefore important for the tourism capacity to be carefully managed and controlled in a sustainable manner. Furthermore, a strong management is needed to avoid the proliferation of fake and inauthentic structures, which can further erode the character of the historic centre that visitors are willing to gaze. Based on Souk Waqif urban regeneration, the built environment should not be conceived as a physical entity, a functional container, an accumulation of goods and commodities, or a pattern of land uses. It is primarily, a setting for social actions, sensuous experiences and cultural expressions. It is well known that inhabitants are the catalysts of urban life in the city. They create and constitute the socio-cultural and economic systems, which bring life to the physical environment.

The right to work is another imperative of sustainable development; therefore there is a need to encourage the revival of the traditional crafts in historic centres. These will give a new breath of life to a historic city, and will contribute to its regeneration. This approach will enable the creation of jobs for a large number of people unemployed. Once the main heritage resources are conserved, and the cultural and economic activities enhanced, it is possible to present these heritage assets to visitors and tourists. The merit of social intercourse between tourists and local residents as a way towards fostering better understanding and good will between nations is a major benefit gained from tourism. Whilst this can be possible in countries where the flux of tourists is comparatively acceptable, however, in cases of mass tourism, tourist's tastes and habits have proofed to be in many circumstances offensive to the local population.

Many of the other socio-cultural problems linked to tourism are related to the degree of intensity of tourism development. While it is difficult to measure, there is a relationship between tourism density and the growth of local resentment towards tourism. The flow of tourists into a region increases the densities at which people live and overcrowds the facilities which tourists share with the local population. Therefore, overcrowding might reduce the value of the holiday experience and creates additional strains for the host community.

When opting for cultural heritage tourism, a cautious approach is needed regarding a respect to the local traditions and customs of the host community. Therefore, a strict management of cultural heritage tourism should be established in order to maintain a balance between social and economic needs. Over-emphasis on the tourist function creates pressures for new services and associated development, sometimes to the detriment of the local population, and can lead to damage significant cultural heritage resources. It is therefore important for the tourism capacity to be carefully managed and controlled in a sustainable manner.

Important underlying trends are globalization and urbanization. As tourism can be seen as a geographical and social phenomenon, understanding tourism in cities should include the wide spectrum of urban studies, urban and tourism geography, and social science. Knowledge and new insights from such studies should be integrated in place branding methodologies. Despite the fact, that some of these (interlinked) research areas are still in their infancies, as has been demonstrated in this paper, there exists a rich body of literature which could provide valuable insights to help governments to adjust their policies to reach their tourism ambitions. Based on our extensive literature research, we propose a research agenda which at least include the following key topics:

- What are the spatial patterns (spatial distribution and space usage) of tourists in medinas and how is this related to the morphological layout of a city and the historical shaped developments of the urban tourism infrastructure?

- How to pursuit sustainable equilibrium between cultural heritage tourism and a livable city, by contributing to urban quality and the well-being of local communities, and to avoid tensions, conflicts, and anti-tourism movements due to cultural commodification and tourism-induced gentrification?

- How smart cities objectives can be linked to cultural heritage tourism policies from a place branding perspective with a special emphasis on the integration and use of information, communication, infrastructure, and services?

- What is the impact of globalization on cultural heritage tourism and on which scale this phenomenon is visible in the urban transformation of a medina?

- How we can find a good balance between the (global) urbanization trend and reverse process of de-population in the medinas?

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Placemaking as a Tool of Social Sustainability: Scripts of Palestinian Resistance on the Israeli Segregation Wall

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Abstract: Under spatially oppressed contexts, quality of life becomes a privilege where life is barely guaranteed. Despite several studies discussing the aftermath of wars and military violence on the community's wellbeing and psychological health, the ongoing impact of any spatial violence remains unfolding. Exclusive of embedded human consequences, colonial power destructs physical and social spaces to strip people's sense of ownership, agency, and place. This research is exploring placemaking as a tool of social sustainability that people utilize to resist the ongoing spatial violence. Focusing on occupied Palestine context, this paper discusses the Israeli-built Segregation Wall as an urban violence performed to obstruct normality of Palestinian everyday life. As such, Palestinian graffiti movement expressed on the wall is explored as a creative practice of placemaking intended to resist the status quo and reclaim agency, restore their meaning of place, and achieve communal wellbeing. Based on the dynamics of everyday life expressed through ethnographic interviews, this paper concludes that graffiti on the Segregation Wall is an inseparable tactic of the Palestinian nonviolent resistance strategy and of their overall *Sumood* against the Israeli occupation. Doing so, this paper contributes to the overall understanding of the interrelations between theories of resistance, placemaking, and social sustainability.

Keywords: Wellbeing; agency; placemaking; social sustainability; resistance; graffiti; Palestine

1. Introduction

There is a wealth of discussion about social sustainability in literature that is targeted for professionals, practitioners, and policy makers to achieve a "social development." This highlights the incomplete assumption that categorizes social sustainability as only a governmental and professional approach rather an aim people live by or for. However, the social sustainability discussion remains limited with the elimination of places like "warzones." As such, a question is raised regarding the extent to which social sustainability might be considered applicable to these places where life is barely guaranteed, let alone socially developed. Broader than the "social development" characterization, social sustainability is defined as a process that can accomplish different social needs among its residents including community agency, meaning and sense of place, health and wellbeing, overall safety and peace, solidarity, inclusion, and justice [1-4].

Karacor has pointed out the importance of placemaking as an approach to achieving social sustainability [5]. Placemaking process shapes with experience the place offering opportunities that empower people to add meaning to their cities [6]. Therefore, this process is seen as a form of spatial agency that change and re/claim places. In the making of places, people aim to create quality public spaces that support people's health, happiness, and wellbeing. Interacting with the urban space in such positive fashion strengthens people's attachment and belonging to the place and renders their meaning and sense of place. Conducted research on placemaking in troubled contexts, either by natural disasters or human-made, has explored many dimensions of this process including the role of placemaking in motivating individual and communal wellbeing [7-9], the role of placemaking in boosting communities' sense of belonging and place identity [10-12], the role of aesthetic and creative placemaking in achieving agency and cultural justice [13, 14], and the role of youth in peacebuilding [15]. Placemaking, in such contexts, becomes a fundamental practice to achieving daily survival and resisting towards overall social sustainability and justice.

This study explores social sustainability in the Palestinian context by studying Palestinians' grassroots practice of placemaking. Palestinians had been living under Israeli military occupation since 1948; when Zionist armed groups ethnically cleansed and forcibly displaced many Palestinians into refugee camps inside and outside Palestine. In 2004, the Israeli military started constructing a Segregation Wall to apply further oppression on Palestinians. This wall is aimed to enclave Palestinians into separate ghettos and devastate the normality of their everyday life. The construction of the Segregation Wall came as an aftermath of *Al-Ejtiyah*[3]; a military Israeli invasion of Palestinian cities in 2002 aimed to suppress the street-level Palestinian uprising against the lived oppression under the Israeli occupation. The 8-meter-high concrete Segregation Wall was designed and constructed to cut through major historical Palestinian urban fabric, resulting in the suspension of Palestinian livelihoods [16]. After the construction of the wall, many Palestinians spent, and still do, hours passing through the Israeli-controlled gates of the wall into the other side, where their schools, work, farms, and social services reside. Many Palestinian farmers got separated from their agricultural lands behind the wall, affecting their economic self-sufficiency. Likewise, religious tourism between the cities of Jerusalem and Bethlehem got disconnected, affecting major economic income for Palestinians. In the West Bank, Palestinians suffer from the visual and physical disconnectivity between them and Jerusalem city and wake every day to "the worst view in the world" as described by the British artist Banksy [17]. This view keeps the memory of the violent 2002 invasion alive in the collective memory of Palestinians. All the mentioned aftereffects of the Segregation Wall, as part of the Israeli military occupation, attack Palestinians' sense of place, leaving them with negative feelings of sorrow and helplessness. As a result, after the construction of the wall, many international and local artists expressed their rejection of injustice caused by the wall through scripting graffiti of solidarity. This paper explores Palestinian graffiti as a placemaking tool enabling Palestinians to practice spatial agency, reclaim their meaning of place, and resist for their wellbeing and healing. Using ethnographic approach, this paper proves that graffiti on the Segregation Wall is one form of Palestinian nonviolent resistance and of the overall *Sumood*[4].

2. Methods and Materials

This study discusses social sustainability through graffiti movement that is widespread on the Segregation Wall to confront the imposed spatial violence of the Israeli wall. Following a qualitative methodology, the present study employs an ethnographic approach to interpret the narratives of Palestinians who are the users of the public space of the Segregation Wall. In total, semi-structured interviews were held in July 2019 with 30 individuals separately. All participants reside near the Segregation Wall in the city of Bethlehem. The interviews were conducted either in person or via online platforms. The participants were randomly selected and approached. The interviewees were asked about their daily experiences around the Segregation Wall and their perceptions, ideas, and opinions regarding the wall and the graffiti. The collected narratives about placemaking emerge into themes of agency, meanings, and conciliation. The following sections present analysis and discussion

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[3] *Al-Ejtiyah* is a military violent attack in 2002, in which Israeli military invaded Palestinian cities and imposed siege over Palestinians. This violent event resulted in many Palestinian casualties, destruction of Palestinian cities, Israeli re-occupation of the West Bank, and the construction of the Israeli Segregation Wall.

[4] *Sumood* is a nonviolent resisting strategy performed by Palestinians since the *Al-Nakba* war events in 1948. It implies that mere existence is a form of resistance. Therefore, every activity is a form of embodied resistance through which Palestinians promote their wellbeing and maintain survival and positive functioning.

about Palestinian graffiti as a placemaking tool under three mentioned themes; place of agency, place of meanings, and place of conciliation.

3. Palestinian graffiti as a placemaking tool

Colonial powers use place devastating strategies to control and dominate affected populations [18]. In other words, they apply different forms of spatial violence to limit people's everyday interactions with place to attack people's security, freedom, and ownership [19]. Similarly, the Israeli-built Segregation Wall is a practiced spatial violence that targets different aspects of Palestinian urban spaces [20]. The restricted mobility and limitations caused by the wall have affected Palestinians' normality of everyday life. The wall as an Israeli war tactic aim to dismantle Palestinians' attachment to their lands and control their time, personal space, freedom of behaviors, ownership, and agency. This was explained by the participants:

> *"When the wall came, all the olive trees inkala' [had been ripped off] … If I want to visit my land, because of the wall now it takes 40 mins instead of 2 mins before." (Abu Akram, personal communications, July 23, 2019)*

> *"We cross checkpoints thahaban w eyaban [while getting in and getting out] to get our daily needs. Our bodies get checked, our stuff and bags get checked by the Israeli forces and dogs." (Raghad, personal communications, July 20, 2019)*

> *"Palestinians lost great areas of agricultural lands that we used to plant with Karm trees (grapes), olive trees, and almond trees. Our family's economic income has really decreased with the loss of these lands. Reaching these lands is very difficult after the construction of the wall. Not because of the difficulty of mobility only but because of the bullying of the Israeli settlers and soldiers on the Palestinian framers." (Abu Rami, personal communications, July 22, 2019)*

Furthermore, the changed scenery of the public realm along with the imposed limitation by the wall's existence has affected Palestinians' sense and meaning of place. Father Ibrahim Faltas, a priest who was a captive inside the Church of Nativity in Bethlehem city during the siege under the escalations of *Al-Ejtiyah*, has expressed that the city looks different and odd to him after the construction of the wall, in which prolongs his experienced feelings of fear and uncertainty in 2002:

> *"In 2002, I only saw that it was just the perimeter of the church that was sieged by [Israeli] tanks and soldiers and just the Palestinians inside held captive. After these years, I see the whole city is sieged by a wall." [21]*

The memory of the Israeli violent invasion in 2002 had been photo-framed by constructing the Segregation Wall as a physical reminder. Consequently, living the aftermaths of an ongoing spatial violence drained Palestinians' welfare and wellbeing. As a result, under the dynamics of everyday near the wall, many international artists (e.g., Banksy, Lushsux, etc.) and other local artists (e.g., Taqi Spateen, etc.) are utilizing the vast surface area of the wall's panels to script their graffiti. Through their art, they reflect different Palestinian symbols including the olive tree, home key of return, Palestinian martyrs, national leaders, *Kuffiyeh* traditional scarf, Dome of the rock, etc., all in which represent and embody the Palestinian history, culture, collective memory, and national identity. Other artworks include various controversial messages aimed to reach larger audience than the Palestinians. Such artworks include Banksy's "girl with balloon"; "girl frisking a soldier"; "two angels"; and others. Palestinians' reactions toward graffiti on the Segregation Wall proves the significance of this art movement as a placemaking tool aiming to reclaim spatial agency, restore their meaning of place, and promote Palestinians' wellbeing as a practice of resistance and *Sumood*.

3.1. Place of agency

As mentioned, Palestinians' sovereignty and freedom to interact with and within their public realm got stripped by the enforcement of the Segregation Wall. The wall is physically designed to sustain the Israeli governmentality and ground the feeling of helplessness suffered by Palestinians. The physical appearance of the wall ensures the achievability of self-disciplinary population discussed by the French philosopher Foucault [22]. The design of the Segregation Wall includes watching towers, spanned every 250 m along the wall [16]. Armed Israeli soldiers are always on duty in the watching towers, in the gates of the wall, and around discrete parts of the wall. Moreover, surveillance cameras are distributed along the wall ensuring full Israeli visual access to the space of the wall and its surroundings. The inhuman scale of the wall, the dark grey concrete panels, and the different policing Israeli "eyes" had managed to intimidate Nidal, a 27-years-old Palestinian, when he was younger:

> *"As a young child, my parents raised me to never approach the wall [or] to get close [to] the Israeli soldiers. However, I [will] never [forget] the day I rebelled and went with my friends for the first time to the wall and touched it. I did not know at that time why this wall is here or what is going to happen for us because we had touched it." (Nidal, personal communications, July 23, 2019)*

In Nidal's narrative, approaching the wall and touching it was a practice of courage that confronted all the imposed controlling measures by the oppressor. Likewise, drawing graffiti on the wall confronts all Israeli laws and feeds the sense of agency felt by the artists and the Palestinian audience. By actively or passively engaging in this art movement, Palestinians believe that they have an area of control and ownership to change the space and experience of the wall. In other words, Palestinians perceive these artworks as a testimony of their imagined, actual, symbolic, and/or temporal power over their place, everyday life, and future. Moreover, by the artistic representation of the Palestinian symbols, collective memory, national identity, and the oppressed everyday life, Palestinians believe that they can change the echoed message of the wall. They reclaim agency by switching the oppression narrative of the wall into a narrative of Palestinians' steadfastness, resistance, and resilience:

> *"Graffiti is a language that is easily readable by everyone in the world. The world can easily read our [Palestinians'] struggle with the images on the wall" (Jehad, a Palestinian resident living by the wall in Bethlehem, personal communications, July 24, 2019).*

The right to represent the past is a right to the city in which thrives people's agency [23]. As a result, Israeli laws condemn this artistic movement since its emergence in the First *Intifada*[5] [24], long before the construction of the wall.

3.2. Place of meanings

What identifies a place from another is the persistent sameness of threefold components; physicality of place (form), activities within the place (function), and the individual and group meanings created through people's experiences and intentions regarding that place (meaning) [25, 26]. Accordingly, "the complex bundle of meanings, symbols, and qualities that a person or group associates (consciously and unconsciously) with a particular locality or region" is what constructs our sense of place [27] (p. 135). This indicates that our sense or attachment to any place is mostly emotional and contextual. Place attachment is considered a significant place sensitive and positive emotional attachment that happens between place and people [28]. Individuals attach to places and construct meaning to places where they feel safe and comfortable [29, 30] and find opportunities for interaction and control [31]. Groups attach to places where they find common shared values, ideologies, history, past experiences, and culture bonds. Consequently, experiencing positive social emotions or feelings within the place is essential to encourage creativity [29, 30] and identity

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[5] The First *Intifada* is a Palestinian uprising started in 1987 against the Israeli injustice. It is also referred to as Stones *Intifada* since Palestinians used stones as a weapon to confront Israeli tanks and armed soldiers. The uprising ended by signing Oslo Agreement in 1993.

formation [32]. In addition, people should own the sovereignty and freedom within their places to fully benefit from them [33, 34].

The war techniques of Israeli military reflect occupational aims of devastating and increasing uncertainty in Palestinian places [35]. Spatial violence performed in wars affects social/symbolical spaces of cities. This is achieved by targeting people's cultural property and assaulting their collective memory, place attachment, and sense of belonging. Like Father Faltas' narration, many participants pointed the devastation caused to their sense of place and time by the wall:

> *"Put walls around Palestinians, take their lands and homes, and expect them to live inside these ghettos!" (Mohammad, personal communications, July 27, 2019)*

> *"They [Israeli military] make it harder for us to reach Jerusalem. If I want to pray in Al Aqsa Mosque, I must leave my house hours before the prayer time so [that] I can reach there on time, if I succeed in reaching. This is what Israel really wants by constructing the wall. They want to chock us and make it difficult to stay here. They want us to feel bored, lose hope, and leave our lands voluntarily so [that] they can get it easily." (Abu Mohammad, a 64-year-old Palestinian man, personal communication, July 12, 2019)*

As stated in Mohammad's narration, his perception of place has been subverted from "homes" to "ghettos" by the chocking Israeli practices. Palestinians realize the Israeli war strategy of draining Palestinians to the point of leaving their lands "voluntarily." Therefore, as a resistance tactic, Palestinians keep planning for their liberated future. Imagining just futures is a resisting practice [23], and it has been translated clearly in many graffiti pieces on the Segregation Wall. Some artworks show the city of Jerusalem behind the defeated wall. This artwork reinsures Palestinians' identity as the owners and protectors of the holy city and strengthens their sense of belonging. Other artworks include historical Palestine map and slogans like "from the river to the sea." All these artworks redefine the original boundaries of Palestinian lands, in which reminds Palestinians of their inherited and long-lasting attachment and ownership to all parts of Palestine. Palestinians reclaim meaning of place by the many graffiti artworks reflecting Palestinian national identity, collective memory, collective hopes, and other cultural symbols tying the community together. As a result, graffiti on the wall creates possibilities of enhancing the everyday life as explained by Yusuf:

> *"Graffiti has enhanced the everyday life beside the wall. Young groups in the city [have] found a tool to express themselves whenever they feel bored or angry. They use graffiti to deliver massages to the Israelis." (Yusuf, personal communications, July 23, 2019)*

3.3. Place of conciliation

Place-based health studies have documented and proved the significance of place in impacting, positively or negatively, people's physical and psychological health [8, 36, 37]. The devastation of place is highly associated with a negative impact on the wellbeing of affected people. Likewise, seeking out and valuing places is critical to facilitate healing and recovery [8]. Gesler's conceptual framework of "therapeutic landscapes" explores the ways in which people's experience of place might affect and reconstruct experiences of health and wellbeing [38]. The concept draws attention to the intertwined physical, social, and symbolic dimensions of place that affect health and wellbeing [38]. In this sense, therapeutic landscapes draw on social relations, sense of place, and daily interactions and activities to facilitate conciliation and support people's wellbeing [38].

As narrated by many participants, like Abu Mohammad, the Segregation Wall has caused an ongoing trauma. Alternatively, the narration of Yusuf reflects how Palestinians are trying to cope with the wall's daily psychological oppression by interacting with it. Furthermore, graffiti provides Palestinian youth the chance to express themselves and to amplify their voices locally and internationally:

> *"The moral behind the graffiti is not to enhance the ugliness of the wall. On the contrary, when someone draws on the wall, they want to show how ugly it is to the world in appearance and meaning, to show disapproval and resistance. By this communication tool, one assumes*

that the other side is hearing them, they simply don't. they don't have feelings. If once the Israeli community decided to open their eyes, treat us as visible and see the graffiti on the Segregation Wall, they might feel the need to remove it." (Rifaa, personal communications, July 24, 2019)

As narrated by Rifaa, a Palestinian woman, graffiti is Palestinians' way to reject the invisibility imposed on them by the Israeli Segregation Wall. Re-narrating traumatic experiences through cultural practices helps to recognize injustice locally and globally; and therefore, reliefs in the peacebuilding and healing processes [15]. Consequently, the "reclaimed" spatial agency, the "restoration" of meaning and sense of place, and the emerging place of interaction, expression, and grieve work to cure Palestinians' feelings of sorrow and helplessness, creating therapeutic landscapes and places of conciliation.

4. Discussion

The mentioned extracts shed light on how graffiti as a placemaking practice has managed, symbolically or/and actually, to reclaim spatial agency, restore meaning and sense of place, and support Palestinians' wellbeing. The fact that the widespread artworks confront the imposed Israeli war strategies classify such movement as a tactic of resistance. The unfolding dynamics of everyday life near the wall in the face of the added violence caused by the Segregation Wall have influenced the creative nonviolent form of Palestinian resistance reflected on the concrete structural panels of the "wall space." In fact, more than seven decades of Israeli military occupation have proposed different forms of Palestinian resistance between direct confrontations and other nonviolent tactics; all of which support the ultimate resistance ideology of Palestinian *Sumood*. The military occupation is still ongoing; accordingly, every applied setting of spatial violence motivates the emergence of unique and innovative resistance tactics that yet are waiting to be studied. As summarized in Figure 1, the blurred boundaries of violence and resilience along with the intertwined relation between them describe the complexity of this context. In other words, when re-counting the Israeli war strategies and the Palestinian resistance tactics, the different stacked layers of 73 years of this war context makes it hard to specify a start or an end point of these events or clearly point how one is transforming/affecting the other, rather they only indicate the determination to use every single opportunity to make do towards just life. However, one clear conclusion is that performing a resistive placemaking, like graffiti discussed in this paper, can achieve the reclaiming of agency, meanings, and wellbeing; all in which motivates the pursuing of social sustainability in warzone areas.

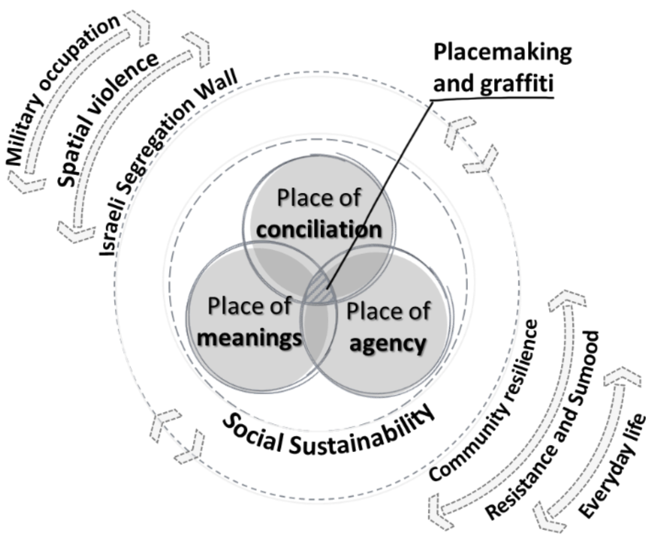

Figure 1. Conceptual framework on interpretation for the forms of resistance.

5. Conclusions

As demonstrated in the chronology of the above discussion, living in areas suffering from ongoing urban violence poses a serious risk on physical and psychological health of affected people. The Israeli military by the construction of the Segregation Wall has imposed a war landscape of trauma, uncertainty, sorrow, and despair which forces Palestinians to experience daily struggles of restricting their freedom, sense of agency, and self-determination. Also, this study exhibits a creative culture in which Palestinians "make" their place in the face of reality. In exploring the graffiti movement on the Segregation Wall, this study highlights the significance of place as an arena of resistance. Affected people's utilization of place becomes a source of resistance [39, 40]. Palestinians' continuous usability and inhabitation of the space of the wall reidentifies them as the owners of the place and illustrates their embodied everyday resistance. They resituate themselves in the urban space by their graffiti cultural practice and refuse the invisibility enforced on them by the wall. By so doing, Palestinians actively participate in restoring their sense of place and control the narrative echoing the reality of the Segregation Wall. Overall, this study proved that graffiti has made it easier to survive the everyday near the wall and to defeat the feeling of helplessness. Palestinian graffiti as a placemaking has proved itself as a creative pattern that focuses particular attention, local and global, on the structural, cultural, and social Palestinian identity of this occupied place. Therefore, graffiti on the Segregation Wall is inspirable from the Palestinians' nonviolent resilience strategy of *Sumood* aiming to achieve social justice and sustainability.

In conclusion, all pillars of sustainability (social, environmental, and economic) discuss the common struggle of human survival and continuity now and in the future. Studying this case has contributed to the overall understanding of sustainability concept and highlighted the interrelations between social sustainability, placemaking, and resistance. Placemaking as a process works to achieve the human-related targets of social sustainability. While social sustainability calls for people's wellbeing and health, placemaking achieve that by promoting communal agency and positive meaning of place. Placemaking becomes the tool/tactic of action/resistance to call for transformation of place, temporary or permanent, to gain battles in an ongoing war. In colonialized areas, the goals that can be achieved by placemaking are central and consistent to those of any resistance practice performed by affected communities to achieve overall wellbeing and resilience. As such, social sustainability concept can be applicable in warzones by seeing it as a resistive practice aiming overall social and spatial justice.

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Statistical Analysis of the Effects of Tenants' Discrimination in Akure Residential Property Market

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Abstract: This study examines the effects of tenants' discrimination in Akure residential property market. Primary data used for this study was obtained through questionnaire survey. A total enumeration survey of all the Estate Surveying and Valuation firms in the study area was carried out, and a simple random sampling method was used to select two tenantsand two landlords from each of the Estate firms. The data collected was used to analyze the effects of tenants' discrimination in Akure residential property Market. The relationship between Landlords' Ages and Sexes, Tenants' Sexes and Occupations, Estate Surveyor and Valuers' Years of Experience and Methods of Tenants Selection, and the Effects of Tenants' Discrimination was determined using the inferential statistical method called Analysis of Variance (ANOVA). The study revealed that Tenants' discrimination isnot affected by the landlords' ages and sexes, i.e., no matter what the age and sex of Landlord, it has no significant effect on tenants' discrimination. Also, the Sex and Occupation of Tenants have no significant effects on tenants' discrimination. But the years of experience and the methods of tenants' selection of Estate Surveyors and Valuers have significant effects on Tenant's discrimination. It was also discovered that most landlords in the study area discriminate against tenants based on their past experiences due to the relationship they have had with different tenants. Thetribes/ethnics of tenants are the primary or most significant factor or reason why tenants think they are being discriminated. Property managers always try as much as possible to adhere to landlords' instruction, thereby discriminating against tenants in the process.

Keywords: Tenants' Discrimination, Residential Property, Landlords, Tenants, Statistics

1. Introduction

Discrimination arises because some people happen to belong to a particular group or because they have certain personal characteristics or attributes, some people have prejudiced ideas or stereotypes or beliefs about them. It is often the result of not treating each person as an individual irrespective of their race, age, sex, etc. [1].

According to [1], we can also have discrimination in an indirect way. In some instances, treating everybody the same way may not be favorable to some group of people. For example, requesting that all prospective tenants have been working for at least five years would be unfavourable to young people who may have little or no chance of complying. Such a rule will be against the law, and it will be indirect discrimination unless the rule in all relevant circumstances is reasonable and necessary. Most of the time, indirect discrimination is often the result of failing to think about the impact of regulations and requirements on different categories of people, and not usually intentional.

Tenant discrimination is a permeative challenge nationwide; it is also hugely under-reported, according to the U.S.A. Department of Housing and Urban Development (HUD), less than one percent of about two million instances of Tenant's discrimination that occur each year are reported.

A lot of people are not evenaware that they have experienced discrimination one way or the other when it comes to housing discrimination. HUD study in the year 2002 suggests that many renters and homebuyers do not understand the activities that are illegal under the Fair Housing Act.Tenant discrimination is said to have occurred when an individual or family is treated partially based on specific attributes, such as sex, race, class, religion, family status, and national origin when trying to rent, buy, sell, finance, or lease a home. [2]. Housing discrimination can lead to racial separation and spatial inequality, which, in turn, can provoke wealth inequality between certain groups. Discrimination is common in the residential market because the Landlord has his own policies before any tenant could rent his property, which the property manager must strictly obey.

In Akure residential property market, the three major stakeholders are Estate Surveyors and Valuers, whohelp in tenant selection; landlords who provide the residential properties; tenants who seek housing, and they are far increasing day by day. It is the duty of an Estate Surveyor and Valuer, i.e., a property manager, to select the desirable Tenant based on some policies and procedures. Policy on tenant selection may vary depending on the category of property, the objective of the property owner, and the facilities provided.

Residential property generally delivers the most balanced income because no matter what the economic dictate, people are always in search of places to live. The need for housing by tenants has allowed the property owners to arbitrarily review rent upward, making the residential property market to be more competitive, and only the high-income earners would be able to go for it. Despite the competitiveness of the residential market, there are still provisions for the middle-income earners and low-income earners in getting houses they can afford, especially in Akure residential property market.

2. Review of Relevant Literature

2.1 Definitions of the Concept of Residential Property Discrimination

Discrimination arises when people are singled out or excluded (irrespective of their merit) based on class, gender, race, sex, or any other group identity. Discrimination has been for a very long time, it is as ancient as humankind, it is a timeless phenomenon, and most of the time it lies at the heart of most humanconflict and differs from places to places. Residential property market discrimination occurs when an individual or family is treated partially based on specific attributes, such as sex, race, class, religion, family status, and national origin, when trying to rent, buy, sell, finance, or lease a home. [2].

2.2 The Review of Relevant Literature on the Concept of Housing Discrimination

In the residential property market, the competitive atmosphere spread rapidly, the discrimination element. One of the primary sources of social exclusion is the lack of accommodation, which is a significant necessity for any life worth living [3]. In developed countries, a lot of experiments have been carried on discrimination into residential property market. According to [4], Arab and Afro-Americans sounding names are mostly discriminated against in Italy, Spain, and the U.S.A. The method used was that the owners of properties are being sent emails. From the study carried out by [4], there are high levels of discrimination against people from Arab and European countries in Italy. In Sweden, [5] discovered that discrimination based on ethnicity and gender does exist. The relationship between immigrants in developed countries and the inter-ethnic groups is the main target of all these studies.

The 1989 Housing Discrimination Study (HDS) was used by [6] to examine the residential property agent's discriminatory actions. According to the author's proposition, information is given about which units are available, the geographic location of housing units shown or recommended, and facilitating the sale of a unit are the three primary kinds of behaviors property agents can use in discriminating minority clientele. The acts of discrimination are being quantified by the likelihood of brokers doing various actions calling back, asking about needs, asking about income, financial assistance, follow-up calls, mentioning the advertised unit is available, and invitations to inspect the advertised unit. The authors discovered that residential property agents discriminate in all cases. How discrimination occurs are measured by these behaviours measure; however, they do not quantify the subtle differences in the way an agent can carry out those actions towards minorities. For instance, if a property owner makes a follow- up call to both minority auditors and white in the study, different tactics may be used by the property agent on the white client to entice him to visit again. In as much as they didn't record the language used during these exchanges, it is not possible to say that in addition to the more overt discrimination, there aresubtle forms of discrimination happening.

The evidence found on discriminatory actions in residential property, fast food markets, and the automobile was discussed by [7]. In the property market, the obvious discriminatory behavior in both the rental and sales markets was highlighted. Property agents usually exclude available units of properties, signal fewer positive comments about the units, show fewer units, make fewer callbacks, and are less likely to help with minority home seekers or discuss financial incentives. These results do show ways property agents can discriminate, yet, within each action, subtle discrimination can still be used by a property agentagainst minorities. Since the effects of the property agent are not recorded nor is the auditor asked to discuss these types of agent behaviours, there is no way the researcher can know this type of discriminatory behaviour.

The 2000 Housing Discrimination Study (HDS) was used by [8] to examine the choices of real estate brokers' as regards the number of properties to show prospective tenants. He discovered that Hispanicsand blacks and are shown 10% and 30% fewer properties, respectively. This difference is majorly attributed to the white customer's influence.

The study of [9] focused on whether landlords in the U.S.A. cities discriminate in the housing market. He used matched pair audits conducted via email for rental property units advertised on-line to test for racial discrimination. The research showed African-American names experience discrimination and are more pronounced in neighborhoods that their racial composition is near "tipping points."

The Toronto’s property market was studied by [10]. Audit method was used in accessing discriminationin this market. The study reveals that the Arabic/Muslim men are the set of people who face the greatest resistance at about a 12% level of discrimination. Audits approaches and complaints are also used in examining the incident of discrimination [11], it's of the opinion that in respect of the matter, the actual occurrence might not be complaints.

Some other things that are also discovered as discrimination in residential housing market are membership in a particular socio-economic class. (for example, single parent households, welfare recipient) or lack of membership in a particular Race, religion, the sponsoring organization, sex, color, status, or the household members national origin, whether there is a member of the household that has a specific disability, the size of the family (However, if the family size requires a unit size that does notexist in the property, the family must be denied assistance), age etc.

2.3 Effects of Tenants’ Discrimination in Residential Property Market

The 2009 report by the Fundamental Rights on the living conditions of Roma and Travelers and that of the European Monitoring Centre on Racism and Xenophobia on discrimination against migrants and minorities in housing in 2005 shows the level of discrimination suffered by Roma, migrants, and persons of foreign origin looking to rent private house throughout the European Union. This can sometimes take the dimension of a refusal to let out a property. Still, another instance, the property owner can be asking migrants or members of an ethnic minority a higher rent.

Although, we don't have adequate data in this area, some studies suggest that regardless of origin some women such as single parents are always victims of discrimination when renting private accommodation. From the study carried out in Belgium in 2006, the idea of having single women or unmarried mothers in residential property is not being supported by a large number of property owners. Some of them believe that in the practical aspects of handling and maintaining a property, women are not as good as men, while this tendency has been exacerbated by the fact that many women have low incomes. The Anti- Discrimination and Equal Opportunities Commission [Haute autorité de Lutte contre les discriminationset pour l'égalité – HALDE] found in France in 2011 that in the private housing sector, families of single- parent are among the types of families that suffer discrimination most frequently, 85% of which are singlemothers looking after one or more children. The report 'How fair is Britain? 2010' in the United Kingdom showed the fact that single mothers, due to discrimination, are more likely to live in poor quality or overcrowded accommodation than other family types.

From the HALDE discussion quoted above, young people under the age of thirty or people who are no longer independent or who are disabled also face a high level of discrimination in access to quality accommodation in France. If Europe-wide studies can be conducted, it would be helpful in order to detect if these groups in the other European States are also significantly affected by this type of discrimination.In national case law, some decisions show that same-sex couples who wish to rent apartments are sometimes discrimination victims.

3. Research Method and Analytical Tool

The sample size for this study covered all the twenty-five (25) registered Estate Surveying and Valuation firms in Akure metropolis (total enumeration). Two (2) Landlords and two (2) Tenants were selected per firm, making fifty (50) Landlords and fifty (50) Tenants, which was one hundred and twenty-five (125) respondents in total. The major method adopted for collecting the primary data for the research study was the use of questionnaires. The inferential technique, called Analysis of Variance (ANOVA) was adopted.

4. Data Analysis and Discussion

4.1 Effects of Landlords' Ages and Sexes on Tenants' Discrimination

The relationship between Landlords' Ages and Sexes and the Effects of Tenants' Discrimination was determined in Table 4.1 below, using the inferential statistical method called Analysis of Variance (ANOVA). This had helped to understand the statistical differences between the sexes and ages of the landlords and the effects of tenants' discrimination and their significance

Table 1: Relationship between Landlords' Ages and Sexes and the Effects of Tenants' Discrimination

Tests of Between-Subjects Effects					
Dependent Variable: LANDLORDS EFFECTS					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	178.028[a]	8	22.254	1.259	.296
Intercept	5279.839	1	5279.839	298.594	.000
SEX	5.586	1	5.586	.316	.578
AGE	58.358	4	14.589	.825	.518
SEX * AGE	132.033	3	44.011	2.489	.076
Error	618.881	35	17.682		
Total	15930.000	44			
Corrected Total	796.909	43			

The ANOVA table above shows the statistical differences between the sexes and ages of the landlordsand the effects of tenants' discrimination and their significance. The values in the table were arrived at, at 5% degree of freedom and 95% level of significance or confidence.

From the table, $p = 0.578 > 0.05$ for sex. This indicates that the differences between the sexes of the landlords and the effects of tenants' discrimination are statistically insignificant. Hence, the sexes of the landlords have no statistically significant main effect on discrimination in tenant selection. All other things being equal and ignoring the effects of age, and the F ratio has a highly significant effect or influence on tenants' discrimination by landlords.

The differences between the ages of landlords and the effects of tenants' discrimination are statistically significant, too, with p = 0.518 > 0.05. Hence, the ages of the landlords have no statistically significant effect on discrimination in tenant selection. All other things being equal, Landlord's ages no matter whatit is, doesn't influence their decision on whether to discriminate against any tenant or not.

The interactions between the two independent variables of age and sex have no statistically significant effect on tenants' discrimination by landlords. The differences are, therefore, insignificant. This is becausethe significance value is less than p = 0.05. Therefore, whether the Landlord is a male or female, or whether the Landlord is old or young does not affect the way he or she discriminates in any way.

Therefore, the implication or likely consequence of the ages and sexes of the landlords on tenants' discrimination is negligible.

4.2 Effects of Tenants' Sexes and Occupations on Tenants' Discrimination

The relationship between Tenants' Sexes and Occupations and the Effects of Tenants' Discrimination was determined in Table 4.2 below, using the inferential statistical method called Analysis of Variance (ANOVA). This had helped to understand the statistical differences between the sexes and occupation of the tenants and the effects of tenants' discrimination and their significance.

Table 2. Relationship between Tenants' Sexes and occupations and the Effects of Tenants' Discrimination

Tests of Between-Subjects Effects					
Dependent Variable: TENANTS EFFECTS					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	552.897[a]	23	24.039	1.904	.089
Intercept	13004.752	1	13004.752	1029.891	.000
Sex	4.233	1	4.233	.335	.570
Occupation	481.911	18	26.773	2.120	.064
Sex*Occupation	47.280	4	11.820	.936	.467
Error	214.664	17	12.627		
Total	23906.000	41			
Corrected Total	767.561	40			

The ANOVA table above shows the statistical differences between the sexes and occupation of tenants and the effects of tenants' discrimination and their significance. The values in the table were arrived at, ata 5% degree of freedom and 95% level of significance or confidence.

From the table, the p = 0.570 > 0.05. This indicates that the differences between the sexes of the tenants and the effects of tenants' discrimination are statistically insignificant. Hence, the sexes of the tenantshave no statistically significant main effect on discrimination in tenant selection. Tenants' discriminationis not affected or influenced irrespective of whether the Tenant is a female or male.

The differences between the occupations of tenants and the effects of tenants' discrimination are statistically insignificant, too, with p = 0.064 > 0.05. Hence, the occupation of tenants has no statistically significant main effect on discrimination against tenants in tenant selection.

The interactions between the two independent variables of sex and occupation have no statistically significant main effect on discrimination against tenants. The differences are, therefore, insignificant. Thisis because the significant value is higher than p = 0.05.

Therefore, the implication or likely consequence of the sexes and occupation of the tenants on tenants' discrimination i[s negligible.

4.3 Effects of Estate Surveyor and Valuers' Years of Experience and Methods of Tenants' Selectionon Tenants' Discrimination

The relationship between Estate Surveyor and Valuers' Years of Experience and Methods of Tenants Selection and the Effects of Tenants' Discrimination was determined in Table 4.3 below, using the inferential statistical method called Analysis of Variance (ANOVA). This had helped to understand the statistical differences between the years of experience and methods of tenants' selection of Estate Surveyor and Valuers and the effects of tenants' discrimination and their significance.

Table 4.3: Relationship between Estate Surveyor and Valuers' Years of Experience and Methods of Tenants Selection and the Effects of Tenants' Discrimination

Tests of Between-Subjects Effects

Dependent Variable: ESTATE SURVEYORS AND VALUERS EFFECTS					
Source	Type IIISum of Squares	Df	Mean Square	F	Sig.
Corrected Model	158.333[a]	8	19.792	6.704	.011
Intercept	3566.597	1	3566.597	1208.041	.000
Years of Experience	47.367	2	23.683	8.022	.015
Methods of Tenants Selection	93.500	5	18.700	6.334	.016
Years of Experience *Methods of TenantsSelection	8.167	1	8.167	2.766	.140
Error	20.667	7	2.952		
Total	7404.000	16			
Corrected Total	179.000	15			

The ANOVA table above shows the statistical differences between the Years of Experience and Methods of Tenants Selection of Estate Surveyors and Valuers and the effects of tenants' discrimination and their significance. The values in the table were arrived at, at a 5% degree of freedom and 95% level of significance or confidence.

From the table, the $p = 0.015 < 0.05$. This indicates that the differences between the years of experience in property management and the effects of tenants' discrimination are statistically significant. Hence, the years of experience of Estate Surveyors and Valuers in property management have a statistically significant main effect on discrimination in tenant selection by Estate Surveyors and Valuers. Tenants' discrimination is highly affected or influenced by the years of experience of Estate Surveyors and Valuersin property management.

The differences between the Methods of Tenants Selection and the effects of tenants' discrimination are statistically significant, too, with $p = 0.016 < 0.05$. Hence, the Methods of Tenants' Selection have a statistically significant main effect on discrimination against tenants in tenant selection by Estate Surveyors and Valuers.

The interactions between the two independent variables of Years of experience in property management and Methods of Tenants Selection have no statistically significant main effect on discrimination against tenants. The differences are, therefore, insignificant. This is because of the significant value, i.e., 0.140, isgreater than p = 0.05.

Therefore, the implication or likely consequence of the years of experience and the method of tenants' selection of Estate Surveyors and Valuers on tenants' discrimination is very significant.

5. Conclusion

This study was carried out because of the rampancy of tenants' discrimination in the residential property market; the effects of tenants' discrimination on property transactions were considered. From the findings,it can therefore be concluded that tenants' discrimination is not that rampant in the study area. People believe that the most important thing is the ability of the prospective tenants to pay the initial and subsequent rent and to keep the property in good shape. Tenants' discrimination is not affected by thelandlords' ages and sexes, i.e., no matter what the age and sex of Landlord it has no significant effect on tenants' discrimination. Also, the Sex and Occupation of Tenants have no significant effects on tenants' discrimination. But the years of experience and the methods of tenants' selection of Estate Surveyors and Valuers have significant effects on Tenant's discrimination.

Conflict of Interests

The authors declare that there is no conflict of interests.

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Exploring Children's Relationship with Natural Elements in Schools under UAE Hot Climatic Conditions; Exploratory Literature Review

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Abstract: In today's world, entire populations spend ninety percent of their time indoors, a fact largely substantiated in the literature as yielding negative impacts on people's health and well-being. As a first response, the current green design movement stressed the need to reintegrate nature in the built environment, which carries significant positive impacts on building occupant's health and well-being. In this regard, Biophilia –people's affiliation with nature- is an aspect often studied to reach the optimum integration, partly based on nature's positive effects on cognitive performance, productivity, and the psychological state of buildings' occupants. Children living in a hot desert environment such as that of the United Arab Emirates (UAE) may further lack exposure to natural elements, which, in turn, can have negative impacts on their health and well-being in such critical developmental age. The literature indicates a knowledge gap of studies investigating children's preferences of natural elements in learning environments of the Middle East or countries of similar hot climatic conditions. Hence, this paper reports on a literature review exploring first, in brief, the concept of humans' affiliation with nature, then reviews more specifically what has been established in terms of children's current experiences with natural elements in learning environments under desert, extremely hot climate, and their possible preference for vegetation, water, and other natural elements, as prospectively architecturally integrated to their learning environment. A literature review was conducted and facilitated capturing the children's present perception of a pleasant experience when associating learning environments with natural elements. The study's preliminary results highlighted the current gap in the literature when it comes to children's experiences and preferences in countries with hot climatic conditions.

Keywords: Children, Nature, School Environment, Preferences, Hot Climate, Exploratory.

1. Introduction

A finding supported by the National Human Activity Pattern Survey (NHAPS), aimed at assessing exposure to environmental pollutants, proving that we are an indoor species and that the total time we spend outdoors is the most insignificant part of our days, often so small that it barely shows up in the totals found in the study. [1] The reason behind this disconnection people experience from the natural elements of the environment is a negative outcome of the limited greenery and the rise of urbanization [2]. Whereas connecting them to nature is recognized for its various benefit on cognition, mood, and surgery recovery, physical health, among other benefits [3, 4, 5, 6, 7, 8, 9]. Research has proved other benefits specific to children's development and learning experience, children's relationship to nature was the focus of researchers who proved that children experience special advantages after being connected to nature.

It is important to explore the concept of Biophilia, as a first step in understanding humans' affiliation with nature, and the relationship people, and children have with natural elements. The theory of 'Biophilia' was first formed by Wilson, when he suggested that "humans possess an innate tendency to seek connections with nature and other forms of life" [10]. He defines biophilia as "the urge to affiliate with other forms of life" [10]. The general benefits of connecting indoors to outdoors and the positive effects of this connection on humans were studied in a substantial amount of literature by many researchers in the field.

Other researchers focused further on the effect of connecting children to nature. The disadvantages of this possible lack of connection to the outdoors were explored in a study titled 'Health and behavior of children in classrooms with and without windows, where it was concluded that windowless classrooms should be avoided for permanent use. [11] Another study explored visual landscapes and psychological well-being, where findings suggest that the effect of nature exposures was to increase Positive effects, including feelings of affection friendliness, playfulness, and elation [12].

This paper includes an insight on the previous work done in the literature on the basis of the suggestion that the hot climatic conditions of countries such as the United Arab Emirates (UAE), may call for the need for more schools designed to eliminate any deprivation or a lack of interior-exterior connection to the outdoors compared to their peers in other parts of the world. Hence, any lack of connection with the outdoors in learning environments may compromise children's engagement with and appreciation for nature. A review of the literature reveals, however, few empirical studies about the preferences of children for the use of natural elements in their learning environments, and barely any studies were conducted in the Middle East or countries of hot climatic conditions.

This exploratory literature review aims to investigate the concept of humans' affiliation with nature from previous studies, as well as to explore what has been established in terms of children's current experiences with natural elements in learning environments, and their possible preference for vegetation, water, and other natural elements, as prospectively architecturally integrated to their learning environment. The paper also focuses on the existing literature that explores the concept under extreme climates, in this context hot climatic conditions, with the possibility of correlating an observed sense of deprivation among children living under these environmental conditions.

2. Biophilia and Children's Relationship with Nature

2.1 The preference for Nature; Biophilia

The Biophilia theory was used in several disciplines, in field of Architecture, Biophilic Architecture was studied by Söderlund in a review of the rationale and outcomes. He stated that contemporary cities have high-stress levels, mental health issues, crimes, and illnesses, while the built environment shows increasing problems with urban heat island effects and air and water pollution. [13] "Biophilic Cities" provide close and daily contact with nature, they can also help Build Social Capital and Trust: Forests, parks, and green spaces are important places for socializing and for forming new friendships. The existence of these type of "Biophilic Cities" in hot climatic conditions is limited, since providing close and daily contact with nature needs the facilitation of natural elements people want to connect with, and foster an awareness of Beatley's suggestion of the limited existence of Biophilic cities in hot climatic conditions supports the objective of this study in exploring the preferences of children in these climates of a stronger connection to nature. [14]

Adding elements of nature to living spaces can presumably induce positive changes in cognition and emotions, which again may affect stress levels, health, and well-being. Since the indoor environment is the usual daily setting for most of the present population, even minor effects of adding plants can add up to a substantial decrease in the health burden on a global scale. [15] The impact nature has on reducing stress levels was initially studied by Ulrich in 1991, when he proved the efficiency of stress recovery during exposure to natural and urban environments. [9] Chang supported the findings of Ulrich's study in 2005, by studying the positive human responses to window views and indoor plants in the workplace. [6] Improving attention is another known impact of nature on humans, established as early as 1989 in a study of the experience of nature from a psychological perspective. [16] The positive effect of nature on mental restoration was a focus for researchers such as Hartig and Van der, In their studies "Tracking restoration in natural and urban field settings" [17] and "Preference for nature in urbanized societies: Stress, restoration, and the pursuit of sustainability”. [18] Another aspect of the impact by examining coping with attention deficits was studied in “Coping with ADD: the surprising connection to green play settings” [19] and “Children with attention deficits concentrate better after a walk in the park” [8]. Direct physical health benefits were also a focus for many researchers. The green exercise was demonstrated in the Ecotherapy agenda, where 108 people were involved in green exercise activities with local mind groups and then surveyed. The activities included gardening projects, walking groups, conservation work, running and cycling groups, 94 percent of people commented that green exercise activities had benefited their mental health. [5] Therefore, connecting people to nature in building design has evidence of positive impact from many fields, with studies showing: Window views of natural landscapes reduce stress in office workers. [7,9] Trees and outdoor gathering places are associated with increased social interactions and a sense of community in poor urban neighborhoods. [4] Passive viewing of tropical fish in a fish tank reduces blood pressure and increases relaxation. Recovery from surgery is aided by daylight and nature views, nature exposure is an important determinant of human mental and physical well-being. [4] Aspects of biophilic design – Bringing the outdoors in: Seven key Biophilic design parameters have been identified in the “14 patterns of Biophilic Design” book that together explain 16% of the variation in pupils' academic progress achieved. [20] These are Light, Temperature, Air Quality, Ownership, Flexibility, Complexity, and Color. [20] Disconnecting people from these natural elements is a negative outcome of urbanization. [2] Another recent study found that Biophilic design Reduces 8.6 mmHg systolic and 3.6 mmHg diastolic B.P., reduces skin conductance level by 0.18 μs, improves short-term memory by 14%, decreases negative emotions, and increases positive emotions. [3] Therefore, based on the studies above, the incorporation of Biophilic Design in the design of learning environments may yield a significant positive impact on children.

2.2 Children and Nature

Nature Play & Children’s Affiliation with Nature: According to Hand, urban gardens are important in supporting children’s Biophilia. [21] Children’s affiliation with nature was studied long before that in a study of “Developmental Psychology and the Biophilia Hypothesis”, [22] where a structural-developmental approach is framed for investigating biophilia. Kahn’s research in the Brazilian Amazon provided some initial support that there exist universal forms of children’s environmental moral reasoning and values. Thus, in line with the biophilia hypothesis, it’s possible that there are aspects of nature that help raise children’s environmental constructions. [23] Kahn had previously collaborated with Friedman in a similar study. In their study titled “Environmental views and values of children in an inner-city Black community.” seventy-two children were interviewed on their conceptions and values of nature. Kahn and Friedman assessed whether children were aware of environmental problems, discussed environmental issues with their families, valued aspects of nature, and acted to help the environment. Overall, children showed sensitivity to nature and awareness of environmental problems. The findings of this research were discussed in terms of moral-developmental theory, and the place of social-cognitive research in understanding the human relationship to the natural environment.

Similarly, Mahidin & Maulan examined children’s preference for natural environment setting in their study “Understanding Children Preferences of Natural Environment as a Start for Environmental Sustainability”, this research was conducted to enhance environmental awareness and improve environmental educations programs for children [23]. The importance of understanding children's views and preferences towards the environments was justified by Mahidin & Maulan as children having different needs, aspirations, and behavior than adults since their minds are still developing. [24] In a study that attempts to classify children’s attitudes towards nature, the effect of personal experiences on preschool children’s biophilia and attitudes toward nature was studied by Yanez, in his research, thirty-six children from different geographical areas (urban n = 27; rural n = 9) participated in one-on-one structured interviews about their attitudes toward and being in nature. Results revealed no significant difference in biophilia between children by geographical area. However, common themes in children’s attitudes emerged, the first theme is that “young children define nature by identifying specific elements”; the second is “young children are aware that their actions have consequences for the condition of the natural environment"; and the final theme concludes that "children understood that the expectations guiding behavior in the natural environment apply to everyone". [25] "Children and Nature" book incorporates research from cognitive science, developmental psychology, ecology, education, environmental studies, evolutionary psychology, political science, primatology, psychiatry, and social psychology. The book points out the vital and seemingly irreplaceable importance of children's direct experience of nature in even modest and sometimes compromised natural settings, which is further suggested by the results of studies in diverse cultural and economic locations. These findings also indicated that direct encounters with nature provide children with unique and critical developmental opportunities for discovery, creativity, and personal autonomy. [26] In "Into the Woods: A Study Exposing Children to Outdoor Classrooms", a survey given to parents and faculty of a childcare center located in Muncie, determined that the impediments to establishing forest kindergartens. For a comparative analysis of the survey, a classroom of seventeen three to five-year-old children was observed. Landscape architecture students conducted behavioral mappings to determine the duration children spent at a given space, the activities they engaged in, and the density of the children in each space, in order to establish design principles based on children's reaction to natural settings. The study concluded three design principles that must be followed to establish forest kindergartens: 1) Engagement in a diversity of spatial configuration, dimension, and materials; 2) Utilization of pathways between nature classrooms as learning spaces, and 3) The facilitation of deep immersion in nature for all-day/all-weather classrooms. [27] The findings of this study could be used for a suggestion of how this current study is concluded, translating the findings into guidelines or design principles.

2.3 Children and nature in the learning environment

In "Learning in the outdoor environment: A missed opportunity?", the findings of a research project that aimed to document the current use of the outdoors by a group of early years teachers working in South Wales. Interviews and observations were conducted in four schools, it is suggested that the teachers missed many of the opportunities afforded by the outdoor environment to enhance children's learning. [28] The Classroom Environment's Impact on Learning was studied in Ramli's "Improving the Classroom Physical Environment: Classroom users' perception" which investigated classroom users' perception of their conventional classroom and how they perceive the preferred classroom physical environment. A questionnaire survey was used both for teachers and students as classroom users'. The results showed that 90 percent of classroom users' agreed that changes in the classroom environment need to be implemented. The significance of this study was to further boost the awareness about the importance of classroom physical environment and to improve classroom design in line with government aspirations to improve students 'and teachers' performance towards world-class education. [29] "The impact of classroom design on pupils' learning: Final results of a holistic, multi-level analysis" established seven key design parameters that together explain 16% of the variation in pupils' academic progress achieved. These are light, temperature, air quality, ownership, flexibility, complexity, and color. [30] Indoor-outdoor spatial relations proved to have an influence on child engagement and teacher motivation, in an investigation of that influence, findings suggest that specific architectural attributes of preschool classrooms (windows and views) may support teacher motivation and child engagement in childcare settings. [31] There is special concern about the unhealthy lives of children, as seen in rising child obesity rates, unhealthy diets, and lack of physical activity, also little connection with outside nature. [24] "Last Child in the woods" directly links the lack of nature in the lives of today's wired generation -nature-deficit- to some of the most disturbing childhood trends, such as the rises in obesity, attention disorders, and depression. [32] Rivkin addressed the same concern, when he studied the importance of schoolyards in his "Schoolyard Habitat Movement". [33]

All these studies suggest a close relationship that children –specifically- have with nature, which proves the importance of studying their preferences on a global level, in different climates, In terms of context, the choice of the learning environment for the investigation of children's preferences was made on the basis of children spending long periods of time in schools. The importance of the school environment was explored by many researchers, in order to eventually optimize their learning and growing experiences. [31, 33]

3. Climatic Challenges of Connecting to Nature under Extreme climate - The UAE context

Few studies report on the extreme climate -whether cold or hot- and its impact on the relationship with nature in general and in schools specifically. Although people's relationship with nature in cold climates is relatively more explored in literature as compared to the hot desert climate, where the UAE is a typical representative context.

3.1 The UAE Context

The preference and potential benefits of nature in general, and to children specifically, having been established as seen in the previous body of literature. However, the provision and facilitation of these benefits may be specifically challenged under extreme climates. The United Arab Emirates has a desert climate, with mild winters and very hot and sunny summers. The annual precipitation is below 100 millimeters (4 inches). The country is made up of seven emirates, almost all overlooking the Persian Gulf (Abu Dhabi, Ajman, Dubai, Ras al-Khaimah, Sharjah, and Umm al-Quwain), and one overlooking the Gulf of Oman (Fujairah). In Dubai, the daily average temperature goes from 19.5 degrees Celsius (67.5 °F) in January to around 36.5 °C (98 °F) in August. [34] This type of weather puts a number of constraints on using nature in the built environment, which are seen in the avoidance of the increasing outdoor temperatures by staying indoors and turning on the ACs, the limited vegetation in such environment also acts as a limitation to the incorporation of plants indoors. Several other impacts are experienced by people living in hot climates that should be mitigated when integrating nature in the built environment. Based on the findings of an Intergovernmental Panel on Climate Change (IPCC) and hundreds of references quoted in the 2009 Report of the Arab Forum for Environment and Development (AFED), it can be stated that Arab countries are in many ways considered some of the most vulnerable in the world to the potential impacts of climate change. The most noticeable impacts are the increased average temperatures, the less and more erratic precipitation, and sea-level rise (SLR), considering that the region already suffers from aridity, recurrent drought, and water scarcity. [35] Moreover, a large proportion of electricity in the UAE is consumed in meeting air conditioning cooling demands in buildings where up to 80% of a building's total electricity demand is for cooling. [36] Another challenge is the high demand for natural resources. Since the discovery of oil in the United Arab Emirates, the country's population has risen constantly. This has put considerable pressure on the natural resources and the infrastructure of the country, which has had to provide water, food, and facilities for millions of new residents [37].

In such circumstances, directing a part of natural resources to create natural settings in schools needs a high level of awareness of the positive effects of such incorporation. In the UAE, addressing Green schools has been initiated by the Emirates Green Building Council (EGBC)'s 'State of Our Schools, which defined a 'green school' as one that 'provides a healthy environment for occupants conducive to learning while optimizing environmental performance and encouraging environmental literacy. In the context of schools, there is comprehensive research to support that indoor environmental quality (IEQ), which includes lighting, acoustics, thermal comfort, and indoor air quality, has an effect on students' health, productivity, and performance, physical and mental development. The findings of EGBC can later be used to prove adding more Biophilic design features in schools could serve not only as a psychological and cognitive enhancer, but a way for preventing damage from poor IAQ and purifying the air as well. [38] An initiative increasing the number of green schools in the country is the Abu Dhabi Urban Planning Council's "Pearl Rating System", which is a green building rating system developed by the council as part of their sustainable development initiative, Estidama. The system can be applied to all types of buildings, with different requirements for each. [39] Several efforts are seen in the UAE for fostering children's relationship with nature and raising their awareness. For example, a social enterprise in the United Arab Emirates organizes workshops for students that are adapted to their ages. An interesting initiative by the organization is the “Sustainability Learning Space”. Which is an educational space that Eedama installs at schools. This serves as an interactive sustainability and science museum with different stations designed specifically for schools. Each station tackles an item of the interaction between humans and their environment (both natural and urban). [40]

Figure **1**. An urban garden installed by Eedama as one of their projects. [40]

4. Literature Gaps

As previously mentioned, Kahn suggests that nature is not a mere cultural convention or artifact but part of the physical and biological reality that bounds children’s cognition, [22] and Kahn & Kellert’s “Children and Nature” book also pointed out the importance of children's direct experience of nature in compromised natural settings, which is further suggested by the results of studies in diverse cultural and economic locations. [26] These studies looked at the issue from a cultural and economic perspective, but little, if any, has been done to see if children’s perceptions differ with the different climatic conditions. Furthermore, the preferences of children and their personal interpretations of what natural elements they would like to see incorporated in their learning environment were rarely a focus for researchers. Another literature gap noticed is in the age groups studied for similar topics, Hand asked children to place at least 30 dots on the aerial photo interface to indicate where they spent most time outdoors; these points represented their use of the environment. The age group used for research is (5-7), researcher suggests that the results of a similar workshop would be significantly different in other age groups were observed. [21]

5. Conclusion

The aim of this study was to investigate the concept of humans’ affiliation with nature with a specific focus on children’s current experiences with natural elements in learning environments under extreme climate, and their possible preference for the integration of natural elements in their learning environments. The results of the literature review concluded that the incorporation of natural elements in our direct environments can have substantial benefits to our mental as well as physical health in general, and beneficial effects for children in a learning environment during critical developmental age. However, the review also highlighted the current gap in the literature when it comes to children’s experiences and preferences in countries with extreme climates, in this case, extreme hot climatic conditions, as well as the lack of design solutions that respond to children’s preferences as derived from the contextual specificities of the desert hot climate conditions. Furthermore, the preferences of children and their personal interpretations of what natural elements they would like to see incorporated in their learning environment were rarely a focus for researchers, calling for further focused investigations.

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Post-Occupancy Evaluation of Residential Buildings in Bahrain, Focusing on Occupants' Habits Impacts on Indoor Air Quality (IAQ).

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Abstract: An overall understanding about the occupants' habits, including their opinions regarding mechanically ventilated spaces is an important condition for improving the indoor comfort, especially in hot arid climate, where the mechanical ventilation is needed more 50% annually. In addition, uncomforted occupants tend to take actions to improve their state, which may increase the energy consumption. A user satisfaction survey assessing the occupants' satisfaction and experience was conducted for 72 participants, and a structured interview was conducted for 15 participants to evaluate their satisfaction and understand their taken actions and measures to improve their situation. This study involved two post-occupied residential unit's typologies (51 villas and 21 apartments) situated in the kingdom of Bahrain. The data collection of this study considers the user's energy consumption patterns and environmental control behavior in using ventilation systems. The results obtained demonstrated that almost 70% of the residents were satisfied and the preserved IAQ was jugged "good", or "moderate". Analyzing the data on occupants experiencing sick building syndrome symptoms revealed that almost 50% of the respondents experienced at least one of the symptoms. Furthermore, the study underlined that residential unit orientation, building and finishing materials, occupants' behavior and habits are the reasons behind their discomfort and their excess energy consumption.

Keywords: Post-Occupancy; Evaluation; Habits; Residential; Bahrain

1. Introduction

The effects of indoor air pollution on human health and quality of life are significant. it has received increasing attention from the international scientific community, and environmental governances for improving the comfort, health, and wellbeing of building occupants. It is one of the major contributors to the urgent climate change issue, as well as a major source of concern for human health in terms of indoor air pollution [1]. Indoor air quality has a significant impact on human health and quality of life because people spend more than 90% of their time in both private or public indoor environments such as homes, offices, schools, and others [2, 3]. For many people, indoor air pollution may pose a greater health risk than outdoor pollution. All occupants, especially those with chronic respiratory and cardiovascular diseases, can be harmed by poor indoor air quality. Some studies affirmed that indoor environment is composed of a mixture of outdoor pollutants that enters indoor spaces via natural and/or mechanical ventilation systems, as well as other indoor containments such as tobacco products, candles, emissions from building materials and/or furniture [2, 4]. Therefore, sustaining a healthy indoor environment is challenging throughout the life cycle of the building. This paper outlines the main indoor pollutants and containments experienced by residential units' occupants. The descriptive analysis is focused on residential units because they consume roughly 48% of total energy produced [5], and it has been confirmed that there is a significant relationship between the number of occupants, CO2 and cooling load [6, 7]. Finally, some recommendations have been made to enhance the indoor environment that will help to reduce the poor indoor air quality impacts on occupants.

2. Materials and Methods

This paper presents the results of two research methodologies known as a randomly distributed online questionnaire to 72 participants residing in Bahrain in either a villa or an apartment, and a structured interview with 15 participants divided between 10 Female and 5 males. The IAQ of the residential buildings is examined from the perspective of the occupants' satisfaction in three aspects: thermal environment, indoor air quality (CO_2 and other air pollutants), and acoustic environment.

Most residential units that were considered in this study were two-story villas or an apartment within a multiple-floors building. These units were mainly equipped with mechanical ventilation (i.e. (Spilt Unit AC or Window Unit AC), and ceiling fans. In addition, they were occupied by 4 to 6 occupants per unit for from 4 to 14 years.

The investigation was done in two stages. In the first stage, survey about the occupants' satisfaction of indoor air quality and ventilation were supplied randomly to members of Ahlia University (students and faculty). In the second phase, a structured interview questions were given to some students to conduct the interviews with their family members of the same residential unit.

2.1. User Satisfaction Survey

This paper presents the results of two research methodologies known as a randomly distributed online questionnaire to 72 participants residing in Bahrain in either a villa or an apartment, and a structured interview with 15 participants divided between 10 Female and 5 males. The IAQ of the residential buildings is

The intention of the survey questionnaire was to understand how occupants experience their current home living environment. User satisfaction surveys are widely used to evaluate the experiences, habits and responses of occupants to their indoor environment; such surveys are potent tool in research [8, 9]. The randomly selected research participants were asked to complete the online satisfaction survey when they are at home. The cost-effective survey was developed by using Google Forms online questionnaires platform and adapted after the model used by Park, Loftness, and Aziz, [10], and consisted of 20 questions including aspects of personal information, such as gender, age, period of occupancy, and number of people sharing the same unit. The focus of the questions is related to the ventilation system types in relation to the indoor air quality including sensational factors (temperature and humidity), noise, and data related to sick buildings syndrome (SBS). The survey was distributed twice in November 2020 and April 2021 considering the seasonal differences and their impacts on the indoor air quality. Of the 72 respondents, 91.7% were females between that age of 20 and 39. According to the responses of participants, most of them are living in villas, not apartments and have reside in their homes from 4 to 14 years, Table 1.

Table 1. The participants responses (personal information).

Gender	Male	6 (8.3%)
	Female	66 (91.7%)
Age	10 to 19	1 (1.4%)
	20 to 39	54 (75%)
	40 to 59	16 (22.2%)
	More than 60	1 (1.4%)
Type of residential unit	Villa	52 (72.2%)
	Apartment	20 (27.8%)
Years of occupancy	1 – 3 years	13 (18.1%)
	4 – 14 years	37 (51.4%)
	More than 15	22 (30.6%)

In addition to that the user satisfaction survey focused on the number of occupants sharing the same residential unit, the common time that all occupants stay at home (i.e., 1-3, 3-6, more than 7), factors that may affect the indoor air quality with home (i.e., environmental, and personal behavior), and sick buildings syndrome symptoms.

2.2. Structured Interview

The purpose of the structured interview was to underline the participants awareness of indoor air quality, opinions about the indoor air quality, the factors effecting the indoor air quality, the adaptations done to improve the indoor air quality as addressed in some previous studies authored by Park et al. [10], Trofimova et al. [11]. Table 2 describes the structured interview questions.

Table 2. The structured interview questions.

Q1: Are you familiar with the term "Indoor Air Quality"? **a) Yes** **b) No** ***If the answer is "No", an explanation of the term will be provided by the interviewer.***
Q2: How do you evaluate the indoor air quality at your place? *(choose 1 answer and why?)* a) Excellent b) Moderate c) Bad
Q3: What are the factors that affects the indoor air quality at your place? *(All topics can be discussed- mention the space living room, bedroom, kitchen)* a) Natural ventilation b) HVAC system c) Pollutants (CO2, Bukhoor, Air-freshener, VOC, Scents (smells) … etc.) d) The vapor and humidity e) Architecture (Building orientation, large windows, low ceiling …etc.) f) Interior finishing materials (Carpet, paint, stone, irone, curtain fabrics, furniture materials, flooring, surfaces…etc.)
Q4: What do you think can be improved in your place to enhance the indoor air quality? (free open-ended question)

3. Results and Discussion

This section will illustrate the results of both the user satisfaction survey and the structured interview which were conducted separately and analyzed together for validation purposes. A thematic analysis was used to analyze this research results to identify and interpret patterns of meaning. The resulting themes are (a) occupancy level, (b) awareness, (c) factors affecting indoor air quality, (d) sick building syndrome symptoms, and (e) suggestions.

3.1. Occupancy level

The survey results showed that most of the participants confirmed that 4-6 occupants are sharing the same residential unit, which represents 45 participants out of 72. The minority stated than 1-3 occupants are sharing the same unit, which represents 10 participants only, while 17 participants indicated that more than 7 occupants are sharing the same residential unit. The overall results indicates that Bahraini residents tend to live in groups sharing the same unit. The interview outcomes confirmed that many of the participants are staying together with their families regardless of their marital status. Addition to that, sharing the same residential unit may have a noticeable impact in saving energy as more than 65% of the electricity used in households goes for the AC use [12]. Therefore, if the number of occupants is increased within the same residential unit, it will consequently contribute to the overall CO_2 emission reduction, which has a significant impact in the air quality. Moreover, the survey results presented that "Evening" is the time were all the occupants be at home, Figure 1.

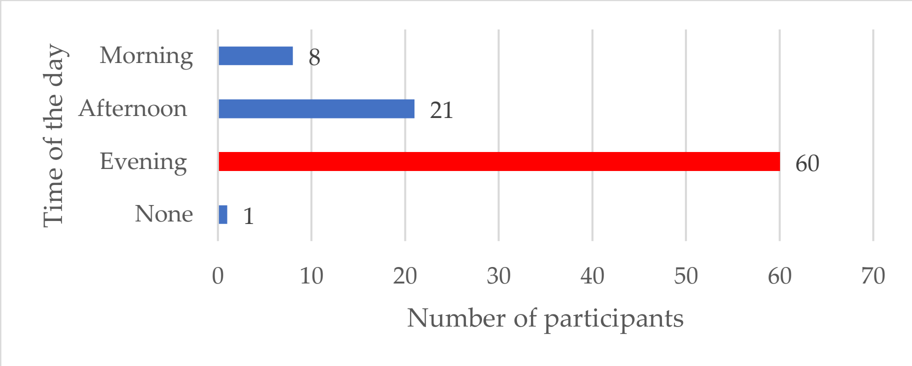

Figure 1. Time that all residents be at home, survey results.

3.2. Awareness

Of the 9 (61%) participants confirmed their familiarity of the "indoor Air Quality" terminology, Figure 2. In this regard, some of the participants demonstrated a high interest in the topic of indoor air quality and acknowledged its importance in enhancing the human health and comfort. Since, that some of the participants were interior design student, the question receives a significant attention as the indoor air quality maybe affected by indoor finishing materials and furnishing, as well as occupants' behaviors and activity, as stated in some previous studies [7, 10].

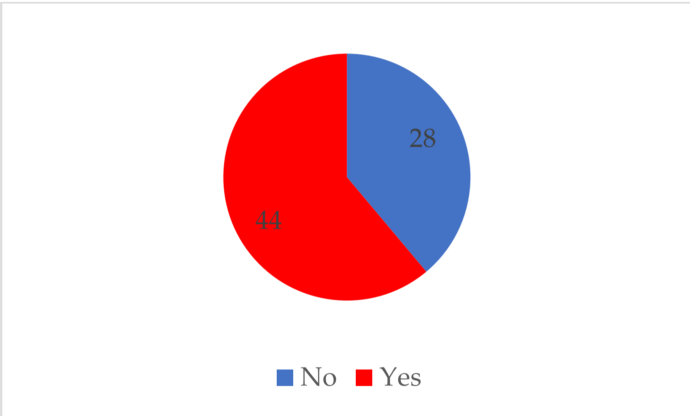

Figure 2. Participant's awareness level, Survey results.

On the other hand, the interview participants seem to have less awareness about this scientific terminology, yet most of the participants underlined that green buildings may contribute to enhancing the life quality of individuals, health and safety [13].

3.3. Factors affecting indoor air quality

Several variables, including environmental factors, architectural design, and personal behaviors. The survey results indicated that using air freshener and bukhoor "burned scents", and smoking cigarettes and shisha are the main personal behavior observed by the occupants themselves within their households, Figure 3.

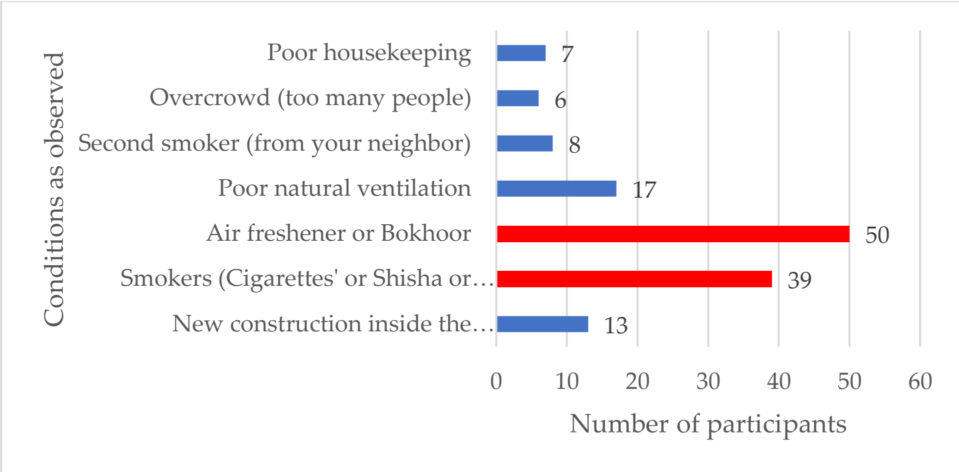

Figure 3. Conditions as observed by the survey participants.

During the interview, number of participants indicated their moderate satisfaction about their residential unit. Some participants indicated the high temperature and excess daylighting within some of the spaces, and their discomfort to use such spaces (i.e., Livingroom and kitchen), this is related to the building orientation. While others indicated the issue of having a constant using of incenses (i.e., Bukhoor), which is related to personal behaviors. Finally, some indicated the problem of odors within their residential unit, many from the kitchen and toilet, as well as from the air conditions. The odor from the wet areas is mainly related to the building architecture and building orientation. While the odors emitted from the AC is mainly due to the lack of cleaning and continuous maintenance. Some previous studies underlined that odors project from AC indicates the air is highly polluted by COx, NOx, VOC, and particulate matter, [14]. The indoor air pollutants could cause acute health problems, that need to be accounted from the first phases of design [2, 15, 16].

3.4. Sick building syndrome symptoms

The survey participants indicated that they complain with symptoms associated with discomfort mainly due to headache, dry or itchy skin, dizziness and nausea, Figure 4. In addition to that, other symptoms such as nose, throat, and eye irritation.

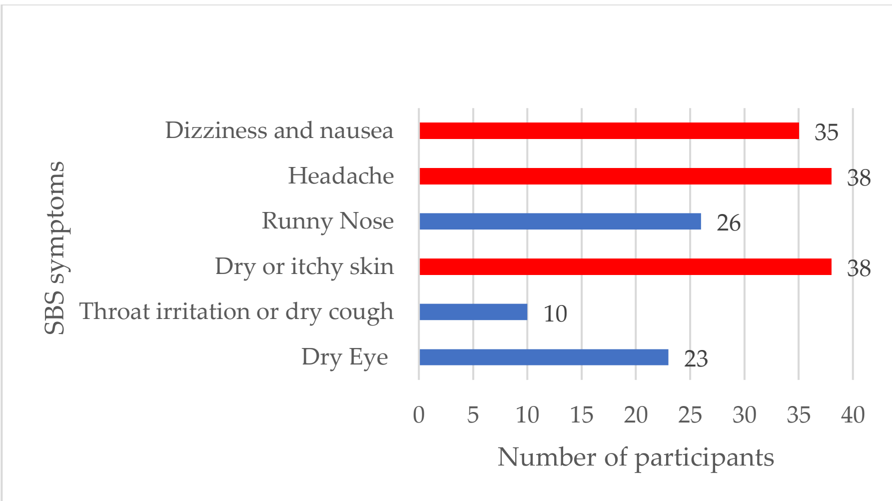

Figure 4. Participant’s Sick Building Syndrome symptoms, Survey results.

Equally, some of the interviewees indicated that such symptoms especially were found in their bedrooms after a long night sleep, some stated that it is mainly from the air conditioners. Similarly, it was discovered that using air conditioners while sleeping resulted in a significant build-up of carbon dioxide for all types of air conditioners [17]. Also, some interviewees specified some discomfort at bathrooms and kitchen such as dizziness and nausea, but they were not sure what are the causes of such discomfort. Some previous studies claimed that pollutants from the outside, such as those emitted by plumbing vents, and building exhausts, can enter the building through poorly placed air intake vents, windows, and other openings [18, 19]. It is anticipated that such discomfort is also related to the building orientation because some of interviewees were asked to check and send the orientation of the spaces of discomfort, and it was confirmed that bathrooms or kitchens located in the south of south east suffers from lack of ventilation and causes discomfort and irritation. Other interviewees reported some discomfort related to eye and through irritation of newly moved spaces due to the paint and new furniture. Finally, 55.6% of the survey of the survey participants and about 60% of the interview outcomes agreed that such symptoms are dissolved after leaving the space, as confirmed in previous studies [17-19].

5. Conclusions

Other than the known variables qualified to indicate the thermal comfort and indoor air quality such as the temperature and the fresh air intake, this paper presented an overview of other variables extracted from the residential unit orientation and its impacts on the air flow and movement, the building and finishing materials that may cause some indoor air pollutants due to its porosity and permeability nature, as well as the personal habits such as smoking tobacco or burning aromatic scents, known as "bukhoor". Altogether, were hypothetically seen by residential units' occupants as the main reasons for their IAQ discomfort. Therefore, improving the occupant's health and wellbeing should be the targeted goal of any future developments.

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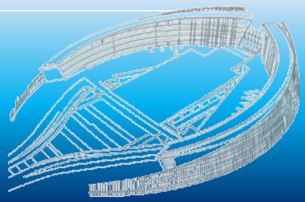

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Mass Customization of Housing: Towards New Systems and Machines

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Abstract: Integrated processes for design and fabrication have paved the way for mass customization of architectural components and systems. Housing, a vital sector in the building industry, is a multifaceted process that witnessed various manifestations towards individualization over the past few decades. Nowadays, design flexibility in housing systems is becoming a crucial aspect, informed by consumers' lifestyles, demographic patterns, and lifecycles change at a rapid pace. As the housing market demands more efficient and agile strategies, prefabricated building systems have always offered a viable alternative for flexibility and customization, following a renewed surge of interest in the last decade focused on new modes of digitized design and production. This paper presents a framework for potential implementation of mass customization in the prefabricated housing industry. The framework stems from a critical analysis of previous research efforts with specific focus on enabling design and fabrication technologies. Additionally, the framework offers an open model that could accommodate continuously evolving design and production technologies.

Keywords: Architecture; Housing; Prefab housing; Mass customization; Design and fabrication technology.

1. Introduction

Industrialized building systems, prefabrication of architecture or off-site fabrication of sub-assemblies generally employ some strategy of modularization though different scales of components to achieve some type of adaptability and personalization. In architecture, the fertile partnership between Gropius and Wachsmann for the General Panel House Corporation exemplifies how component modularity allows one to imagine a multitude of design options from some simple basic additive or subtractive choices component-based ranges [1].

The building industry today is highly industrialized; it offers complete customization potential without any strategic link to rationalization of system building. Architects and builders pick and assemble continuously produced components (doors, windows, beams, finishes, etc.). This high level of custom building infers a perceived uniqueness of buildings, which repeat a highly inefficient design and construction process for each building generating waste and loss of productivity.

The desire for an industrialized building process that optimizes construction efficiency, costs, mass-production while offering potential for personalization has spanned eras. Modernity in architecture proposed the union of architecture and industry through variable component building systems. Mass production, wartime technological advances and post war building programs created the conditions for rapid expansions in modularity and repetition to the building industry. In architectural theory, modularity became synonymous with the potential to create variable architecture from a set of systemically coordinated parts. From Gropius and Wachsmann's packaged house, to Walter Segal's self-build house to Ken Isaac's living structures, designers sought to combine the advantages of mass production with architecture's need for singularity and uniqueness [2]. Dimensional and modular coordination first proposed by Bemis in the 1930s is still the framework for applying modularity in architecture.

Along with the rise of computer technologies in the 1960s, the notion of diversity, difference, and individuality in production of consumers' good emerged, with the aim of offering an alternative to mass production. This new paradigm directed a shift in various domains and was thought of as potential player to inform new systems for quality mass housing. Toffler's 1970 book "Future Shock" anticipated these changes as technological capacities, and he further described them as a "third wave" in a subsequent study [3]. Also referred to as mass customization by Stanley Davis in his 1987 book "Future Perfect" [4], this process was formally systematized by Joseph Pine in 1993[5].

Many segments of diverse industries have been shifting their business model towards greater customization in response to increasing consumer demand. The ability to achieve a certain level of customization has percolated investment goods such as machinery and telecommunication systems to consumer goods such as cars, furniture, personal computers and watches. Given the principle importance of customer satisfaction, and the new type of informed marketplace, the implementation of such a production strategy has proven attractive to companies seeking to remain competitive.

Pertaining to the building industry, mass customization seems to hold a great potential as buildings can become unique and highly customized products. However, the building culture including the prefabricated housing industry, which is the focus of this research, has been relatively slow in adopting new strategies. It has alternatively opted for developing a model based on either custom design, or model repetition.

Mass customization of housing aims at shifting standard production practices towards customized typologies, enabled through clearly defined design and production parameters. It is argued that recent applications of digitally integrated processes in the form of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) have resulted in a paradigmatic shift in production ideology. Individual building components can now be mass customized in ways previously considered impossible. This method permits optimal variance in response to differing local conditions, such as uniquely shaped and sized structural components or variable openings [5].

While prefabrication is widely considered to be a viable approach to achieving mass customization, the industry has been facing challenging limitations in the past few decades that have inhibited the complete adoption of such an approach. The prefab housing industry has been challenged with age-old connotations associated with repetition, low quality and flawed designs. It is believed that mass customization could offer a new way forward, as its principle purpose is the production of high-quality housing at an affordable cost. This standard of quality relates not only to the level of user satisfaction in terms of basic housing needs, but also to the functional and aesthetic criteria of a house, achieved through the integration of advanced production techniques that deploy computer-aided manufacturing processes to manage waste.

This paper presents an open framework for the mass customization of prefabricated housing, with focus on technological enablers. In order to build up the framework, the paper first highlights a series of research efforts and industry applications that tackled mass customization of housing from various angles, leading to identifying some limitations. Then, we conduct a systematic approach to develop the framework with focus on technological enablers in design and fabrication, ones we consider crucial for successful implementation of mass customization. Finally, the proposed framework is recognized as an open model that could accommodate ever developing design and fabrication technologies.

2. Mass Customization in Architecture

Mass-customization in architecture is considered as an industrial by-product designating adaptable and flexible models of production. This adaptability encompasses the capacity to oblige individuals' desires within a system articulated to production agility. Architecture and mass-customization strategies are connected through industrialized building systems as these systems imply a business model of mass production combined with a model of building variability through some type of modularity, either dimensional, systemic or a combination of both [1].

Recent research efforts and industry applications exploring the realm of mass customization in architecture has been primarily focused on technological enablers in the form of innovative computational design processes and digital fabrication tools. For instance, new modes of collaboration such as BIM (Building Information Modeling) and parametric design have paved the way for more control over the building process through supporting the notion of integrated design and file-to-factory protocols. These technologies allow for flexible collaborative environments to increase efficiency in the design, fabrication, and assembly of components [6].

One major challenge in applying mass customization strategies to architecture relates to the evaluation of the flexibility of the product, and the way it is built. It must be concurrently customizable, properly designed, in concordance with design codes and regulations, and accurately manufactured. Consumer products are usually modularized in a way that partially limits customization due to technical constraints [7]. However, the field of architecture is distinct in its networked structure. In the design, production and verification processes of creating a building, there is usually no single party that has the necessary specialization in all areas to manage such a project [5]. Accordingly, in order to realize a mass customization design and fabrication environment, a high level of communication between users, designers and manufacturers must be shared and integrated. Fragmentation poses a major obstacle, as fabricators in the building industry generally consist of small- to mid-size companies whose production volumes are normally insufficient for generating the economy-of-scale effects of the modularized production setting in a typical mass customization model.

Richard [8] defined four significant aspects that serve to enable mass customization in architecture:

- Flexibility of the product: Concerned with the spatial variations of the product while in use. This could be achieved through the use of movable/demountable partitions, mobile 3-D functional modules, and interchangeable exterior envelope panels.
- Flexibility of the tool: Concerned with the ability of the tool to become the generator of diversified products, by operating on different levels. This includes cutting- edge digital manufacturing techniques.
- Multipurpose framework: Concerned with product platforms that could accommodate different options, either through the addition of particular components, or the introduction of secondary modifications.
- Combinability: Defined as the possibility of generating a multitude of combinations from a set of standard components produced in a large quantity. This concept operates through modular coordination and simple interfacing rules for the joints.

These aspects were derived from general theories and approaches to mass customization and situate the user, designer, and manufacturer in a complementary relationship via either direct or indirect communication. However, buildings can be considered to be singular products, whose design involves typological, cultural and social aspects that have yet to be robustly accounted for by the customization process.

2.1 The case of housing

There have been several successful research efforts exploring the potential of utilizing advanced computational design protocols to go beyond a straightforward application of custom-build housing. These explorations tackled the concept of mass customization from a critical angle, looking at the level of customer involvement with the aim of proposing a process model to include homebuyers at an early stage of the design process. The literature review on the mass customization of housing reveals heterogeneous concerns, where some approaches focus on the link between design and production, and how digital collaborative environments and emergent fabrication techniques could support the delivery of customized housing and others examines various fabrication tools and machines to enable efficient production of products with remarkable variations. Within this diverse milieu, some particularly pertinent research is highlighted here.

One of the early efforts is the work of Duarte [9], reflecting on his extensive analysis of Alvaro Siza's mass housing project in Malagueira, Portugal. Duarte proposed a comprehensive model for the mass customization of housing, built around an interactive computer program that generates housing designs following a given language. The design system used description and shape grammar as technical mediums for coding design rules. Later on, Duarte [10] [11] presented different versions of his work that looked deeply into the computational model.

Along with a rising awareness of the internet's potential as an interactive medium that might be applied towards the customization of prefabricated housing in the North American market, Huang [12] developed a model to support homebuyers' participation in the design of their dwellings, based on a decision support system. This model employed an interactive questionnaire that guided users in a sequential process towards finding the appropriate solution, relying on a catalogue of prefabricated modular housing systems. As housing prototypes were built in BIM software, a library of housing variants with coordinated modularly was established, allowing for interchange of components.

Pertaining to the linkage between design and production, which is considered a crucial element when implementing mass customization, Benros and Duarte [13] proposed an integrated model that combines a design system and a prefab building system to generate customized designs allowing for production. To achieve such integration, a computer program was implemented for customers to explore and visualize of design solutions and the subsequent automatic data generation required for production. Rules for both design and construction were systemized and then encoded into the computer program.

In a unique approach, Puusepp et al. [14] proposed an online configurator prototype to involve homebuyers' in the design of prefabricated homes. The process starts with offering architects the ease of creating configurable models using BIM/CAD, combined with a decision support system for spatial configuration, and a pricing module. Clients can then access the model via a web-based configurator and customize the design, while getting live feedback about geometry design, energy efficiency and cost articulation. However, choices are outlined and limited by the architect. Finally, the configuration data is then sent to the architect for verification, and recreation of the configured mode in the preferred design software. Additional research efforts include Larson et al. [15], and Niemeijer et al.[16] , Carbone and Eid Mohamed [17] , TT Lo, B Mohamed, and MA Schnabel [18].

Pertaining to prefabricated housing industry, a number of successful global practices explored the potential of establishing collaborative partnerships with architects, computational specialists, and fabrication technologists towards advanced design and manufacturing processes in response to market demands, with focus on affordability, durability, and the social and cultural needs of homebuyers. These efforts explored primarily the application of internet-based configuration systems as means of effective communication with homebuyers.

Online configurators integrate interactive systems for participatory design via web technology, situating the online interface as the foremost site of contemporary design platforms. This networked platform engages customers in the design of their homes through a sequence of decision-making processes that ultimately lead to efficient customization. Various housing manufacturers in Europe, Japan, and the United States, following similar applications in the automotive, clothing, and computer industries, have implemented this approach.

Commonly, prefab housing companies engaged in this field tend to build and invest in databases of variable housing prototypes, which are searchable by type, area, average cost, and number of bedrooms. Once a housing model is selected, homebuyers are able to access an online customization tool that offers selections of different exterior/interior finishes, roof styles, and systems. Some pioneering examples of companies implementing online configuration system in the US housing market include livinghomes, *bluhomes* and *connect-homes*. Figure 1 represent a screen shot of the customization model developed by the two companies. While *livinghomes* used a static website that relies on pre-rendered images, *bluhomes* developed a 3D environment that homebuyers can navigate interactively to walk through the housing model, and customize various features.

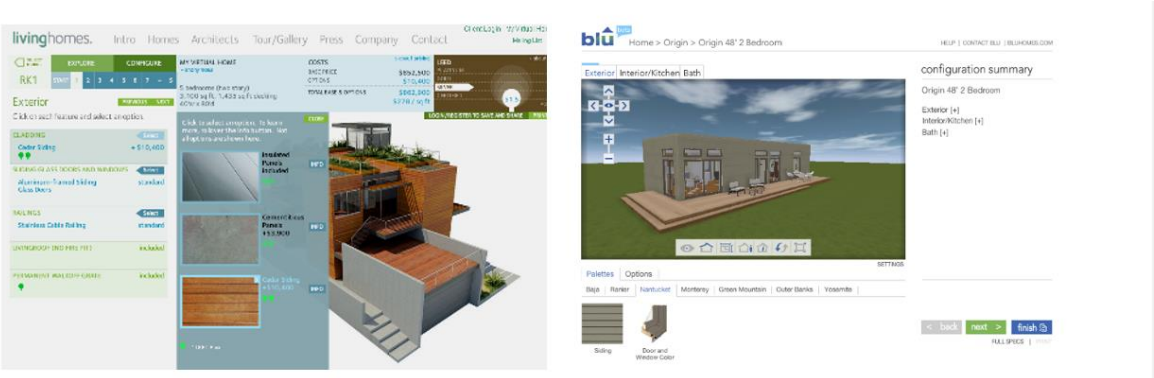

Figure 1: A printscreen of the configuration system by two companies in the US market, Livinghomes and bluhomes. Livinghomes employs interactive visualizations that respond to customers' choice. Bluhomes system used to rely on a 3D plugin that users download to navigate and customize the selected housing model (Source : http://www.livinghomes.net/configure.html?model and http://www.bluhomes.com/homeconfigurator/).

2.2 Mass customization of housing: challenges and opportunities

The review of various research efforts and industry applications highlights the fact that interest in the mass customization of housing emerged as logical consequence to significant developments in digital design and fabrication technologies, coupled with demand for personalized products. Such developments offered an opportunity to orchestrate a connection between homebuyers, information, and tools in a comprehensive manner, thus leading to a set of methodologies and approaches to facilitate the implementation of mass customization in architecture and housing. However, it is evident that the housing industry has been reluctant in implementing such a strategy, manifested in the gap between available technologies and ones adopted by buildings and prefabricated housing

Throughout the past decade, some prefab housing companies across North America, Europe and Asia have invested to implement mass customization through application of online configurators. Commonly product configurators rely primarily on providing homebuyers with different alternatives in spatial layout, external or internal finishes, and then offering them to make decisions. Homebuyers can select from a range of layouts A, B, or C, kitchen blocks A, B, or C, an optional extra garage or even an extra story. While such a trend is viable, yet we argue that it is subject to considerable limitations as developing a wide range of design variations could be considered an exhaustive process, especially when aiming to respond to wide choices, and be efficiently fabricated can become. As a result, the number of alternatives in some cases has to be kept limited to three or four options to avoid additional overhead cost, and spare homebuyers the confusion that could be associated with the decision making process.

Given the continuous development of technological enablers for mass customization in the form of computational design systems and fabrications tools, we argue that it is important to rethink the process based on various research efforts that have highlighted the role these technologies could play. Additionally, we aim at putting homebuyers at the forefront of the process, while considering companies capabilities to adopt customization. Finally, the proposed framework in the following section tends to be structured as an open model, thus accommodate ever changing technologies , without being limited to a specific method.

3. An Open Framework for Mass Customization of Housing

Mass customization approaches and strategies are classified according to the level of customer involvement in the value chain. Salvador et al. [7] argued that there is no one ideal way to adopt mass customization, even if one is following successful business models. In fact, companies should adapt their mass customization strategies according to intensive market studies, customer requirements, product flexibility, and accessible design and production technologies. Even though the fulfilment of these factors is critical, it is still not adequate condition to guarantee mass customization success.

Given the disparity between previously mentioned extant research efforts and industry applications, the following section proposes a comprehensive approach for the mass customization of housing, in the form of a system framework that can be pursued by prefab housing companies to enable homebuyers' participation in the design of their dwellings at the early design stages.

The proposed framework relates to a multidisciplinary process that involves handling large amount of information. While it could be argued that the three main active participants in the customization process are the homebuyer, architect, and manufacturer, yet the process requires different levels of expertise in system theory, computational design, user interface design, and fabrication technology. In that sense, we believe that the proposed framework emerges as the logical consequence to a thoughtful understanding of to mass customization strategies, prefabricated housing systems, computational design tools, in addition to extant efforts towards the implementation of customization in the housing industry.

The proposed framework is structured based on three main stages:

- **Stage I:** Aims at clarifying the process by which the mass customization model could be structured based on identifying the various levels and activities that are involved. The process in initiated by defining the problem which is basically relevant to identifying the level of customization. Tseng and Piller [19] identified four phases at which customization can occur: design, fabrication, assembly, and delivery. While the lowest level of customization happens when customers are only involved in delivery phase, the highest-level means involvement in all four of them. Pertaining to the proposed framework, and its relationship to housing design process, we identified five points at which homebuyers' involvement relates to the level customization as shown in figure 2. In that sense, the level of customization is defined by the freedom of decision making offered to homebuyers. It is also devised by the company's technological capacity, and readiness for customization. As per previously analyzed industry application, we argue that common application of mass customization has been limited to the lower end in the hierarchy chart presented in figure 2 (layout alternative selection, internal and external appearance of the housing unit).

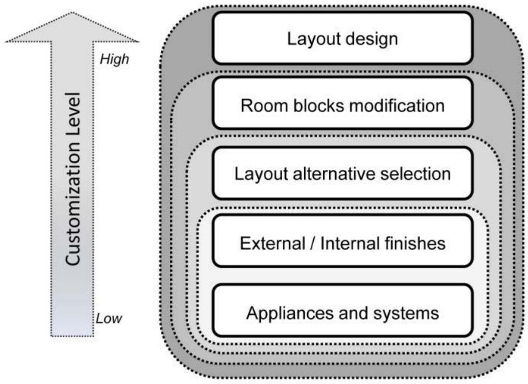

Figure 2. Levels of customization in housing organized sequentially from high to low based on point of homebuyers involvement in the design of their homes. It represents the level f decision making offered to homebuyers.

- **Stage II:** Explores the process of selecting a methodology to devise a solution to the formulated problem. Based on the company's technological capacity, available means of communication with architects and clients, in addition to the desired level of customization, two paths could be devised. On the first hand, homebuyer's involvement in layout design dictates the application of a computational process in the form of a generative design model that can produce housing design solutions based on homebuyer's data, construction parameters and constraints. Such a process requires identifying relationship between homebuyers' preferences, design data and site inputs, in addition to establishing the generative algorithm model. On the other hand, room blocks modification can be implemented through an interactive configuration system, which would allow homebuyers to make choices from a predefined set of choices. Typically, the main components of a configuration system are the database and the configuration logic. While the database comprises the whole set of component types and their instances, the configuration logic identifies the existing constraints between different components, to ensure valid product variants.

- **Stage III:** Focuses on implementing the design system and verifying its capability to deliver design solution in response to the selected customization path, and in compliance with the requirements defined in the preceding stages. Implementation will follow once the system is clearly articulated and understood, and thus specific generative tool or configuration logic has been elaborated and verified. At this point, the system operator and degree of automation can be also defined. Implementation would require multidisciplinary expertise in areas of design computation, BIM, prefabricated building systems, and user interface design.

Figure 3 illustrates the different stages of the proposed framework and represents the concepts required to build the design system as described earlier. We believe that each stage could be further developed independently, given that there there are several points of interaction within the framework according to technological applications.

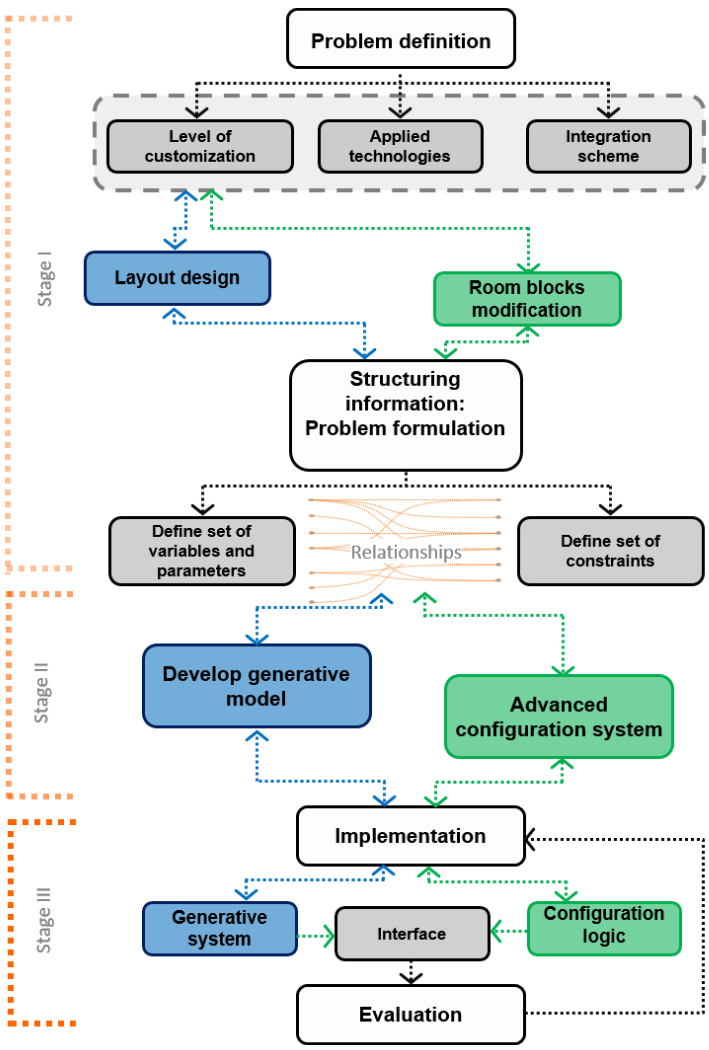

Figure 3. A diagrammatic representation of the design system framework demonstrating the various phases: problem definition, formulation, design generation/configuration method, implementation, and evaluation.

3.1 New tools and machines

Over the last decade, there has been a remarkable development in generative design tools, coupled with new modes of fabrication. From adaptive generative design tools, to large- scale robotic fabrication, such emergent technologies have paved the way for a new paradigm to effectively implement mass customization in architecture, and specifically housing [20].

Typically, generative system are implemented with the aim of producing of a variety of potential solutions to a specific problem. It is an approach to developing applications that can generate, evolve, or design objects, architectural structures, or spaces autonomously, relying on concepts such as Artificial Intelligence (AI) and Machine Learning [21]. As mentioned earlier, integrating generative tools towards mass customization of housing has been explored as a core component within a design system, with the aim of generating design solutions in response the homebuyer's profiling process. Considered as one of the early efforts, Larson et al. [22] highlighted the notion of using generative tools towards customization, referring to three crucial enablers for customization: preference engine, design engine and production engine. While such an approach raised questions regarding design system operator, and where/how homebuyers could interfere in the application, recent development of digital design and fabrication tools could offer a promising insight on the capability to adopt such an approach in the near future. .

On the one hand, integrated generative tools are becoming more accessible, where design solutions could be generated based on simple input of design parameters and constraints. On the other hand, the remarkably growing role of industrial robots in architecture has inspired research groups in academia and architectural practices to reimagine the role such technology can play the building industry. From bricklaying, components assembly to large- format 3D printing, industrial robots have proven the ability to offer a new paradigm in construction given their tremendous possibilities. Ideally, fabrication machines can be integrated withing the design logic, thus offering a model for production of customized building components. In that sense, Figure 4 represents a reinterpretation of the previously described framework, while considering integrating state of the art technologies in the process.

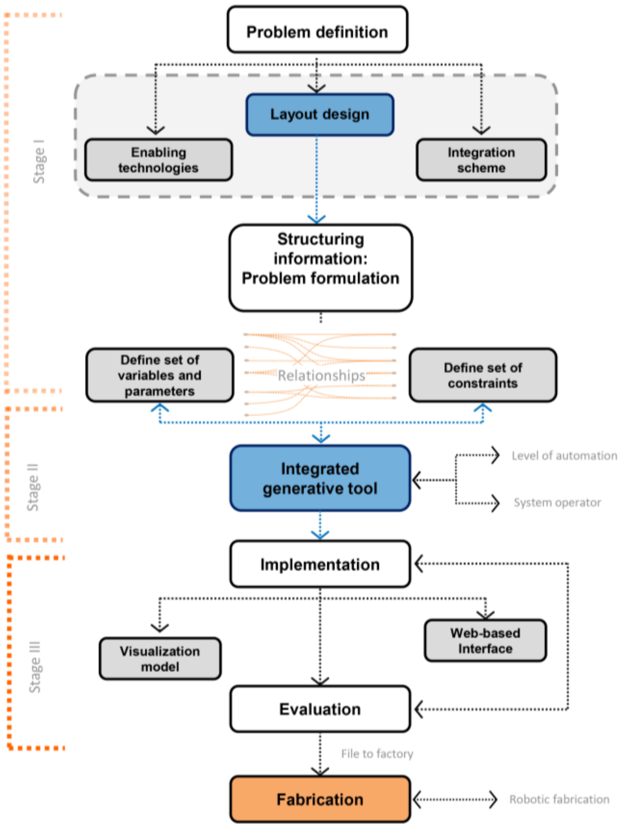

Figure 4. A diagrammatic representation of the proposed mass customization demonstrating the various phases, thus reflecting on previous efforts, and considering emergent design and fabrication technologies.

4. Reflections

Based on the analysis of research efforts, as well as industry applications, two approaches to mass customization systems in housing could be identified. First, research on the mass customization of housing reveals remarkable interests in advanced computational design and fabrication tools, and exploring their potential in enabling customization in housing. While computer-based design systems were proposed based on their capabilities to generate housing layouts in response to specific homebuyers' input, other efforts focused on the role of integrating numerically controlled machines for efficient production. Second, the prefab housing industry encouraged by wide application of information technology, manifested in internet- based configuration models that provide choice-making platforms.

As a result of studying various approaches, it could be argued that mass customization of housing is a remarkably complex process that requires orchestrating a digital platform that could bring homebuyers, architects, and manufacturers together. Today's digital design and manufacturing technologies are reforming design thinking, and altering the way buildings take shape, thus paving the way for effectively implementing customization on a wide range.

The proposed framework in this paper aims at offering a systematic approach that prefabricated housing companies can pursue towards implementing mass customization effectively, rather than celebrating the production of custom homes. It aims at devising a model that could potentially bridge the gap between research efforts, and current industry practices. The framework takes advantage of recent developments in design and fabrication technologies, while maintaining a robust understanding of the various dimensions of mass customization. In that sense, the proposed framework establishes a model that builds on previous efforts, while being flexible to accommodate future endeavors.

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Design of Library Extension Featuring a Parametric/Dynamic Façade and Integrated with the Landscape in UAEU Campus.

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Abstract: The building industry is in constant change and UAE is a leader in innovative solutions for green buildings. The standards used in achieving sustainable buildings such as LEED, Estidama have contributed in building structures that reduce the energy consumption. The strategies applied in a building in order to have low energy consumption vary depending of the region and climate. In UAE, a country with hot arid climate, these strategies have relevant importance.
The aim of this study is to investigate dynamic/parametric façade in a new building, to be built in the city of AL Ain, United Arab Emirates University Campus. The new structure is an additional Library Building (with additional function to the current building). The building follows the Estidama Pearl Rating System. The architecture has to consider the heritage of UAE and adapt to the current landscape. The building analysis includes: flexible internal spaces, passive architectural solutions, structural system adapted to the building function, connection to the surrounding building architecture and the urban tissue. The project follows Estidama 2030 standards.
New softwares such as Rhino and plug ins like Grasshopper make possible calculations of parametric façade that previously were proven difficult to apply. Dynamic/ parametric façade optimizes the solar gains in the internal spaces. The study of the materials of this façade is the second relevant focus on this study. Due to the new technologies now available for the mass use (3D printing technology), advanced innovative materials is possible to achieve the Estidama targets more efficiently. The construction period considered for the full project is one year. This constrain makes the project challenging and impacts the payback period of the advanced façade.
Based on the results, the solar radiation analysis helped identifying the areas of the façade where the parametric structure will be applied, as well as the specific design, openings, time of the day where the openings will adapt to minimize the energy loss in cooling. This research brings innovative thinking in terms of the technology used in calculating several parameters for the advanced façade, materials used for the application of this façade, building construction time/cost management.

Keywords: parametric architecture, energy simulation, LEED, Rhino, Grasshopper.

1. Introduction

It is defined as the use of complex shapes and curved geometry with material optimization or design iterations integrated with the functional process. Parameterization allows the integration of envelope, shape, and performance variables in one single and transparent process, making it difficult to separate them. The reliance of computational strategies to the design process and to enhance that process by encoding design decisions using computer power and language, and through Building Information Modeling (BIM). The outcome is a graphic representation of the steps required to achieve the end designs. It is also known as responsive façade, and it is a building exterior that can change in response to its surrounding environment to maximize its performance. The façade helps in controlling the interior environment within the building to minimizes the energy consumption of building services systems. The reliance on cooling and ventilation systems, as well as artificial lighting and energy requirements. Some dynamic facades also include methods for generating energy like solar energy.

By utilizing dynamic and parametric façade technology, the design project of the library extension will gain certain advantages. Aside from aesthetics, functionality, and computerization help in making a high quality, innovative product, and in managing complexity.

A parametric/dynamic façade forms an integral part of the building aesthetics and building performance that follows a design and engineering approach, which is where the disciplines of art and science meet. The key characteristic is the ability to manage the energy flows through the building envelop by regulating, enhancing, attenuation, rejection, or entrapment. There are several factors to be considered when designing a parametric/dynamic façade, which are the topology, type of control system, parameters of control and targets, and movement of the façade components and automation.

A solar insolation analysis should be conducted to identify the intensity points of the sun angles and radiation, with and without the designed façade.

The first case study King Fahd National Library and its objective is analyzing the façade, structure, and functional spaces to relate to our library extension design. King Fahad National Library is located in Riyadh, KSA. It was an already existent public library that has been renovated by Gerber Architekten in 2019. It has an area of almost 60,000 sqm and accommodates more than 150,000 books. [1]

The second case study is La Bib Public Library and its objective is mainly to analyze the floor plan and interior spaces to help in the area program and space organization. La BIB Public Library has been constructed in Dunkerque, France in 2019. D'Houndt+Bajart Architects & Associates is the designer of this 3,870 sqm building. The concept is basically an indoor landscape by creating long green sets of benches which attracts visitors to walk along the space. [2]

The third case study is District of Columbia public library has been established in Washington in USA during 2011. The Freelon group architects is the designer of this 21472 ft^2 sqm library. The objective of the case study is mainly to analyze interior spaces to help in the area program and space organization as well. The building is designed is to provide sunlight and view to the building and to prevent heat.[3]

The fourth case study's objective is mainly to analyze energy consumption and functional spaces. Free University's Philology Library has been established in Germany specifically in berlin. Norman foster + Partners designed this 151, 560 sq ft library and it includes about 700,000 books. The Aim in the design of systems was a building that could be largely naturally ventilated & tempered gently.[4]

Al Bahar Towers are office buildings that utilized a smart, dynamic façade and shading system. The shading device is inspired by the traditional Islamic lattice of parametric geometry. Principles of Bioinspiration, regional architecture, guide-grid and performance-oriented technology were interpreted withing the concept.[5]

The Kiefer Technic Showroom, located in Austria, incorporated a user-control façade made from 122 perforated aluminum panels with upgraded insulation, EIFS white plaster. The façade is electrically driven with Sunscreens: folding elements made of perforated alum, electrically driven. Each panel is connected to fixed motors that allows the panels to fold and rotate.[6]

Arab World Institute in France is designed by Jean Nouvel Atelier and built in 1987 in Paris. The institute has adapted a 30m x 80m responsive façade that is inspired by the Mashrabiya. The façade is composed of 113 panels with 27,000 diaphragms, operating on the principle of a camera lens to control the penetration of the sunlight. It combined traditional Arabian architecture style with high-tech style.[7]

Based on the above literature examples, it was found relevant to investigate further in a dynamic/parametric application on a façade of a library building in the climate of Al Ain. The typology of the building analyzed in this study is largely used in university campuses around UAE.

Therefore, the findings of this study with innovative structures might be relevant to reach the sustainability goals set by UAE government.

2. Methodology

The methodology follows a linear approach. The study starts with a detailed site analysis. The data refers to the information taken from the United Arab Emirates university. All the plants are carefully categorized in order to sustainable re-use them in the project. The surroundings building architecture is also analyzed in order to connect the new building in the architecture. The climate analysis then is also carefully studied in order then to design a building that adapts to the climate changes of the city. The project design uses an organic language and the connection with the surrounding greenery was a priority. The different design concepts are developed thru software such as REVIT and RHINO/ Grasshopper. The adaptability of different software helped reaching the level of analysis showed in this study. The main steps followed in the study are:

- Site analysis and program definition,
- Climate analysis,
- Architectural and structural project,
- Parametric/ Dynamic Façade.

2.1 Site analysis and program definition

The site location and surroundings is shown in (fig2.1). Site analysis has been done as shown in (fig2.2) and decisions has been done based on the study. The soil type here is Tropopsamments and has low dunes and a range of suitability. The soil is not very strong but there is no special treatment needed for the soil. Our decision is to use a type of specific foundation which is shallow foundation, and this will achieve the requirement. In the topography part we will have a flat land and no hills. This area is totally straight and has no bumps or hills. According to the existing landscape elements, construction may cut existing trees and remove water bodies. We can Take advantage of greenery and Integrate design with some of the greenery existing. There is no pedestrian access to site for students, student access is only through the library. However, there is buss access, and some staff entries could be used for students as well. The space is enclosed by a fence that must be removed and we must provide new students entry. Since the site surrounded by building, the only source of noise is the bus sound. So, we will provide sound insulation in the building and adding some fountains to reduce the amount of noise surrounding the space.[8]

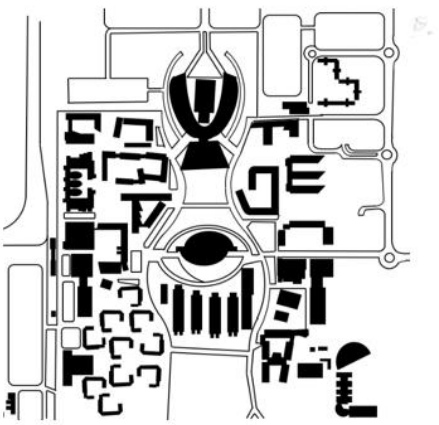


Fig.2.1 Urban Fabric

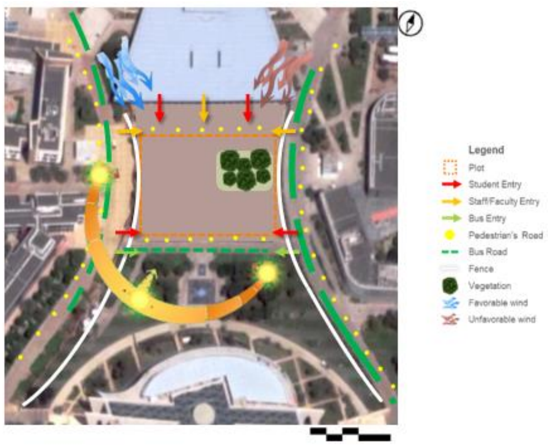


Fig.2.2 Site analysis decision map

The existing UAEU Library has been analyzed for its structure, spaces, and areas. In order to help us in the library extension area program and to analyze necessary or unnecessary spaces in the extension. The UAEU existing library has spaces including café area, carrels in the beginning of the left entrance arrow in the red color (fig 2.3). The reading area is the most used space in that building.

At the second main entrance into the library the reception will be in the beginning in case of any question or help. At the south east, the library will have common spaces, meeting rooms and kitchens. Finally, the doors placed on south east takes us to the site we are analyzing. The library is considered a long span structure, with a structure system of steel post and beams. Steel columns are 0.15m x 0.15m, and their spacing is 16.8m. The structure shows according to the horizontal and vertical grids shown the columns. The library structure is a very symmetrical structure that makes it easier for the load to be handled.

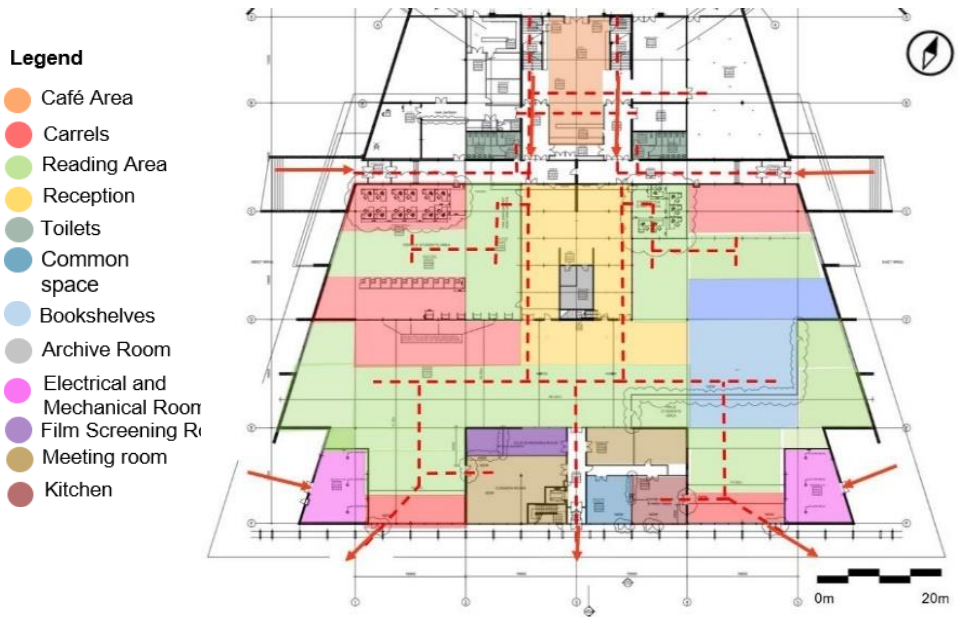


Fig.2.3 UAEU existing library floor plan study

2.2 Climate analysis

Generally, United Arab Emirates has a hot climate, the temperature in most months is higher than comfort level and annual temperatures as shown in (fig2.4). For that, design a parametric/dynamic shading device would help in reducing solar gain and appropriate materials that follows sustainability codes (Estidama) will be used in our building. If we turn to humidity shown in (fig2.5), in general humidity levels are low, so we will utilize cooling strategies, active or passive. Moreover, there is high levels of radiation annually shown in (fig2.6). Thus, we will use radiation for solar energy generation as shown in (fig2.7). Illumination levels shown in (fig2.8) is a guide for lighting design.[9]

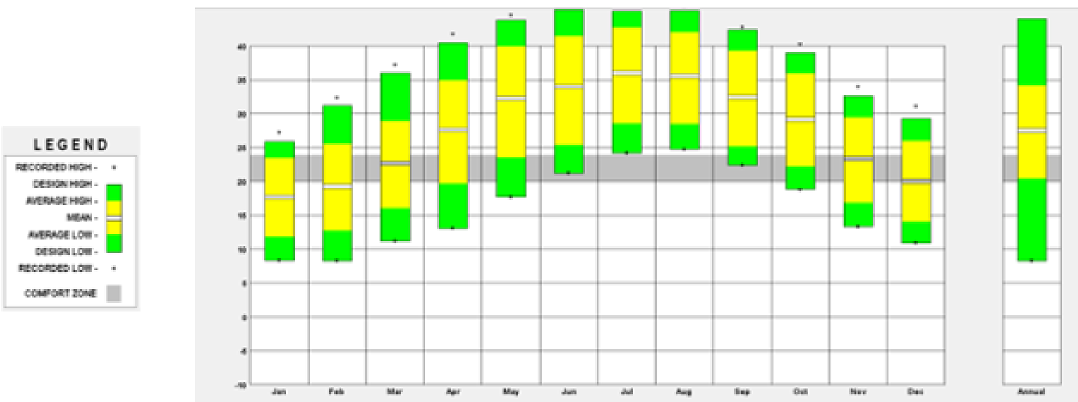


Fig.2.4 Temperature levels in Al Ain

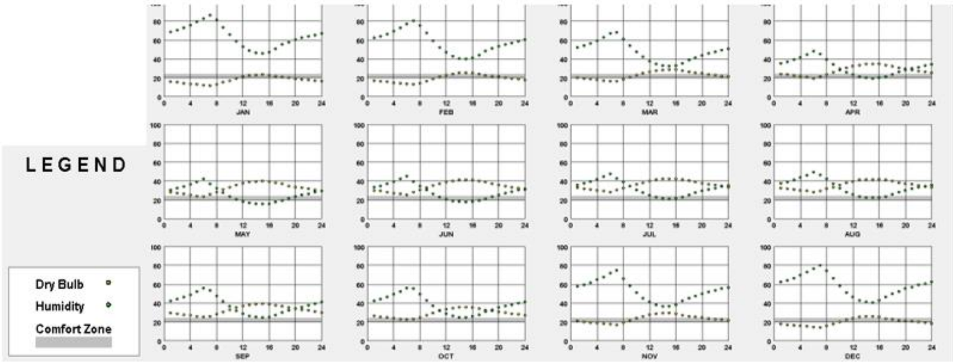


Fig.2.5 Humidity levels in Al Ain

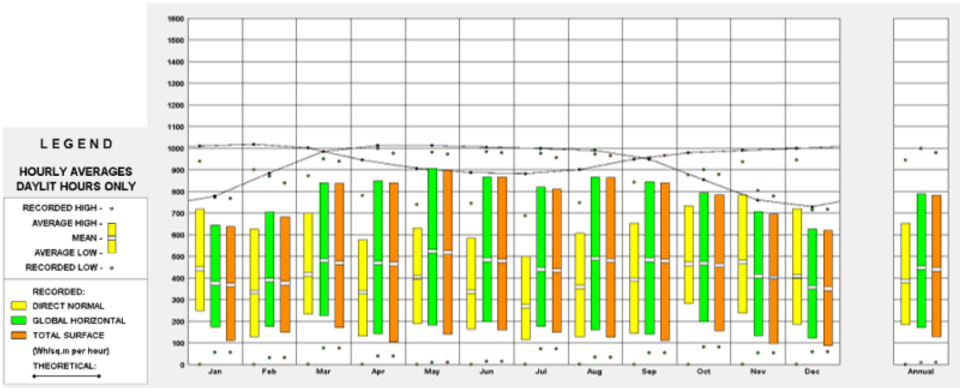


Fig.2.6 Radiation levels in Al Ain

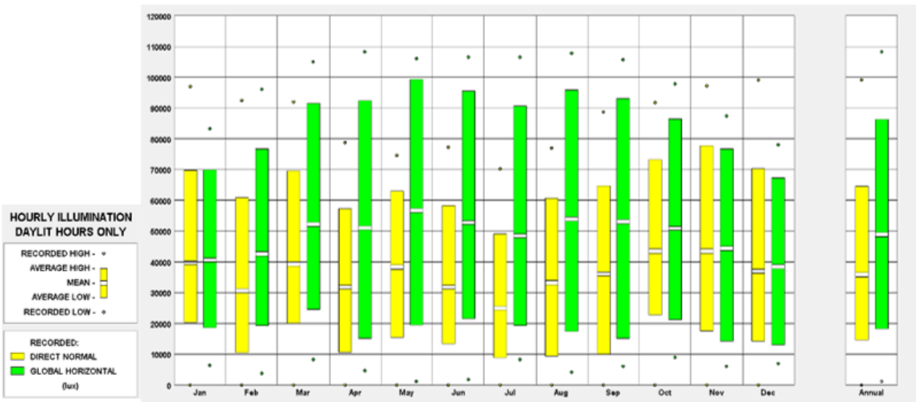


Fig.2.7 Illumination levels in Al Ain

2.3 Architectural and Structural Project

The second development is one of the best developments because it has that integrated shape and landscape that allows the circulation to be easy shown in (fig2.8). Also, the landscape development has the actual number of trees already found which is equal to the ones shown according to the type as illustrated in (fig2.9). The program and function plan has all the areas organized and it will be 1034sqm. However, there are some strengths and weaknesses, opportunities and threats. The studies show that the strengths of this building is reflecting the art and creativity, flexibility, integrated with landscape and integration of space that gives the comfortable feeling. There are other weaknesses mentioned in the SWOT analysis shown in the figure above. For example, the most weakness found is the load of the dynamic façade. The figures below illustrate schematic drawings of the chosen development.[10]

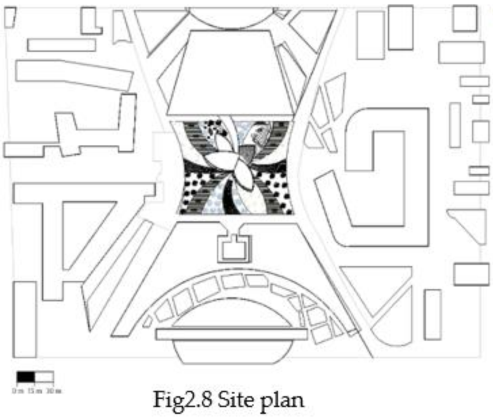


Fig2.8 Site plan

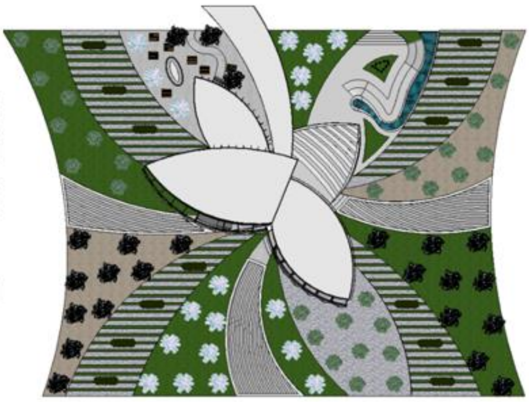


Fig2.9 Landscape

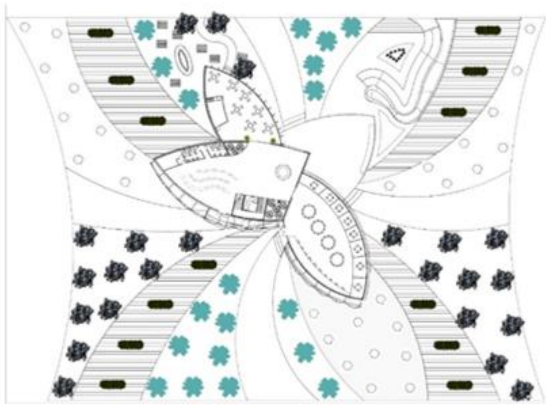


Fig2.10 Floor plan with landscape

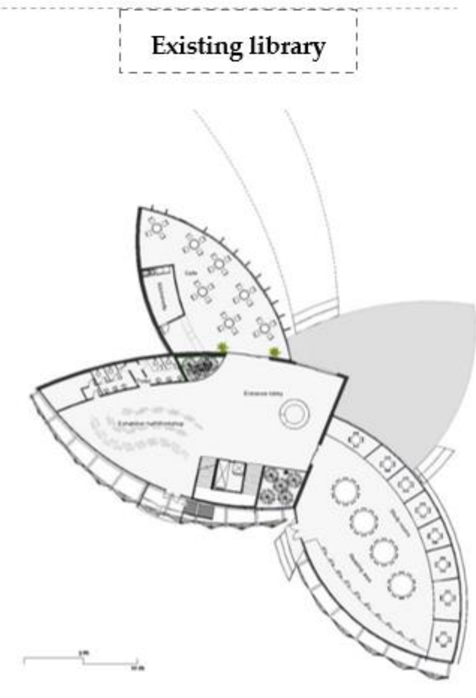


Fig2.11 Architectural GF Plan

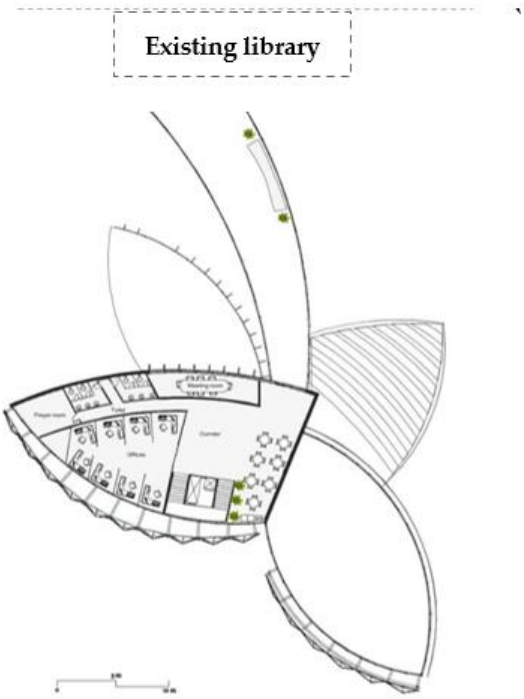


Fig2.12 Architectural FF plan

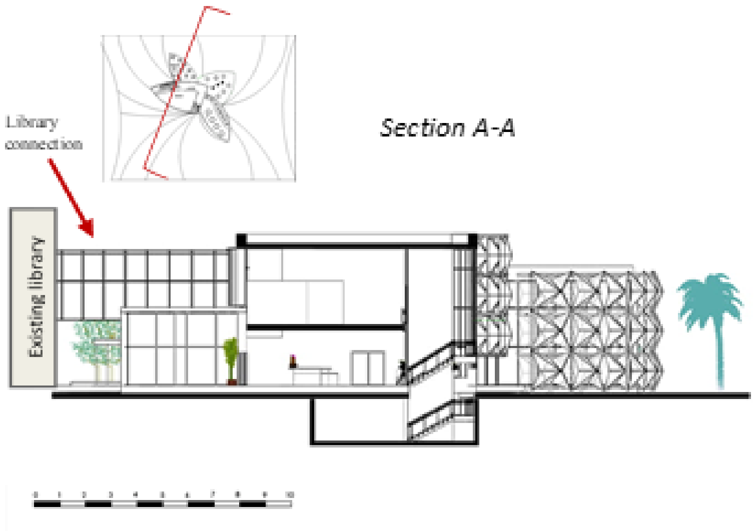


Fig2.13 Architectural Section A-A

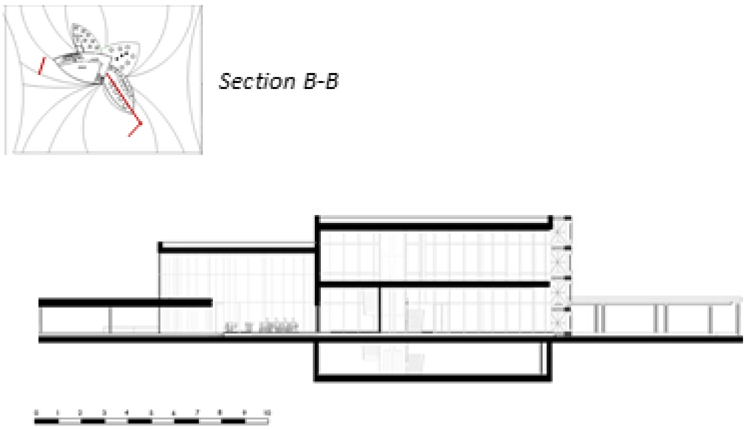


Fig 2.14 Architectural Section B-B

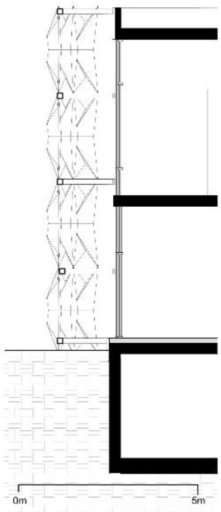


Fig 2.15 Wall Section

Fig 2.16.a South elevation

Fig 2.16.b East elevation

Fig 2.16.c West elevation

Fig 2.16.d North Elevation

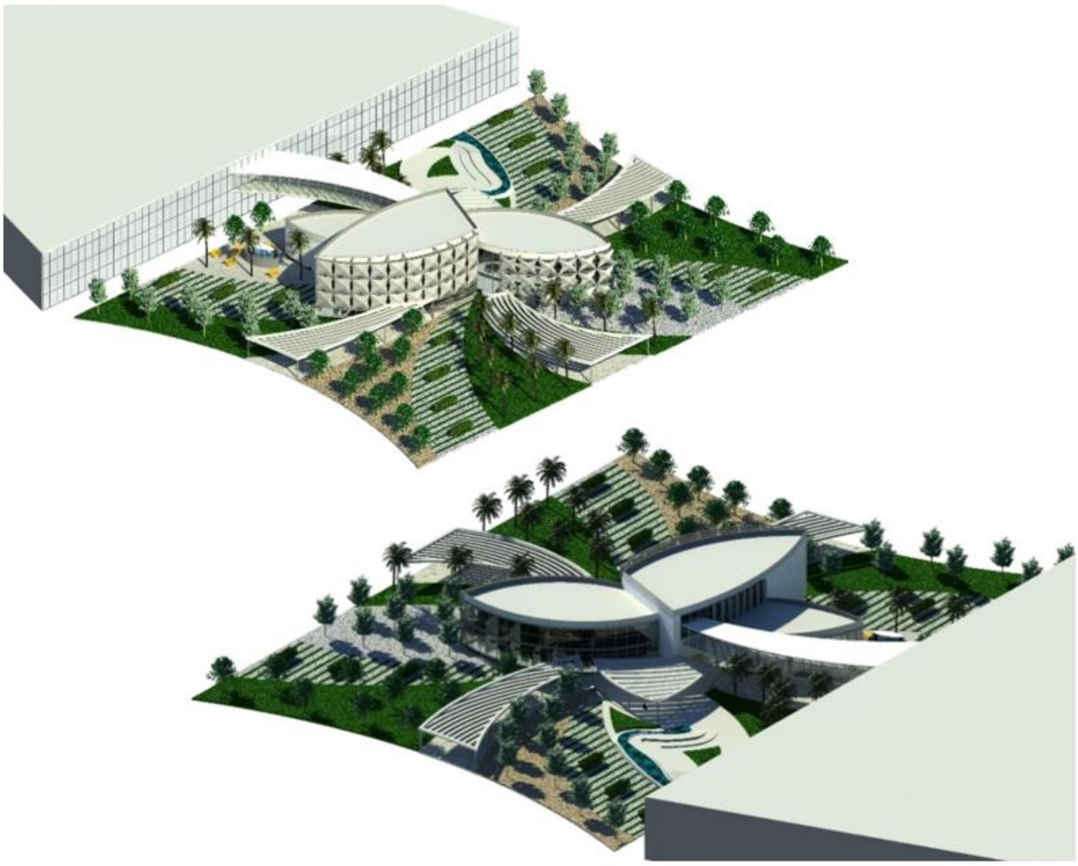


Fig2.17 3D rendered eye bird Views

2.4 Parametric/Dynamic Façade

Alternative 1 – Islamic geometry inspired pattern is inspired by Islamic geometry found in many places in the middle east region as shown in (fig2.18). Mechanism of the pattern is folding inwards and outwards based on the sunlight. Next is to draw the pattern, each point is defined. To create the mechanism of fold inwards and outwards, a point is defined at the center away from the plane to allow for folding distance as illustrated in (fig2.19). [11][12]

First before drawing the pattern, the surface needs to be defined and divided it up according to its dimensions.[13]

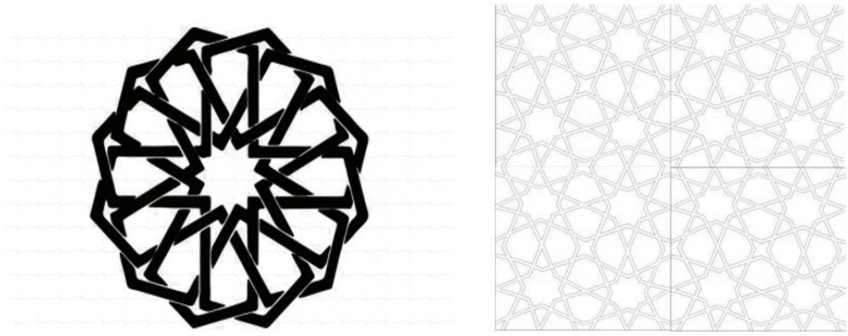


Fig2.18 Alternative 1 pattern

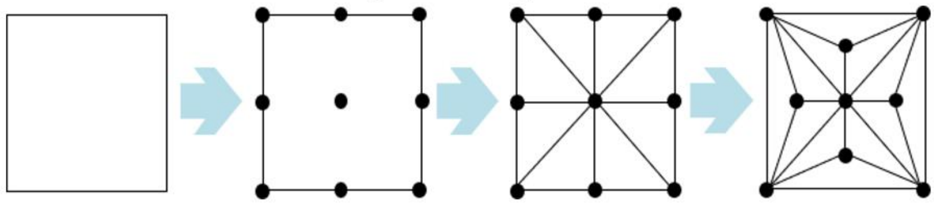


Fig2.19a Alternative 1 Development

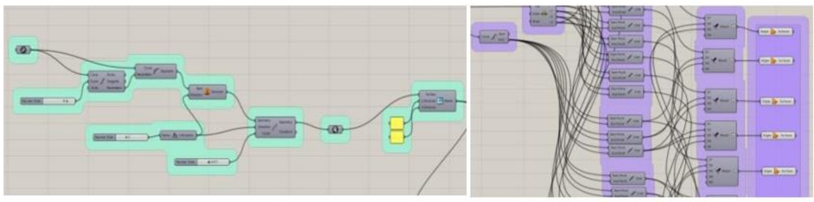


Fig2.19b Alternative 1 Grasshopper script

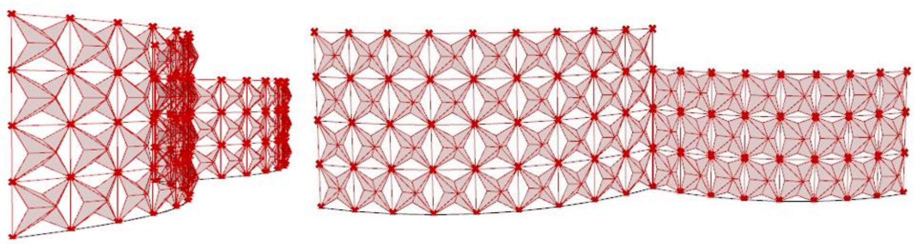


Fig2.19c Alternative 1 Grasshopper Generated

3. Results

This section focuses on studying solar radiation on UAEU library extensions design. First of all, our study will target the peak hours of the library have been determined by questioning the administration of the existing library, and the peak hour are from 8AM to 3PM.

In addition, we will target the two solstices which in June and December and equinoxes which are in March and September specifically on day 21 of each of those months which is the most critical as shown in (figs 20 and 21). The analysis has been done using ladybug plugin in grasshopper, we plugged in the peak hours and the months specifying the day. The dynamic façade is applied to help us minimize the surface area of the dynamic facade and place it in the most critical points receiving the highest radiation which is the south façade.[14][15].

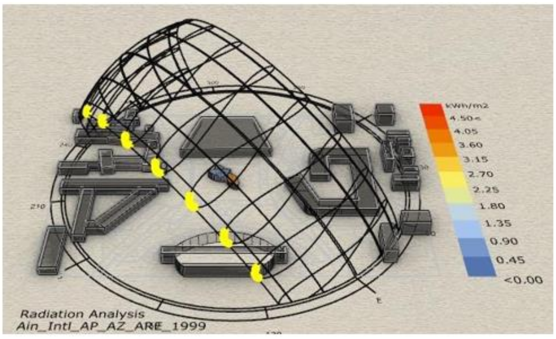


Fig 2.20.a Winter sun path 21/12

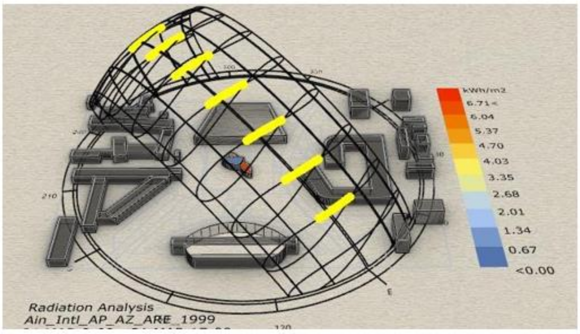


Fig2.20.b Autumn sun path 21/9

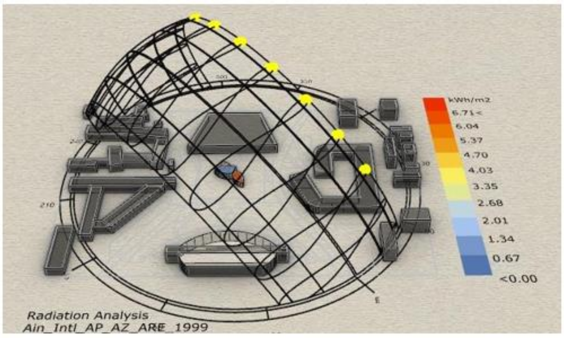


Fig 2.20.c Summer sun path 21/12

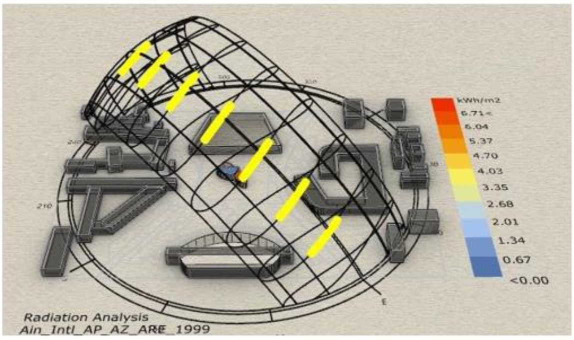


Fig 2.20.d Spring sun path 21/3

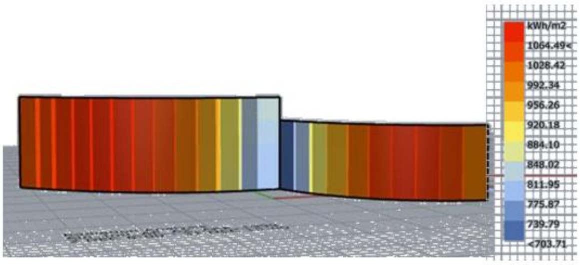


Fig 2.21.a Winter radiation 21/12

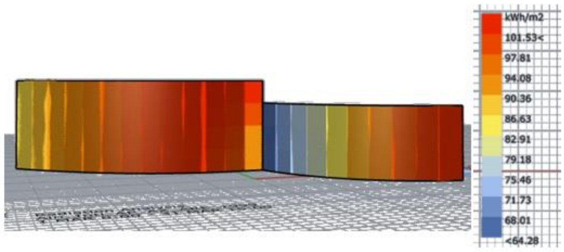


Fig 2.21.b Autumn radiation 21/9

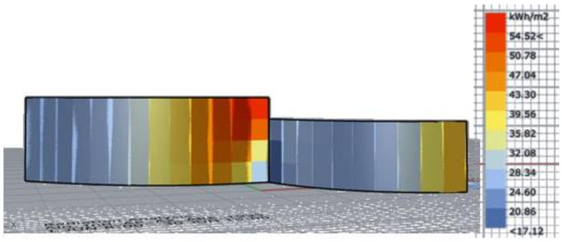


Fig 2.21.c Summer radiation 21/12

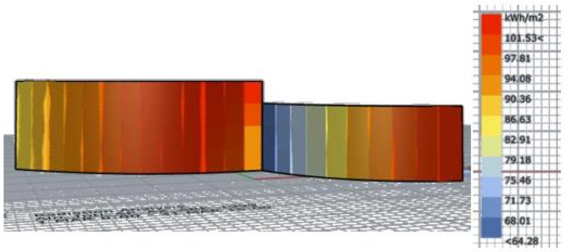
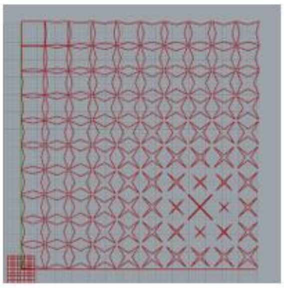


Fig2.21.d Spring radiation 21/3

The option selected which is Islamic geometry inspired has been generated in grasshopper and adjusted it base on the library's design. It is applied on the south façade where the most shading is needed shown in (fig3.1). First for the mechanism, the facade responds to sunlight. It folds inwards or outwards to some extent based on the amount of sunlight according to angle and surface exposed. The following three figures illustrate the operations on the whole façade surface, however the operations will vary on each part of the façade according to angles in reality.[16][17]

3.1 Parametric/dynamic structure



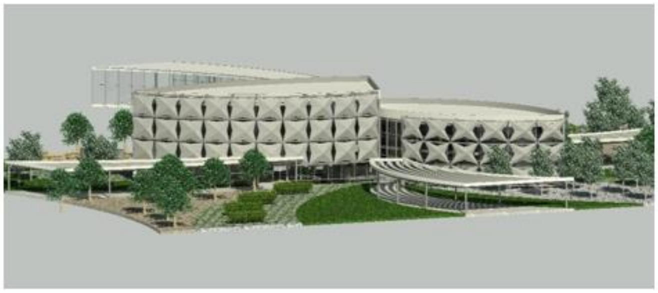


Fig3.1 Dynamic facade

Fig 3.2.a opened operation

Fig3.2.b Half-opened operation

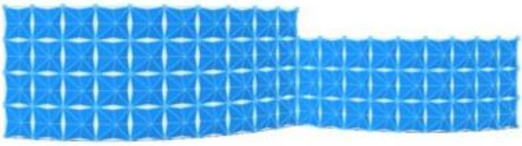


Fig 3.2.c Fully closed operation

Fig3.3 Dynamic façade eye view

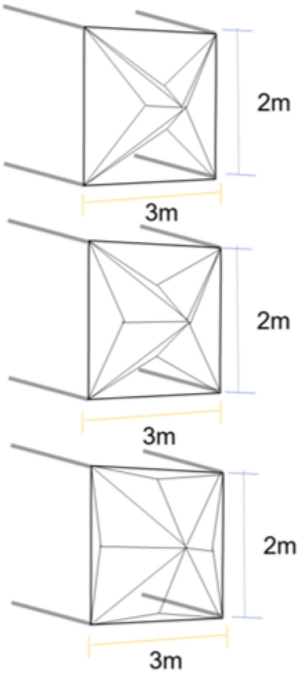


Fig 3.4 Modules of dynamic façade with different phases of movement

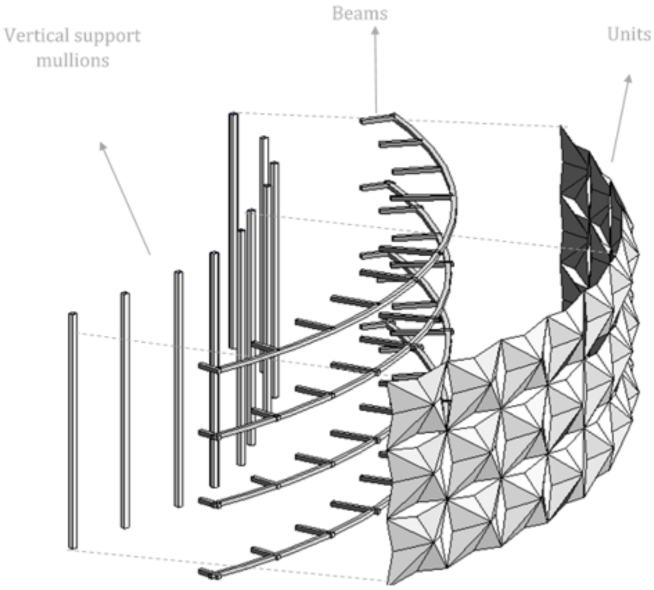


Fig 3.5 Structural of dynamic façade

Each unit of the dynamic façade has size of 2m by 3m as shown in (fig 3.4). The material selected for the units is PTFE which is selected in chapter 3 because it is the most suitable for our project objectives as it allows natural daylight and shades the building from harmful sunlight and glare simultaneously. The assembly and structure of the dynamic façade is illustrated in (fig3.5).

In the environmental impacts in this project will result in relocating the trees that work well with the climate. These types of trees are the most lasting in the hot climate or desert climate needing less water and requiring low irrigation status especially close to the UAE environment and drought resistance. The use of horizontal water body in the integration of landscape will help in enhancing the air quality of the site. Also, there is a benefit impact on the environment by using the dynamic façade and the glazing systems in the building that can be enhancing the sun light entrance without the usual heat found in the UAE climate. This will help in reducing the energy used by artificial lighting.[18]

4. Discussion

This study aims to design a dynamic /parametric façade as a smart solution to reduce the solar gains in the internal spaces therefore to reduce the energy consumption. The Design of several options before choosing the more adaptable one helped understanding the shape of the new building on the given site. During the initial stage of the site analysis difficulties were encountered in finding the correct materials.

The use of the Revit software was done for the initial stage of the project. Then a shift to Rhino Grasshopper was done in order to apply the python language and decide on the most efficient structure design to achieve the main objectives. The passage from one software to the other was prevent to be challenging mainly because of unrecognized elements of the design that had to be re-drawn. The optimization process in RHNINO grasshopper need more study in evaluation each parameter considered. The cost shall be also included in the evaluation/optimization process.

However, the design of the main building and the design of the dynamic/ parametric structure follow the sustainable principle of design and adaptation of a new building in an existing environment. The connectivity of the new building with the surrounding landscape is achieved due to the use of such innovative façade system.

5. Conclusions

The aim of this study is to investigate dynamic/parametric façade in a new building, to be built in the city of AL Ain, United Arab Emirates University Campus. The new structure is an additional Library Building (with additional function to the current building). The building follows the Estidama Pearl Rating System. The architecture has to consider the heritage of UAE and adapt to the current landscape. The building analysis includes: flexible internal spaces, passive architectural solutions, structural system adapted to the building function, connection to the surrounding building architecture and the urban tissue. The project follows Estidama 2030 standards.

The use of the parametric façade shows a drastic reduction of the façade solar radiation. This change impacts the cooling load of the building. The dynamic façade enables the users to have a maximized external view of the outdoor spaces. The parametrization includes optimization of several parameters in order to have the adequate solution for the problem stated initially.

This façade treatment, including advanced technology brings innovation in applications of complex structures in the country and the region. The field of application is quite large, therefore this study is relevant and can contribute to the work of other researches. Moreover, the typology of the building analyzed in this study is largely used in university campuses around UAE. The findings of this study with innovative structures might be relevant to reach the sustainability goals set by UAE government.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "conceptualization, L. Bande., H.

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Exterior Refurbishment and Fire Safety Strategies for High-Rise Council Estates in the UK

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Abstract: This research investigates the current exterior refurbishment strategies for high- rise council estates with the aim to enhance fire regulations and reduce risk of fire in buildings. This research outlines the main causes of the catastrophic Grenfell Tower fire and the current Building Regulations that were enforced during the time of its exterior refurbishment (i.e. replacement of fabric/cladding). Potential recommendations/enhancements made subsequent to the Grenfell Tower fire, proposed by the relevant institutions and its professionals, are analysed. A case study based in the borough of Westminster is then analysed in order to assess its proposed exterior refurbishment strategy in relation to compliance with the building regulations and safety requirements. The results reveal that although the refurbishment strategies have improved, there are some defects in the enforcement of the regulatory systems that should be addressed.

Keywords: Grenfell Tower; Fire Safety; Refurbishment; Building regulations.

1. Introduction

This work was developed with a view to the topic "Professional Delivery of Sustainability". While sustainable strategies are being implemented and enforced to reduce the collective carbon footprint, it is also important to ensure that they are in fact safe and do not pose a risk to the safety of a building's occupants, particularly in high-rise residential buildings. An example of unsafe refurbishment is the catastrophic fire that occurred at Grenfell Tower in London in 2017, claiming the lives of many innocent people.

The original construction of Grenfell Tower [1,2] was commissioned by the Kensington Chelsea borough council in the 1970s. According to [3], the tower design was commissioned in 1963 by the firm "Clifford Wearden & and Associations". The planning permission was then granted in 1970 and construction of the tower started in 1972 and was completed in 1974 by the main contractors "A E Symes" [4]. The tower comprised of 24 storeys which had anticipated to contain 124 residents [3]. The primary structure was comprised of mainly in-situ concrete columns and slabs and precast concrete beams. The exterior façade was comprised of insulated precast concrete, which improved the thermal performance of the building.

The refurbishment of Grenfell Tower had started in 2014 and was completed in 2016 [5]. In 2012, the TMO (The Kensington and Chelsea Tenant Management Organisation) had undertaken consultations for the refurbishment of Grenfell Tower, which had included improvements to its façade and mechanical and electrical enhancements [6]. A planning application was submitted to propose these alterations to the local authority, at a total cost of £9.7million. The architectural firm "Studio E Architects" was appointed and the main contractor "Rydon Group" was responsible for such works [7]. In terms of the specific proposed alterations, according to [8], the exterior façade included: a cladding system which covered the entire surface of the building, new windows replaced old existing windows and the implementation of a communal heating system.

The events of the Grenfell Tower fire were published widely at the time and for many weeks after. It was a catastrophic event which will always be remembered in the history of the UK. The incident happened on the 14th of June 2017. The fire had first started on the fourth floor of the building due to a faulty Hotpoint fridge freezer. The fire had rapidly spread from the east side of the building to the north until it had surrounded the whole building and, unfortunately, 72 people lost their lives due to the incident [9], The fire spread quickly, specifically through the cladding system [10]. When the flame had escaped the building, it started to burn the aluminium panelling, and then the fire entered through the gaps between the panelling and the insulation. This was effectively the reason for the alarming rate of spread upwards and was also one of the reasons the fire could not be controlled by the firefighters. According to [11], another cause of how the fire had rapidly spread throughout the building was from the 10 columns located around the building. These columns were covered with the same cladding which was one of the building's design features. As the same type of combustible cladding and flammable insulation was used, the fire had quickly spread through the air gap, creating a chimney-like effect. Looking at the materials used for the cladding systems, the panels were combined with poly aluminium sheets and polyethylene, which acted as a filler [10]. As this material melts at low temperatures, it caught fire, which also played a part in why and how the fire spread very quickly.

When it comes to the construction of a project, it is vital that the proposed design complies with the relevant building regulations; "Part B: Fire Safety" being one of the most important ones. "B4 -1" in "schedule 1" of the Building Regulations 2010, deals with the compliance with fire safety in terms of external fire spread [12]. According to the regulations, the external wall/façade of a building must be able to prevent the spread of fire over the walls, meaning that, in the case of Grenfell Tower, it failed to comply with B4-1 [13,14]. According to Dezeen [13], the air gaps between the insulation and the cladding panels led to the fire to spreading throughout the entire building. It is stated that the cavity barriers with strips were poorly installed and included gaps, making them ineffective in the event of a fire. Correct installation of the cavity barriers could significantly reduce the risk of fire spreading at such a rapid rate. The Approved Document B (fire safety) states that for a fire separating element (cavity barrier strips) to work, any openings in the building, such as joints, services, etc, must be sealed.

Weaver [15] states that the building regulations at the time were not fit for purpose as they had allowed for cost-cutting materials, as well as allowed contractors to be excessively budgetary, which had led to the cladding used on Grenfell to become flammable. To this end, this paper intends to investigate the current exterior refurbishment strategies for high-rise council estates that comply with the UK fire safety regulations.

2. Research Methods

The relevant refurbishment systems/strategies used for Grenfell Tower and the causes of the fire have been investigated. The current Building Regulations at the time have been assessed to identify areas for improvement. A high-rise council estate was selected and analysed as a case study to assess and understand design, decision making and control procedure in relation to its exterior refurbishment strategies. A detailed analysis of the proposed materials and strategies was conducted to ensure that all selections comply with the Building Regulations. A visit to the building site was made and images were taken, with a focus on the cladding systems/exterior façade, and CAD detailed drawings were produced. A comparison with the Grenfell Tower in terms of the components/materials was then made to assess the appropriateness and compliance of the proposed cladding strategies.

3. The outcomes

Following the Grenfell Tower incident, a series of inquiries into the event in relation to the cause of the fire were made. Some of these inquiries included the original state of the building and modifications to the exterior façade of the building, and justification to whether the refurbishment of the exterior facade was compliant with relevant fire safety and building regulations [16]. One of the main outcomes of the inquiries was related to recommendations for enhancements and modifications to the regulations and guidelines as well as to the use of combustible materials [17].

Accordingly, the UK's Ministry of Housing, Communities & Local Government (MHCLG) allocated £600 million towards the replacement of the combustible cladding systems on high-residential buildings for both the social and private sectors, as well as provided advice on the range of cladding substitutes which met the fire safety/rating provisions. For new buildings, the MHCLG has banned the use of combustible materials used on any new high-rise residential buildings [17]. Additionally, the government has emphasised the importance of the testing and classification of cladding systems and further recommendations on how testing can be improved and conducted through the "Construction Product Standards Committee"[17]. This would allow for the identification of combustible materials before they are used in buildings, resulting in increased fire safety.

"Building a Safer Future" suggests that the regulatory system put in place by Building Control and local authorities is not fit for purpose. Ignorance and/or lack of knowledge, misunderstanding and priority of time and cost to safety have been highlighted as the key issues. regulatory oversight and enforcement tools should be added to the above issues [18]. This implies that when relevant building regulations are not implemented or considered in a project, the penalties are so small that they are ineffective and hardly consequential for the rule-breaker(s). Some recommendations have been made to address these issues: more severe enforcement powers which would lead to the consideration of building regulations when constructing a project; a simplified regulatory approach to building standards which would make it easier for people to implement and understand in their projects. In terms of proposed materials, there should be a reduction in desktop studies and more physical testing of materials/systems to ensure that they are safe to use [18].

A new regulatory framework for multi-occupancy Higher risk residential buildings (HRRBs) has been developed specifically for buildings of 10 or more storeys. Figure 1(a) [19] indicates the map of the previous regulatory system in place and Figure 1(b) [20] indicates the new proposed map. The old map was highly complex and had "overlapping" sets of legislations which had made it harder to understand and follow. However, the new HRRBs map has been refined and is easier to follow, ensuring its use is effective and beneficial [18]. The main purpose of the maps is to give assistance and guidelines for constructing and maintaining high-rise residential buildings. This is represented in the form of a flow chart which, in each section, includes legislations/building regulations that must be abided by. The UK Government is strongly considering restricting or even banning desktop studies-especially on cladding systems [21]. The Government is also working on improvements to Building Regulations fire safety guidance.

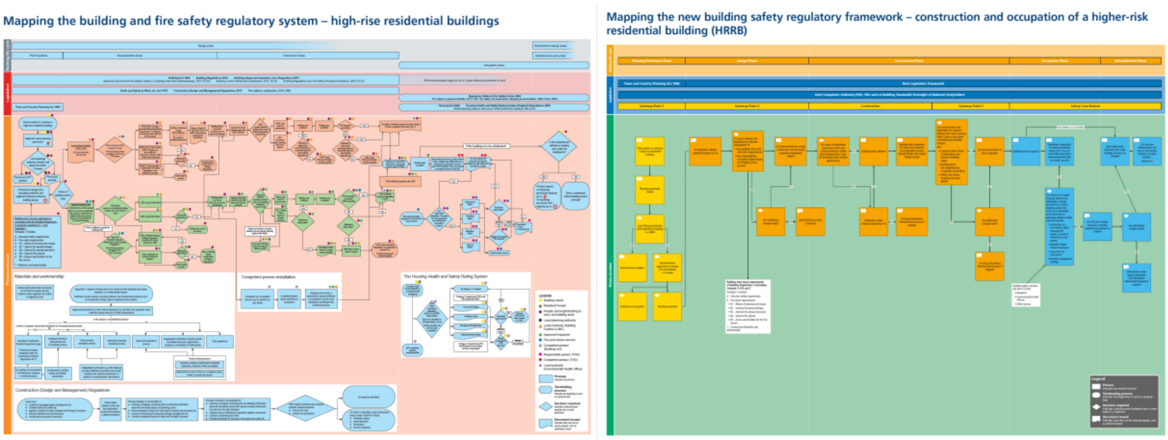

Figure 1. Mapping the building and fire safety regulatory system- a: old framework (left); b: new framework (right) [19,20].

4. Case study

After the Grenfell Tower incident, the government requested tests to be carried out on buildings that were more than 18 meters high and had an exterior cladding system. The outcomes of the tests revealed there were many buildings that needed urgent attention. According to Torpey [22], there were 254 unnamed buildings and 124 residential buildings which failed their cladding tests. The amended Building Regulations 2018 (SI 2018/1230) put a ban on the use of external combustible materials for high-rise residential buildings which are above 18 meters [23].

The case study selected for the purpose of this research is one of the high-rise residential blocks, referred to as “Polesworth House”, located in Westminster, London (Figure 2), that had failed the cladding tests [22]. The building is assessed in terms of its current state (external facade) and the proposed new external refurbishment strategy. In terms of Building Regulations, the local authority (the City of Westminster) is responsible for ensuring that its building cladding meets the requirements of the Housing Act [24]. There are multiple steps that the local authority has taken to ensure the safety of Polesworth House.

Figure 2. “Polesworth house”; Left: 2012 [25]; Right: 2020.

The primary structure of the building is composed of a concrete frame with its current architectural style, known as Modernism. The tower has a total of 21 floors above the ground and a height span of 61 meters [26]. The tower was constructed by “Wates Construction” Contactors and was completed in 1962. The existing cladding system is comprised of Rainscreen (Face fixed 4mm ACM), pressed metal work and column casing [27]. As the cladding was confirmed to be combustible [28], the local council developed a detailed plan for the safe removal of its cladding system with an estimated removal by November 2017.

To analyse the building and the current stage of its cladding system replacement, a visit to the site was made and a photographic survey was carried out. These images indicate that the combustible cladding system was taken down, exposing the original building façade (Figure 3).

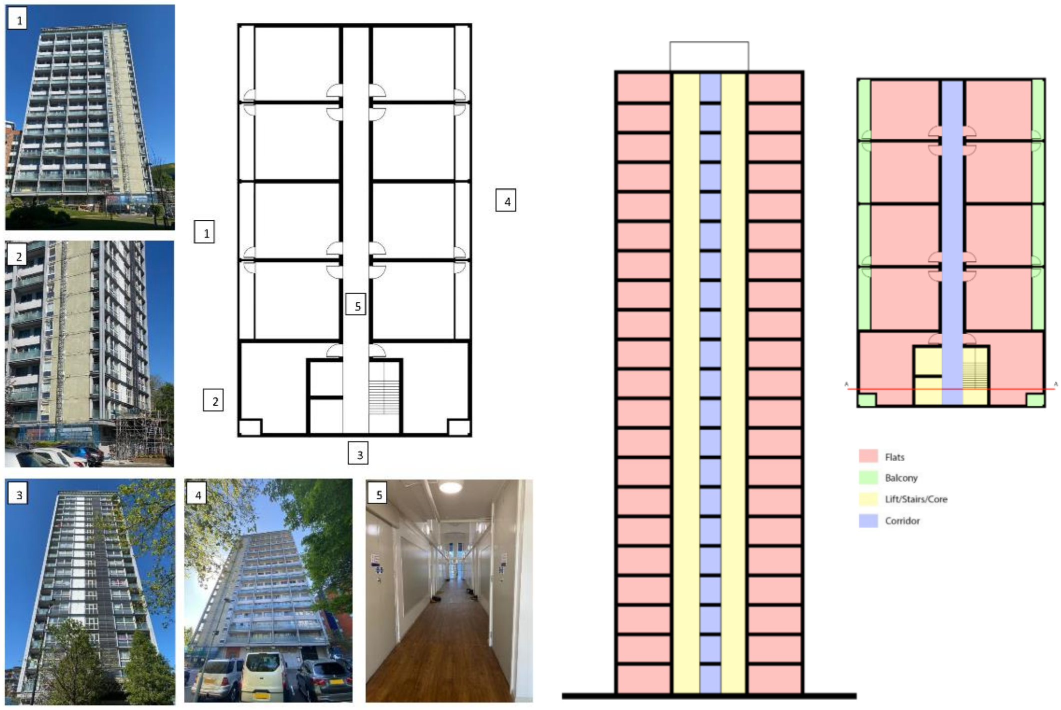

Figure 3. The case study building “Polesworth house”; an approximate section and plan.

In terms of the new exterior refurbishment strategy (Figure 4), the council taken a different approach and is proposing to install a refurbishment system referred to as the “external wall insulation” (EWI) rendering system [29,30]. Comparing this external wall insulation cladding system to the ACM cladding system, one of the main reasons for this consideration was the fact that the main system in recognised as an A1 system, meaning that it is completely non-combustible. According to The Green Age [31], EWI is not recognised as a rainscreen cladding nor a cladding system in general, which means that it would not be subject to any ongoing testing criteria. This results in a rapid installation process. There are other reasons as to why EWI is preferred over ACM. Table 1 summarises the advantages and disadvantages of the systems.

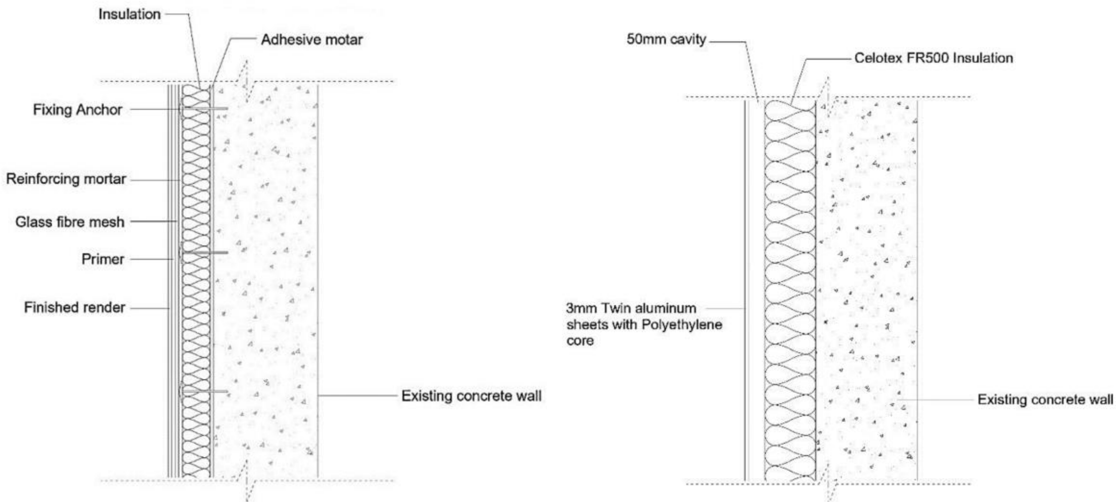

Figure 4. On the left is a wall detail of the proposed exterior refurbishment strategy (EWI) for “Polesworth house”, compared to a wall detail of the previous cladding strategy.

Table 1. Comparison of EWI & ACM

Advantages of EWI over ACM	Disadvantages of EWI over ACM
• EWI system is constructed of non-combustible materials. • EWI system does not include a cavity or air gap, eliminating the changes of fire spreading through the cavity/airgap. • EWI system is a cheaper option when compared to ACM. • The life Expectancy of EWI systems is predicted to be for 60 years. • EWI has improved thermal comfort for residents. • This strategy could be adopted by other high-rise residential buildings, which would reduce the risks of a fire occurring as the system would be rapidly installed without delay. • Enhanced fire safety standard	• Rendering of EWI systems may not be pleasant when compared to ACM systems as they look more modern. • The EWI system can only be installed during specific temperatures as it involves some wet- works. This drastically limits the flexibility of its construction operations, as its schedule is dependent on the weather conditions of the site location. • Installation of EWI systems may be longer as delays may occur from the cause of weather conditions.

When it comes to the refurbishment of other high-rise domestic buildings, EWI (exterior wall insulation) systems may not be the best option as, in some cases, they are classified as 'non-aesthetically pleasing'; this is subjective but entirely depends on the client. In this case, there are multiple manufacturers who produce ACM (aluminium composite material) cladding systems that are classified as non-flammable. An example of this is referred to as "Alucobond A2", which, according to RCM building boards & facades [32], is an ACM cladding system that can be used for buildings over 18m. The system consists of two aluminium cover sheets filled with a mineral polymer core, which has high levels of rigidity and impact resistance, which therefore means it has superior durability overall in comparison to other available products. Most importantly, it is non-flammable and abides by the current fire rating standards "EN 13501-1 class A2-s1,d0". Figure 5 illustrates a typical assembly of how the system is put together [32].

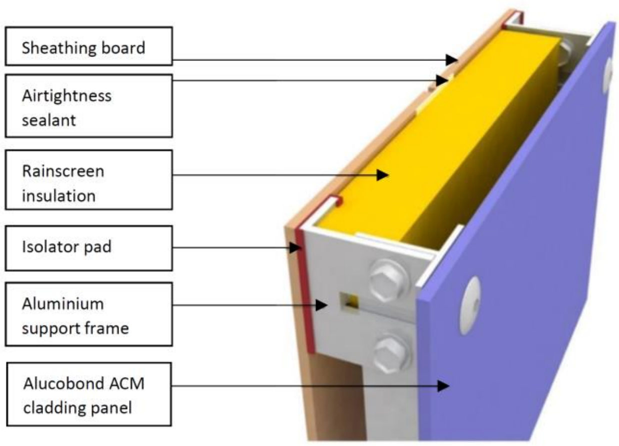

Figure 5. A typical assembly of the "Alucobond" ACM system [32].

According to Tristone Solid surfaces [33], the "EN 13501-1 class A2-s1,d0" standard includes classifications of the different ACM systems which also consists of guidance that must be followed.

In terms of the Alucobond ACM cladding system, it is classified as grade A2, which means that no combustible materials were used in its manufacture. In addition to this, the system is also BBA (British Board of Agrément) certified, which, as stated by Metrotile [34], is a certification recognised in the construction industry for high quality products, high quality manufacturers, etc. As the system is built up from non-combustible materials, in an event of a fire, the rate at which the fire spreads is significantly reduced [35]. To guarantee that the cladding proposed by "Alucobond" is non-combustible, multiple fire tests have been conducted. According to Alucobond [36], four BS8414 large scale tests replicated many scenarios that would occur in a fire. This included measuring the speed and distance of the flame in terms of internal and external fire spread, the combustibility of the components in the system and the burning droplets and smoke produced by the flame. The cladding systems included non-combustible panels and non-combustible mineral wool insulation. Apparently, the system had not shown critical rises in temperature or a major development in the flame exceeding the enforced requirements of the BRE (Building Research Establishment). In the case of Fire Retardant ACMs, the fire may start on the ground floor and develop to the first floor and then be delayed, meaning that the cladding system stalls the development of the fire, in turn giving ample time for residents to escape and reach a safe proximity away from the building. This also gives enough time for firefighters to put out the fire and prevent it from developing further.

5. Recommendations

In the case of the Grenfell Tower, the main cause of the fire was the combustible ACM cladding that was used. This had also involved incorrect installations of the system and defective cavity barriers, which had resulted in the rapid spread of the fire around the building. One of the main reasons for the incident was the unclear regulations (which may have been one of the reasons the lack of full compliance with the fire regulations) as well as the enforcement systems. The Grenfell Tower is an example of how the regulatory systems are not fit for purpose.

Accordingly, there are multiple enhancements/recommendations which can be implemented to ensure the fire safety of high-rise residential buildings. First, it includes making sure that manufacturers and contractors abide by up-to-date regulations, and, if possible, exceed those standards to assert a'strive for better' approach in the construction sector. This consists of enforcing stricter penalties such as fines, closure of the company or the removal of its chartership. The existing fines/penalties do not live up to the seriousness of the consequences that can result from incompliance (i.e. the fire at Grenfell Tower taking many lives), and thus it is important to approach this in a stricter way. The second includes making testing of all types of exterior refurbishment strategies mandatory and then this must be approved by the relevant institutions before it can be used in practice. This would include real-life testing and possibly fire simulations to be used, based on the classification of the components used in the specified system. As well as having the full plan building application for submission, the third recommendation could include mandatory inspections at the commencement of a project, carried out by a professional body from the local authority, and at other significant stages of the construction pertaining to the installation of its exterior systems, with fire safety at the core of its inspection. This would comprise of ensuring the system used is non-combustible, the system is secured to the building while adhering to the relevant Building Regulations, and guaranteeing that fire precautions such as cavity barriers and fire stops are implemented correctly based on the regulations and the manufacturers' specifications. This guarantees that contractors who ignore building regulations and standards are not constructing the building for the sole purpose of making a profit, and are consistently supervised during the relevant stages of the construction. Finally, the guidance and enforcement of the maintenance of the exterior façade could be improved as systems could fail over time, which may decrease its duration of fire resistance and durability factors in general, which, as a consequence, can also impair its resistance to fire.

5. Conclusion

The major cause of the fire at Grenfell Tower was the combustible cladding system, which had resulted in the repaid spread of fire, as well as the poor design and the Building Regulations being "not fit for purpose" playing a part in the incident. When it comes to different exterior refurbishment strategies for high-rise residential buildings, there are a limited number of external systems which could be used due to the high risk of a fire occurring. The replacement of the combustible cladding system with EWI (external wall insulation) and Enhanced ACM (Aluminium composite material) would improve the situation. Further on from the horrific incident at Grenfell Tower, the UK Government has taken precautions to prevent the likelihood of similar events occurring again. The issues that caused the fire at Grenfell Tower have been identified and recommendations such as new regulatory systems have been provided. The implementation of such recommendations would guarantee that buildings are built and maintained in accordance with the regulations, improving the safety of residents of high-rise residential buildings.

Author Contributions: Hashemi designed and supervised the project; Fahmi carried out the investigations.

Conflicts of Interest: The authors declare no conflict of interest.

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Identifying the Process for Automated Vision-based Construction Progress Monitoring.

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Abstract: The vision-based construction progress monitoring process is a technique that provides vital information on the status of the construction process to make important decisions by getting the vision dataset as an input acquired through various methods. This technique aims at reducing labor-intensive tasks involved in the traditional construction progress monitoring process which makes it accurate and provides the timely status of any potential delays. This paper presented the findings of the literature review conducted to identify the process for automated vision-based construction progress monitoring. This review identifies four key processes involved in the vision-based construction progress monitoring process i.e., data acquisition, information retrieval, progress estimation, and visualization of output. It furthers reports the detail of various methods and techniques involved in these four distinct processes and accesses these methods and techniques for the level of automation provided by each to realize the viability of the automated vision-based process. This paper concludes by providing a re-engineered process for automated vision-based construction monitoring to be an alternative to traditional progress monitoring techniques.

Keywords: Automation; Construction progress; Automated monitoring; Progress monitoring; Computer vision; Vision-based

1. Introduction

Construction projects are complex in nature and their success is bound to successful management of triple constraints of projects i.e., time, cost, and quality. To complete the construction project in time and achieve expected time-related goals, construction management teams conduct vigorous progress monitoring. The efficient progress monitoring determines the control of the project management team over the project outcomes, hence, critical in deciding the fate of the overall construction project. The majority of construction projects still use traditional labor-intensive methods to observe and report the status of construction activities, which involves site staff taking multiple readings during a day, recording the status on a piece of paper, and reporting it to the planning engineers. Furthermore, reviewing the updates, preparation of useful reports, and submission of the said reports to stakeholders still rely on manual and time-consuming processes [1]. This often leads to a delayed intimation of potential deviations from an original plan to construction management teams and stakeholders alike, which causes construction delays and financial losses.

To reduce the uncertainty and shortcomings posed by traditional practices, many research efforts have incorporated technological solutions and proposed IT-enabled techniques to improve the existing progress monitoring methods. These solutions range from a simple collection and documentation of digital photo-based site logs to state-of-the-art vision-based construction progress tracking and monitoring driven by image processing techniques [2]. The computer vision system or vision-based system mimics the human vision and identifies objects or features from the vision-dataset. These systems must be trained, either supervised or unsupervised, to learn from the existing vision dataset to be able to identify or recognize, and color label the feature or object in question present in the input. The majority of vision-based construction progress monitoring processes determine the state of construction activity by comparing the as-built model with the as-planned model. Such vision-based monitoring involves four distinct processes i.e., Data acquisition, Information retrieval, Progress estimation, and Visualization of output; to collect, analyze and present the information. Based on a comprehensive literature review this paper summarizes the techniques and methods involves in the vision-based construction progress monitoring process and identifies the process in an effort towards the viability of the vision-based system in current construction management practices.

2. Literature Review

Advancement in computer vision techniques and image-based analysis also directed the research focus towards the integration of these techniques with existing construction management practices. The major focus of vision-based techniques is on ensuring construction safety, monitoring and measuring construction progress, and assessing and detecting damage or cracks in various structures [3]. The vision-based construction progress monitoring process involves the acquisition of vision-dataset from ongoing construction projects, analyze and retrieve the information present in the acquired vision datasets, estimate the progress of the construction process either by comparing the as-built model and the as-planned model, tracking the movement of any piece of machinery or counting the installed pre-fabricated units and at the end presenting necessary information as an output from this process to make important decisions by the construction management teams to keep the project on track and ensure the timely delivery of project outcomes [4].

The data acquisition process refers to the methods and techniques to capture vision datasets either in the form of digital images or videos. For efficient data acquisition, the key is to cover as many angles and views of the ongoing construction process as possible by keeping the occlusions, hindrances, and obstruction minimum to be able to retrieve useful information during post-processing. Unmanned Aerial Vehicles (UAVs) remain a popular choice of many researchers for collecting vision datasets due to their ability to cover wide areas and a variety of angles that are mostly inaccessible to humans [5]. Handheld devices are also being used extensively on construction sites for collecting photologs to record and report the construction process on daily basis. Image dataset collected from the handheld devices is also being adopted to create a 3D as-built model by various studies [6]. Moreover, few studies also explored the benefits of data acquisition by mounting digital cameras on cranes, camera mounts, and mounted on helmets and safety jackets [7,8]. Lastly, the video feed from surveillance cameras installed on construction sites for various purposes is also experimented to track and monitor construction progress and reported various benefits [9].

The information retrieval process in vision-based techniques is driven by a variety of image-based analyses. Image-based analyses are classified into four distinct classes based on the type of action they perform to retrieve useful information from a given vision dataset i.e., classification/detection, quantification, object tracking, and edge detection. The most common technique to extract useful information is in the form of a 3D reconstruction of an as-built model. To retrieve a 3D model, Structure from Motion (SfM) is widely in use which is a photogrammetric technique and lies under the quantification class of image-based analysis [10]. Another technique to classify or detect various objects from image datasets is a Deep Learning (DL) based technique called Convolutional Neural Networks (CNN). Many studies have explored the usefulness of CNN in retrieving the required information and allows matching it with as-planned input to gauge the progress of any construction process [11]. The feature extraction techniques like Speeded Up Robust Features (SURF) [9] and Histogram of Oriented Gradients (HoG) [7], and classifiers like Cascade Classifier (CC) [12] and Support Vector Machines (SVM) [13] are among frequently used techniques to retrieve useful information from vision datasets [3].

The concept behind progress estimation through vision-based construction progress monitoring is to compare the as-built model, retrieved from performing various information retrieval techniques on an acquired dataset, with the as-planned models. The most frequently used as-planned models are Building Information Models (BIMs). The progress estimation process involves the superimposition of the as-planned model over BIMs, which is knowns as BIM registration [4]. The registration process refers to noise reduction, plane matching, and fine alignment of as-built and as-planned models [7]. Moreover, the literature explored Augmented Reality (AR) to present the output of the vision-based construction progress monitoring process to help construction management teams to visualize construction status and interact with it [14]. However, the integration of construction management principles into the vision-based process for viable output for construction management teams remains least explored [15].

3. Research Problem

A typical construction project comprises many complex construction processes going on simultaneously and the ultimate goal of any construction management team is to track and monitor all processes efficiently to be able to deliver the desired outcomes in stipulated time. The member of the planning and control team, usually a field supervisor, spends most of his time on site accessing the status of various activities and manually recording and reporting through a paper-based system. In recent years, these paper-based systems are partially replaced by handheld devices i.e., tablets, mobile phones, etc. This traditional process of tracking and collecting construction progress status is highly dependent on the judgment of a field supervisor, labor-intensive, and error-prone [2]. Similarly, the process of organizing and reporting the construction progress status to upper management and stakeholders requires additional efforts at the end of field office management staff. This process has been proven ineffective and efforts have been put into finding the efficient alternative to these traditional techniques from academia and industry alike.

In the past decade, Computer Vision (CV) techniques have revolutionized almost every walk of life. Many research efforts proposed image-based data collection and analysis techniques to track and monitor construction progress. Vision-based techniques have the potential of gathering the information, analyzing the gathered vision-dataset, estimating the progress by monitoring the behavior of workers and equipment or comparing the as-built dataset with as-planned datasets, and summarizing the useful output to assist construction management teams in making useful decisions [3]. The motivation of deploying a vision-based construction monitoring process stems from its ability to reduce the time and labor-intensiveness of the whole process [16]. This arises the question that does current vision-based concepts and techniques have the potential to replace the existing practices? This study aims to assess the viability of current vision-based techniques by conducting a comprehensive literature review and identifying the process for automated vision-based construction progress monitoring. Figure 1. summarizes the research problem.

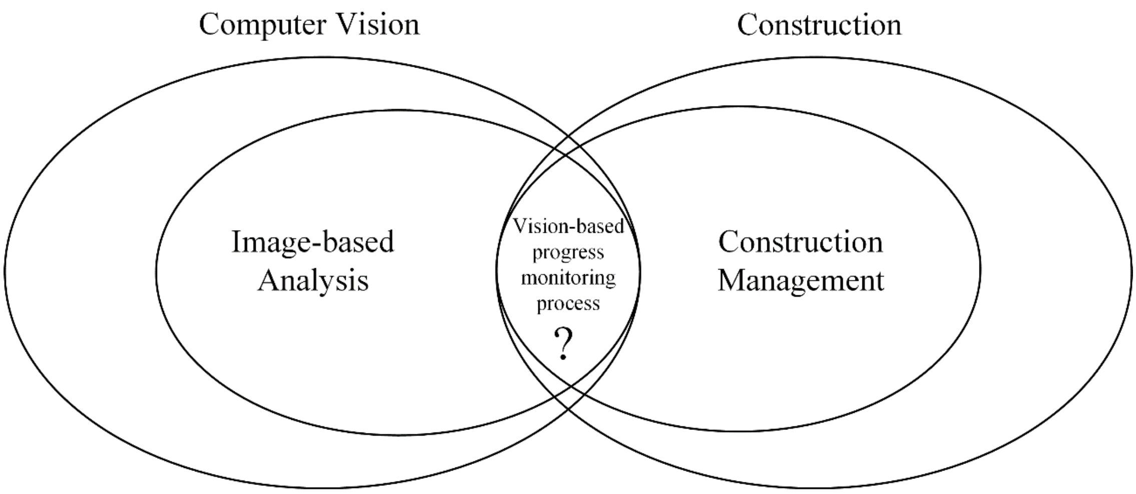

Figure 1. Research Problem

4. Process Identification

The literature review identified a process for vision-based construction progress monitoring. The whole process consists of four distinct sub-processes, also referred to as layers for process explanation purposes. The first layer is data acquisition, which refers to the acquisition techniques being used for the collection of vision-dataset from the construction environment. The second distinct layer is information retrieval, which entails all the image processing techniques to retrieve useful information from the acquired vision dataset. The third layer refers to the comparison between the as-built model and the as-planned model to estimate the progress of various construction activities and is known as the progress estimation layer. The last and important layer from the perspective of the construction management team is the visualization of output. This summarizes the ways this vision-based monitoring process presents the output for analyzing the current status of the project and making useful decisions to get the desired outcome. The four layers of the vision-based construction progress monitoring process are data acquisition, information retrieval, progress estimation, and visualization of output, which are discussed as follows.

4.1. Data Acquisition Layer

The first layer of the process deals with the acquisition of vision-dataset from diverse construction environments. It identifies various methods to acquire the required data with a certain degree of accuracy required for image-based analysis. It addresses the usefulness of each method and level of automation provided by the identified methods. The reviewed literature identifies various methods of data acquisition e.g. Handheld devices, UAVs, cameras fixed on various types of mounts, and surveillance cameras. UAVs and surveillance cameras provide a higher level of automation for the vision-dataset collection and transmission for post-processing. The most frequently used method is taking photos of construction processes using handheld devices, apart from data collection for vision-based monitoring processes, traditional practices hugely rely on images taken by various handheld devices. However, the process of collecting and transmitting vision-dataset using handheld devices provides the least level of automation. Finally, the ideal vision-based construction progress monitoring process should depend on a method that provides quality images and reduces labor-intensive tasks.

4.2. Information Retrieval Layer

The information retrieval process is the second layer of the process that refers to the extraction of useful information from acquired vision-dataset. It identifies various image-based analyses being used for computer vision-based applications i.e. classification, edge detection, quantification, and object tracking. This layer summarizes the most frequent methods and techniques being used in multidisciplinary research being conducted in the domain of construction management. The reviewed literature identifies SfM, CNN, SVM, SLAM, CC, HoG, LoG, SURF, and numerous other algorithms which classify, detect, track and quantify as per their capabilities. The SfM technique was most frequently used and reported very accurate results by providing automatic extraction of 3D as-built dataset using unordered photos which can be further processed to get highly accurate results. However, most SfM based techniques require human intervention during processing and offer the least automation for the vision-based process. Moreover, recently CNN is being explored for construction management purposes and provides very useful information for decision making. The CNN-based techniques also offer the highest level of automation and can be used for real-time construction management purposes as well. Finally, these identified techniques certainly provide the opportunity for automated vision-based construction progress monitoring and further research efforts should reduce the required human input.

4.3. Progress Estimation Layer

In the third layer, progress estimation techniques are discussed. These techniques include the comparison of the as-built model and the as-planned model; which is also known as BIM; and comparison of cost, schedule, 2D plans, and 3D Computer Aided Designs (CAD) models with information retrieved from the second layer. These comparisons return the information on the status of various construction processes and indicate whether the activity or the project as a whole is being executed as planned or otherwise. The most frequent technique being used for such comparisons is BIMs registration or superimposing the retrieved information on as-planned BIM and deducing the status of the project. Few studies have also indicated the progress by measuring the installation status of various pre-fabricated components and indicates it on 2D plans. This layer works in combination with the second layer, as mere superimposing the as-built dataset on an as-planned dataset will not return any useful information, therefore, the information retrieval techniques detect, identify or track the required features from the overlaying models and present the useful information. This combination of both layers acts as a black box for construction management teams, which desire only useful information not concerned with the whole process.

4.4. Visualization of Output Layer

The fourth and final layer of this process is the visualization of output. It identifies various methods to visualize the results of the whole process. The retrieved literature suggests methods such as AR, color labels, and tabular data. The most frequently used output technique is in the form of color labels, which is the standard form of an output from a computer vision-based system. However, the construction management teams desire the output in a useful format, similar to the ones being used in all traditional practices. Few studies have also presented the AR-based visualization which allows the construction teams to interact with the project and get feedback. Finally, recent studies have suggested the Earned Value Management (EVM) as a viable form of output from the vision-based construction progress monitoring process. The EVM has been in use for decades now and provides the necessary evidence to base their important decisions. The research efforts should be provided in integrating the construction management principles and techniques into vision-based processes to make these systems viable for implementation in an actual construction environment.

In this section, each layer summarizes the methods and techniques used by various research studies. The re-engineered process for automated vision-based construction progress monitoring is shown in Figure 2.

5. Conclusion and Future Work

Traditional construction progress monitoring methods are labor-intensive, slow, and inaccurate. In the past decade, various research studies explored the integration of vision-based techniques into the various construction management process. This literature review aimed at identifying the components of the automated vision-based construction progress monitoring process and re-engineer the complete process to be an alternate for traditional methods.

The process for automated vision-based construction progress monitoring comprises four distinct sub-processes i.e. data acquisition, information retrieval, progress estimation, and visualization of output. The data acquisition process corresponds to the acquisition of as-built information in the form of images and videos, collectively known as vision datasets. Popular data acquisition techniques are the use of UAVs and various handheld devices. The information retrieval process comprises various algorithm-based methods to identify, locate, track or recognize useful information from vision datasets. The frequently used and effective techniques are SfM, CNN, and SVM. The process of progress estimation corresponds to the comparison of the as-built model and as-planned BIM model. This comparison requires coarse and fine BIM registration processes that overlay the as-planned BIM model on the as-built model which returns the current status of the construction process. The last process is the visualization of output from the vision-based monitoring process. The VR and color labels are among the frequently explored output throughout the literature.

Further research can explore multiple combinations of alternatives identified by this literature review and present a most viable and automated process for the vision-based construction monitoring process. Furthermore, research efforts can be put into the implementation of the identified process against the traditional techniques and test its effectiveness in an actual construction environment.

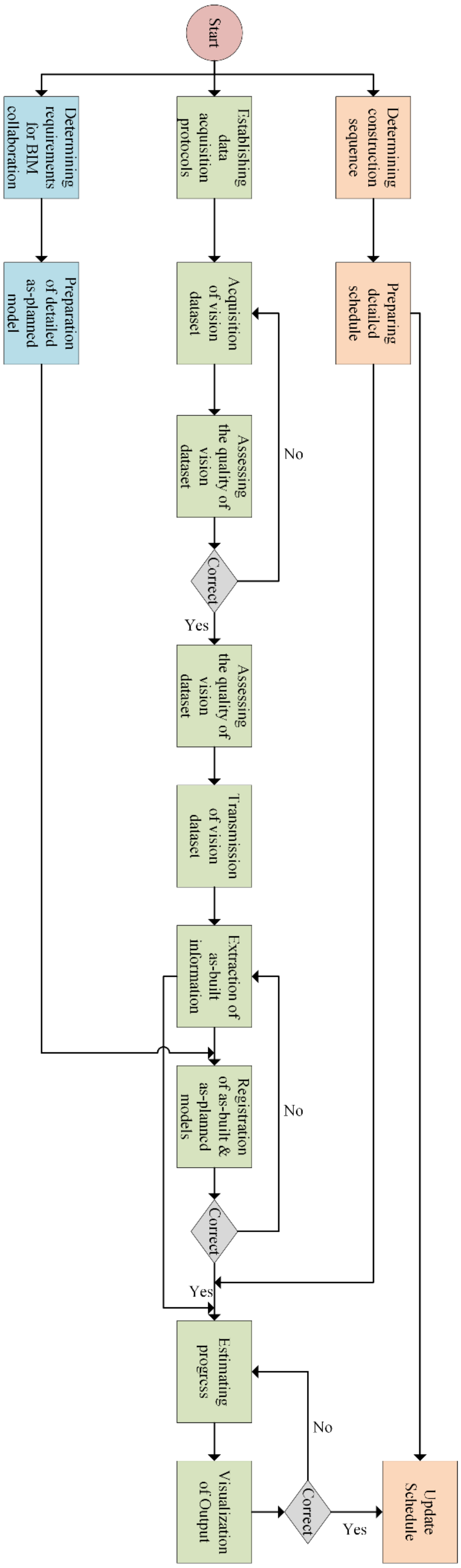

Figure **2.** Process for automated vision-based progress monitoring

Author Contributions: conceptualization, M.S. and M.T.S.; methodology, M.S.; formal analysis, M.S.; writing—original draft preparation, M.S.; writing—review and editing, M.S. and M.T.S.; visualization, M.S.; supervision, M.T.S.; project administration, M.T.S.; funding acquisition, M.T.S.

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A Meta-Analysis on the Performance of Pervious Concrete with Partial Cement Replacement by Supplementary Cementitious Materials

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Abstract: The performance of pervious concrete (PC) depends significantly on the constituent materials used in its production. Cement is the main ingredient of PC that serves as a binder and significantly affects PCs short- and long-term performance. However, its use in PC is not environment-friendly, owing to the emission of greenhouse gases in its manufacture. Meanwhile, economic growth has led to the production of massive amounts of industrial by-products and wastes. Recent research has aimed to tackle both problems with a single sustainable solution, i.e., beneficially recycling these wastes as a sustainable replacement to cement rather than wastefully disposing of them in landfills. Also, their use as supplementary cementitious materials (SCMs) could enhance the economic viability of PC production as its overall cost decreases. As such, the utilization of SCMs in PC while examining their impact on performance has received considerable attention in recent years. This study aims to quantitatively investigate the effect of replacing cement with various SCMs on PC's short- and long-term performance through a detailed meta-analysis. Compressive strength, permeability, and abrasion resistance characterized the mechanical, hydraulic, and durability performance. Data were obtained from research conducted over the last few years (2013-2021). For mixes made with a single SCM, it was observed that the mechanical and durability performance decreased compared to those of the cement-based counterparts while the hydraulic properties increased. Yet, all values exceeded the minimum requirements for using such PC in pavement applications. On the other hand, mixes made with two SCMs noted an increase in mechanical, hydraulic, and durability characteristics. Based on the conducted meta-analysis, it was concluded that a sustainable pervious concrete could be produced with partial replacement of cement by SCMs with limited impact on performance.

Keywords: Pervious concrete; Cement replacement; Compressive strength; Permeability; Abrasion resistance.

1. Introduction

The performance of pervious concrete (PC) is characterized by its mechanical, hydraulic, and durability properties. The mechanical properties are typically compressive, tensile, and flexural strength, while the major hydraulic properties are porosity and permeability. In turn, freeze-thaw resistance and abrasion resistance are regarded as durability properties. The most challenging aspect of PC is finding the balance between the mechanical and hydraulic properties [1]. Indeed, most PC exhibit low mechanical strength but adequate hydraulic performance, restricting their use in pavement applications [2].

The main binder in PC, ordinary Portland cement (OPC), is considered a non-environment-friendly material, being associated with the release of toxic gases and consumption of natural resources. To mitigate its negative impact, cement has been replaced by industrial by-products as supplementary cementitious materials (SCMs). These include but are not limited to fly ash (FA), silica fume (SF), coal fly ash (CFA), coal bottom ash (CBA), palm oil fuel ash (POFA), bagasse ash, palm jaggery ash, red mud (RM), waste glass powder (WGP), metakaolin (MK), pulverized biochar (PBC) and ground granulated blast-furnace slag (GGBS). Some studies found that their incorporation in PC improved the mechanical and durability properties with limited impact on the hydraulic performance [3-10] and an overall reduction in cost compared to PC made with OPC. Additionally, the utilization of SCMs dramatically reduces the greenhouse gas emissions attributed to PC as CO_2 released during OPC production will be reduced [2, 5].

Conversely, other studies noted a more significant impact of SCMs on the performance of PC. Saboo, et al. [11] showed that replacing cement with 15% FA and 2% metakaolin resulted in PC with improved density, compressive strength, and impermeability. Similar results were reported when 8% RHA and 0.3% of polyphenylene sulfide fibers were added to PC [12]. A complete replacement of OPC by FA- and GGBS-based geopolymer binder resulted in superior performance to OPC-based counterparts [13, 14]. Furthermore, a comparison between lab and field PC incorporating 10% CFA was carried out [15]. Experimental findings showed that, despite that the former exhibited better performance than the latter, such PC could be employed in field applications [15]. In other work [16-20], cement was replaced by SF, MK, WGP, GGBS, or PBC in PC. While the mechanical, durability, and hydraulic properties of mixes incorporating MK or GGBS were slightly inferior to those of cement-based counterparts, mixes made with SF, WGP, or PBC were superior.

Despite the promising benefits of adding SCMs and geopolymers to PC discussed above, the effect of incorporating one, two, or multiple SCMs on the mechanical, durability, and hydraulic properties of said PC through a statistical meta-analysis approach has not been carried out yet. In this study, a statistical meta-analysis is conducted to assess the performance of PC manufactured with SCMs and geopolymers. Three performance indicators namely compressive strength, permeability, and abrasion resistance were selected to represent the mechanical, hydraulic, and durability properties, respectively. Due to the recent emergence of PC, limited studies are available on PC's performance, including SCMs. A total of 27 recent publications spanning the period 2013-2021 were considered for this study. The main hypothesis of this work is that "*PC manufactured with SCM is similar to PC manufactured with OPC in terms of mechanical, hydraulic, and durability performance*." Thus, the hypothesis was tested to 95% confidence while measuring the effect size for each performance indicator.

2. Methods

Articles reviewed were extracted from numerous databases, including ScienceDirect, ResearchGate, and Google Scholar, among others. The keywords used for the search were pervious concrete, cement replacement, compressive strength, permeability, and abrasion resistance. Thirty-two publications were obtained and classified based on the sole effect of cement replacement and the combined effect of cement and aggregate replacement. A total of 27 publications were screened based on compressive strength, permeability, and abrasion resistance of PC manufactured with replacement of cement by SCMs. Of these 27 publications, 22 were used for compressive strength, 18 for permeability, and only 4 for abrasion resistance analyses.

To conduct the meta-analysis, Microsoft Excel was employed. Effect sizes (Table 1) were calculated using Cohen's formula based on the difference between PC manufactured with SCM and the control mixes (with OPC). Data extracted based on the three (3) properties under consideration were used to calculate effect sizes using Equations (1) and (2). Fixed- and random-effects meta-analyses were employed to check the variation of the variable under observation. A homogeneity test was also conducted to determine the deviation of the treated variables from the control variables.

$$\text{Effect size} = \frac{\text{Mean}_{\text{treatment}} - \text{Mean}_{\text{control}}}{\text{Standard Deviation}} \quad (1)$$

$$s_p = \sqrt{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{n_1+n_2-2}} \quad (2)$$

Where:

$\text{Mean}_{\text{treatment}}$ = mean for data based on cement replacement

$\text{Mean}_{\text{control}}$ = mean for data based on control mixes

s_p (pooled variance) = standard deviation
s_1 = standard deviation based on cement replacement
s_2 = standard deviation based on control mixes
n_1 = number of data based on cement replacement
n_2 = number of data based on control mixes

3. Results

3.1 Effect size and meta-analysis

Based on the data extracted, 28, 24, and 4 effect sizes were calculated for compressive strength, permeability, and abrasion resistance. Table 1 shows the effect sizes calculated for all the three (3) parameters considered. The values indicate that the performance is almost similar. In some cases, PC made with SCMs performs better than the control made with OPC only, while in other cases, the opposite was noted.

A quantitative meta-analysis was carried out between PC with OPC and SCM based on previous studies conducted. Table 2 presents the results of fixed- and random-effect meta-analyses. For the three investigated performance indicators, i.e., compressive strength, permeability, and abrasion resistance, the difference between the pooled "d" for the fixed and random effect are somewhat similar. This signifies that the parameters under consideration can be considered fixed according to the observed factors. Furthermore, the homogeneity test showed that the p-values were small enough to render the hypothesis "*PC manufactured with SCM is similar to PC manufactured with OPC in terms of mechanical, hydraulic, and durability performance*" acceptable with 95% confidence. Yet, it is worth noting that the pooled "d" value, p-value, and confidence interval were higher in the abrasion resistance than the compressive strength and permeability. This is believed to be attributed to the limited number of studies investigating this durability parameter.

Table 1. Effect sizes for compressive strength, permeability, and abrasion resistance.

Reference	Compressive Strength	Permeability	Abrasion Resistance
[4]	-1.7	1.9	1.5
[6]	0.9	-0.6	-
[9]	-1.2	-	-
[9]	-3.6	1.4	-
[11]	1.2	-2.5	-
[11]	0.6	-2.0	-
[12]	1.2	-1.6	-
[12]	2.0	-1.0	-
[12]	2.2	-1.4	-
[13]	1.4	0.2	-2.4
[14]	1.9	0.4	-
[14]	2.5	0.2	-
[15]	-0.4	-	-
[16]	3.4	-1.0	
[17]	-1.3	-1.3	-0.7
[18]	0.4	-1.9	-
[19]	-2.3	1.3	-
[20]	0.3	-0.5	-
[21]	1.7	-2.3	
[22]	-0.5	-2.1	-2.9
[23]	-0.8	-1.4	-
[23]	-0.8	0.7	-

[24]	0.7	0.6	-
[25]	1.2	-1.0	-
[26]	3.5	-	-
[27]	-0.3	0.3	-
[28]	0.1	-	-
[29]	-0.6	-0.5	-

3.2 Effect of SCMs on the compressive strength of PC

A more in-depth analysis of the results shown in the considered studies is performed. Figure 1 shows the variation of the compressive strength based on the number of SCMs used in pervious concrete. The box-whisker plots include pervious concrete with cement only, with one SCM, and two or more SCMs. The respective medians of these three types of mixes were 18.3, 19.2, and 15.2 MPa. Considering all the studies, it can be thus concluded that incorporating one SCM can positively impact the compressive strength of PC, while two or more SCMs cause a slight reduction in strength.

Furthermore, the maximum compressive strength values were noted in PC mixes made with OPC only, followed by those incorporating two or more SCMs and 1 SCM. The former mixes, i.e., made with OPC only, had the smallest variability in outcomes, with the interquartile range varying between 9.5 and 22.5 MPa. In comparison, counterparts including one and two or more SCMs had interquartile ranges of 10.0-25.6 MPa and 9.4-32.6 MPa, respectively. This is mainly due to the variations in the types and chemical compositions of the SCMs.

Table 2. Meta-analysis for compressive strength, permeability, and abrasion resistance.

Fixed Effect Meta-Analysis			
	Compressive Strength	**Permeability**	**Abrasion Resistance**
Fixed Effect Pooled d	0.215	-0.434	-0.873
Fixed Effect lower 95% confidence	-0.062	-0.742	-1.660
Fixed Effect upper 95% confidence	0.491	-0.126	-0.086
Random Effect Meta-Analysis			
	Compressive Strength	**Permeability**	**Abrasion Resistance**
Random Effect Pooled d	0.263	-0.457	-0.942
Random Effect lower 95% confidence	-0.184	-0.873	-2.378
Random Effect upper 95% confidence	0.709	-0.041	0.494
Homogeneity (P)	0.000021	0.011903	0.023397

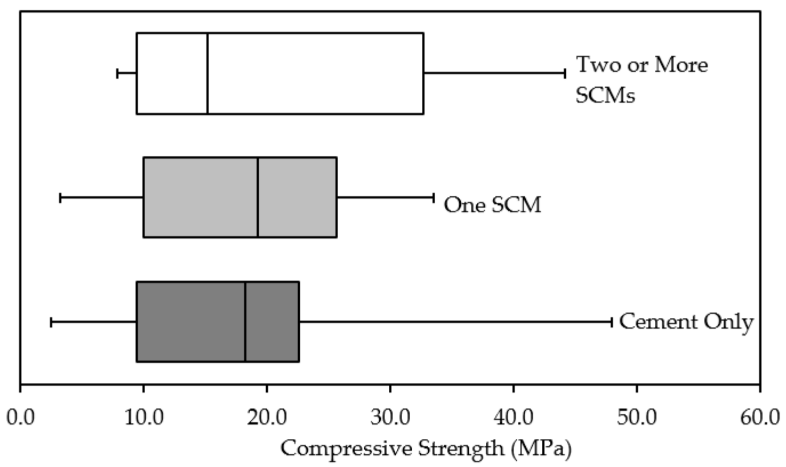

Figure 1. Variation of compressive strength based on number of SCMs used.

3.3 Effect of SCMs on the permeability of PC

Variation in the permeability of PC with OPC and SCM can be seen in Figure 2. The medians of PC mixes made with PC only, one SCM, and two or more SCMs were approximately 0.45, 0.45, and 0.50 cm/s, respectively. This highlights the similar hydraulic performance of PC made with one or no SCM with mixes incorporating two or more SCMs being slightly inferior. These results are well-aligned with those of compressive strength.

Additionally, the minimum permeability was reported for PC mixes without SCMs, followed by counterparts incorporating one and two or more SCMs. In the same order, the variability in outcomes was noted with respective interquartile ranges of 0.26-0.82, 0.30-0.93, and 0.30-1.30 cm/s. Again, the higher ranges for PC made with SCM are owed to the variations in their types and chemical compositions.

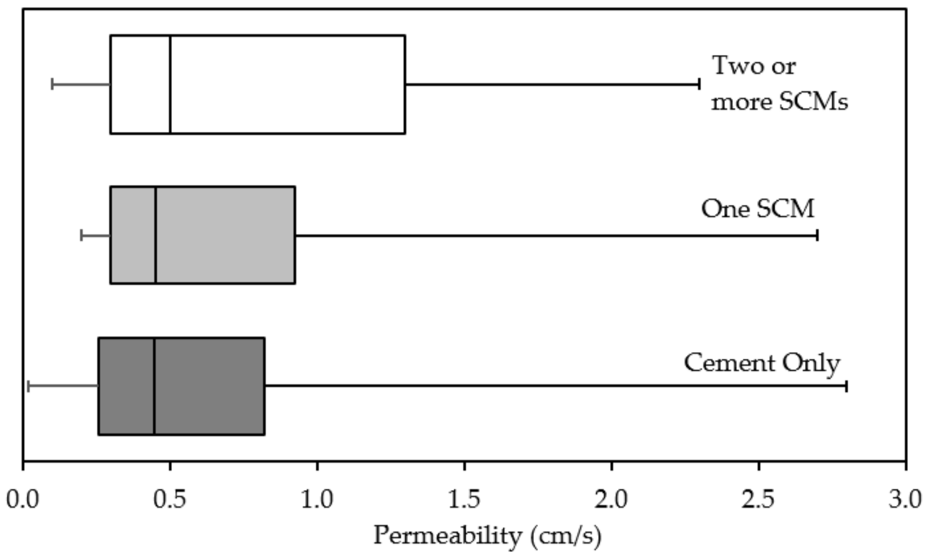

Figure 2. Variation of permeability based on number of SCMs used

4. Conclusions

This study performed a meta-analysis to evaluate the mechanical, hydraulic, and durability performance of pervious concrete incorporating SCMs in comparison to cement-only counterparts. Based on the effect size results, it can be noted that the performance of all mixes was similar. The parameters can be considered fixed according to the limited differences between the pooled "d" for the fixed and random effects. Further, the p-values signified that the hypothesis "*PC manufactured with SCM is similar to PC manufactured with OPC in terms of mechanical, hydraulic, and durability performance*" can be accepted with 95% confidence. A more in-depth analysis showed that PC made with one SCM had superior compressive strength and similar permeability to counterparts made with no SCM. In turn, having two or more, SCMs resulted in a reduction in performance. No such conclusion could be made for the durability performance characterized by the abrasion resistance due to the lack of sufficient publications in this area.

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Implementation of Passive House Standards in the UK, a Roadmap for the Local Authorities

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Abstract: This paper aims to explore as to how the UK Government and local authorities can implement Passive House standards and legislations in a feasible and responsive approach. Existing literature on Passive House implementation in the UK, and its implications are explored followed by discussions on a questionnaire survey on the feasibility of mandatory and voluntary measures. Three effective approaches for immediate implementation are recommended: i) a gradual advancement of fabric-first legislation; ii) support mechanisms (with incentives) for voluntary design and construction; and iii) higher valuation for Passive Homes on the market. The research discusses the implications and barriers of mandatory and voluntary approaches to Passive House standards in the UK domestic market, paving a path for the UK Government officials to implement such approaches/suggestions into the infrastructure of the UK's construction industry.

Keywords: Passive House; EU Environmental Law; Brexit

1. Introduction

Heating accounts for around two thirds of the household energy used in the EU [1]. In 2018 alone, the total energy consumption in the UK increased by 1.1% [2]. These two forces of non-renewable energy consumption are ever more concerning in our global landscape of the 21st Century. The correlation between mass fossil fuel operations and rising global average temperatures is no longer the main subject of debate in the circles of the scientific community; rising sea temperatures, accelerating forest fires, ecological instability, melting icecaps/rising sea levels, pollution and more will soon become everyday reality if we, members of pertaining industries (Designers, law-makers, etc.) and citizens of the UK, refuse to play our part [3].

A post-Brexit UK welcomes a race of progressive energy efficiency laws in the domestic sector. Considering the UK were "a central driver of higher climate ambition within the EU", it is imperative the UK secure that same high ambition in the post-Brexit framework; the discipline of sustainable architecture plus the enforcement of environmentally responsive legislation will open its doors to advancement [4]. During the controversy of the UK Government's decision to scrap the Code for Sustainable Homes in 2015, the application of "Passivhaus as the minimum standard required by Building Regulations" was advocated to achieve "simple efficiency, instead of complex box ticking" [5]. The UK's domestic renewable energy policies have demonstrated to be somewhat advantageous compared to the rest of the world. The UK "has had more generous onshore wind subsidies than Germany" and it "introduced one of the world's highest feed-in-tariffs for residential PV in 2010", which resulted in the "rapid uptake of nearly 1 GW of domestic solar by 31 March 2012." [6]. In addition, the third quarter of 2019 in the UK witnessed for the first time, renewable energy operations producing "more electricity than fossil fuels" [7].

These findings assert a degree of confidence in renewable energy policies post-Brexit, therefore suggesting Passive House (Table 1) to be the golden answer for achieving low-to-zero energy design for the domestic sector. The defining characteristics and benefits of Passive House standards can be put into material perspective. According to the Passivhaus Trust, "an independent, non-profit organisation that provides leadership in the UK for the adoption of the Passivhaus standard", over 65,000 buildings have been "designed, built and tested" to Passive House standard worldwide [8].

The Passive House Database, as this research is conducted, have a record of 168 Passive House buildings in the UK alone [9].

Table 1. The criteria for Passive House.

Number:	Requirement:
1.	An annual heating and cooling demand of no more than 15kWh/m2 per year is achieved, or a maximum peak load of 10W/m2.
2.	Total energy consumption (being 'primary' energy: heating, lighting, hot water & power) must not exceed 120kWh/m2 per year.
3.	Air leakage must never exceed 0.6 air changes per hour, being at 50Pa test pressure.
4.	The thermal comfort of its occupant(s) must be achieved in all living areas throughout the entire year, with its temperatures never exceeding 250C for more than 10% of the hours in a given year.
Recommended:	The specific heat load of the dwelling's heating should not exceed 10W/m2 at its design temperature.

A trend in Passive House standard is clearly growing – globally; however, there are 22.6 million homes in the UK, so only 168 of the 22.6 million are low energy homes [10]. Assuming there are some low energy homes unaccounted for on the Passive House Database but, nevertheless, this is still just raindrops in an ocean. Passive House case studies have been incisively investigated, limited to domestic dwellings in the UK. Their key building features, being the consumption of "minimal energy for space heating or cooling, and result in high levels of occupant thermal comfort", all align with the following Passive House criteria according to [11].

Understandably, the above standards may complicate the average homeowner or the less-informed/lower-skilled Designer and Property Developer/Contractor/Builder (this will be explored in detail later in the report), so a critical analysis of its benefits come with merit to offset its challenges.

Table 2. The personality and benefits of Passive House.

Benefit:	Benefit Explained:
Reduced energy bills	Adopting a design which ensures high levels of insulation and air tightness dramatically loosens the need for traditional heating systems. Specifically to the UK, a dwelling built to Passive House standards – to its minimum requirements - would use just 23% of the energy of an equivalent dwelling constructed to comply with the 2006 UK Building Regulations for its spatial heating; 41% of energy used for primary energy; and 50% energy for hot water [12].
Enhanced thermal and human comfort	Thermal comfort is defined as "being established when heat released by the human body is in equilibrium with its heat production"; its thermal factors – air temperature, radiant temperature, air speed and air humidity – can achieve levels of comfort (in combination with one another) by the standards of Passive House [11].
Improved indoor air quality	Combining air tightness and mechanical ventilation systems allows internal humidity to be at an optimal level between 30-60%; moisture and "odour-rich air from kitchens and bathrooms is extracted, and fresh air introduced" into all spaces. Filtering systems also ensure pollen and other allergens are removed, making sure occupants with asthma are not vulnerable [11].
Improved acoustic insulation	Coupling a reduction in air leakage with the combination of high levels of insulation and effective glazing will result in efficient sound performance, exceeding standards required by current Building Regulations.
Minimised carbon/energy footprint	Although following only the minimum Passive House requirements still require some need of mechanical heating and cooling, a significant minimisation in energy consumption is still achieved. In turn, a dramatic reduction in demand on the national grid – if this is adopted on a legislated scale – will follow.

Financial return/investment	In addition to significant cost savings, the homeowner has the potential to also have financial returns: utilising renewable energy sources, such as PV panels for solar energy, can offset additional costs of energy consumed. Additionally, Passive Houses will always stand out on the housing market; in turn, an increase in market value will ensue.
Better quality design and construction; durability	By following the Passive House standards, i.e. reduced air leakage, high levels of insulation, etc., a minimisation of building defects will result allowing the building to be easier to maintain, easier to put back onto the market (i.e. for investment purposes) and – in general – a nicer home to live in.

On the other hand, traditional domestic dwellings greatly depend on non-renewable energy for consumption when weather conditions take a sporadic turn [2]. Figure 2 shows the correlation between average annual temperatures and domestic gas consumption. Average temperatures are recorded to be relatively stable between 2017 and 2018, and that on a temperature-adjusted basis gas consumption followed the same pattern – relatively stable. However, due to the 'Beast from the East' in 2018, that brought the average temperature in March down by 7° C [13], the overall gas consumption in 2018 increased. The quarterly changes in domestic gas consumption, as shown in Figure 3, reveals "the robust growth in gas consumption in the first quarter" induced by the cold spell that took place [2].

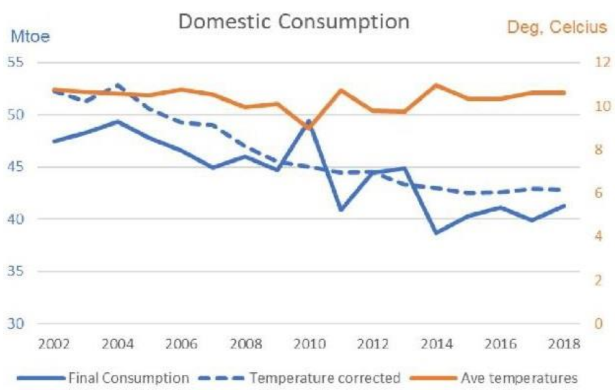

Figure 2. Domestic consumption of gas in correlation to average temperatures [2].

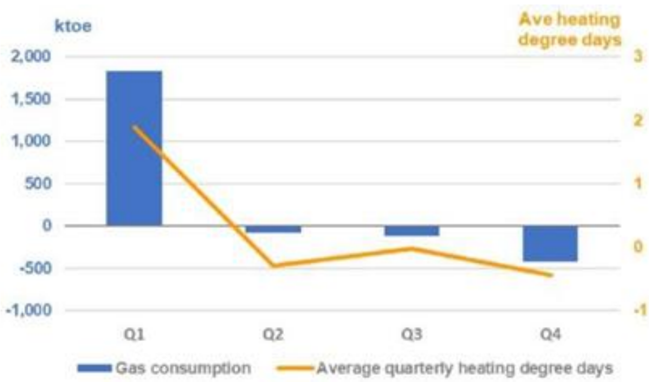

Figure 3. Quarterly domestic consumption of gas in correlation to average temperatures [2].

Considering the above, it would be relevant translating the same concerns of gas consumption to a Passive House in the UK. According to [14], a Passive House requires only 15 kWh of heating per sqm per year (15 kWh/m2a); and in the language of cost savings, for an average-sized UK home, that results in significant savings in gas consumption. Acknowledging the EU's proposed energy efficiency programmes and aspirations/targets must be explored to equip a post-Brexit UK with the energy efficiency programmes and aspirations/targets it needs to emulate – and exceed – those very same standards of low-to- zero energy for the domestic sector. The European Commission has recently enforced, under the Energy Performance of Buildings Directive, an EU policy on achieving energy efficiency in all buildings, that "all new buildings must be nearly zero-energy buildings (NZEB) from 31 December 2020" [15]. Interestingly, in 2016, the "Commission developed guidelines for the promotion of nearly zero-energy buildings in order to ensure that by 2020, all new buildings are nearly zero-energy buildings"[16]; the enforcement of this nearly-zero energy policy was a result of the progress made through guidelines not matching up to the urgency of needing near-to-zero energy buildings. This is an effective response from the EU.

To add to this, The European Green Deal published in December 2019 outlines the EU's renewed approach to near-zero energy buildings (for all buildings). The one which stands out the most, in light of this research exploring a legislated approach to Passive House, states that the EU intend a "Strict enforcement of rules on energy performance of buildings" [17]. It seems the EU have learned a lesson from the relaxed approach of "guidelines" and are shifting to a "Strict enforcement of rules" to meet energy efficiency standards. Enforcement creates results, not guidelines. If a post-Brexit UK wants to lead the way in energy efficiency, effective legislation is needed – not 'effective' guidelines. If a post-Brexit UK adopt Passive House standards for new and existing domestic dwellings, a dramatic reduction in greenhouse gas emissions will take place.

The UK Government have put forward a proposal to improve the minimum standards for fabric performance in new domestic dwellings, a step in the right direction to achieve energy efficiency. The standards (Table 4) "are based on a statistical analysis of data used to produce the EPCs of all new homes built to 2013 Part L standards, and would remove "the worst performing 25% of each thermal element being currently built" in the UK [18]. The 2020 amendment of Part L UK Building Regulations suggest a "big step towards a fabric first approach" which focuses on designing dwellings with energy efficiency in mind from the very start, as well as to switch from CO2 to primary energy as the metric to assess its performance [19].

Evaluating these proposed standards with the criteria and benefits of Passive House in mind, as well as the dire need to reach to near-zero energy consumption in UK dwellings, these standards do not even come close. Indeed, while producing Part L revisions which acknowledge Passive House standards, will be heavily driven by the existing barriers and implications of its implementation on low-to-medium scale Designers, Contractors and Clients.

Table 4. The UK Government's proposed minimum standards for fabric performance in new dwellings; a 2020 revision to Part L UK Building Regulations [18].

External walls	0.26 W/m2.K
Party walls	0.20 W/m2.K
Floor	0.18 W/m2.K
Roof	0.16 W/m2.K
Windows	1.6 W/m2.K
Roof-lights	2.2 W/m2.K
Door	1.6 W/m2.K
Air permeability	8m3.K at 50Pa

2. Pathway to legislate Passive House in the UK

Passive House standards can result in complications for the average homeowner and for the less-informed/lower-skilled Designer and Property Developer/Contractor/Builder. This poses a profound issue, considering that self-employed jobs/small businesses "in the construction sector account for 37% of all jobs" in the UK [20]; this particular occupation of the sector will understandably follow the minimum guidelines of current Building Regulations (Approved Documents) to deliver the job on time with maximised profit. A hurdle such as this requires an immediate response: Pitts [21] argues that "the key to effective implementation in practice of more advanced standards is the need for designers (architects, engineers etc.) to have appropriate knowledge and skills, as well as motivation towards engaging with low energy design"; this analysis targets designers alone as, at the end of the day, contractors build what the designer designs. However, all professionals of the industry must have an understanding of the science and technologies available to consult clients when and where necessary.

A twist to this plot is provided by [21], with his report concluding with evidence that "there has been a move towards the adoption of voluntary high level standards because of potential limitations with mandatory regulations" as well as the benefits that come from achieving high quality design, such as a dwelling achieving the Passive House certification or the BREEAM certification. Furthermore, [22] recognises that "local authorities, housing associations and individuals are motivated to create sustainable buildings" as it has "significant cost-saving and energy security" for years to come. To add to this optimism, another key obstruction to adopting Passive House in local regions – where the self-employed typically operate (i.e. building extensions in their local towns/Boroughs) – is simply "ignorance, but ignorance is slowly but surely coming to an end" [23].

Understanding the concerns raised above, in addition to the research of [24] concluding that "there is a lack of incentives for the building industry to adopt and implement low energy design strategies that are outlined in existing policies and guidance", there are effective methods of jumping successfully over these hurdles (Table 5).

Table 5. Proposed support mechanisms for enhancing the skills of the industry to move toward Passive House as the minimum standard.

Number of Method:	Method
1	The UK Government should advocate – with reiteration – their support of Passive House principles which "would help spread the good news" of its supreme energy efficiency capability [23]. This authoritative approach will definitely encourage the UK as a whole to follow PH standards.
2	In addition to the above, the UK Government can provide local authorities with Passive House programmes/initiatives/schemes to encourage small businesses and the self-employed to adopt Passive House principles. This could involve: • Reductions in taxes to encourage members to keep sustainability at the forefront of their operations, or; • Bonus schemes; • Provide training (for daytime and evening courses for flexible hours) – for free – on the available science and technologies which apply to Passive House. Those who complete the training (Designers, Builders, etc.) are awarded with a PH certification; • Provide financial incentives for clients/homeowners to employ PH certified Designers, Builders, etc., to • conduct their construction (the builder will possess the certificate)
3	To further encourage self-employed Designers, Builders, Contractors, Property Developers, etc. in the residential sector to undertake the training schemes, benefits when on the training could be provided to offset any financial losses, such as: • A reward payment; • Reimbursed transport payments (including petrol); • Free parking
4	Those who complete the training successfully could be rewarded with the following: • A loan to encourage small business set-ups; • Help with recruiting other skilled members who completed the training; • Connections to other skilled members in other disciplines (i.e. if you're a Designer, the training scheme could connect you with PH Property Developers, Engineers, etc.)

Below are produced revisions (Table 6 & 7) to the UK's proposed 2020 Part L regulations, adopting Passive House standards into its framework for: buildability; applicability; ensuring Designers obey Passive House standards from day one of designing; general guidance; to raise awareness. These will be adopted into the Part L Approved Documents to ensure self- employed and lower-skilled members are aware of its implementation (Case studies & [11] used as guidance).

Table 6. Proposed minimum standards of fabric performance for Passive House standard.

External walls	0.125 W/(m2K)
Internal walls	0.14 W/(m2K)
Party walls	0.15 W/(m2K)
Floor	0.125 W/(m2K)
Roof	0.125 W/(m2K)
Doors	0.7 W/(m2K
Windows/Glazing (all triple glazed)	0.75 W/(m2K)
Air permeability/tightness	n50 = 0.55/h; or < 0.55 ACH@50

Table 7. Proposed construction guidelines for Passive House standard.

Highly insulated thermal envelope	Follow fabric standards in Table 7.
High performance triple glazing	Building Inspector to check and approve all glazing to ensure standards are met before final approval/certification.
Continuous air sealed layer/vapour barrier	Building Inspector to be advised of all air sealed layer locations to identify, check and approve its continuity.
Heat recovery ventilation	Building Inspector to check the heat recovery ventilation system is manufactured and installed to Passive House standard
Elimination of thermal bridges/cold spots	• Building Control to approve construction drawings/details to ensure no thermal bridges; • Building Inspector to assess any thermal bridges in construction; building approval/certification is provided when this is confirmed

Understanding the significance of a legislated approach to Passive House – and its potential hurdles and implications – is one thing, but physically applying it to the existing UK regulatory frameworks for real change is another thing entirely.

2. Research Methods

The methodology of this investigation, for the collection and appraisal of relevant research information, will follow a combination of both 'qualitative: primary evidence' and 'qualitative: secondary evidence'. This will allow the paper to achieve not only credible results but - as equally important – to collect a wide range of viewpoints to understand its various dimensions. In addition, the two methods of approach will complement one another throughout the research.

The structural framework of this research is constructed of conducting interviews and producing and handing out questionnaires, specifically targeting members of the construction industry who operate in the domestic sector (both new-build & existing dwellings). Such members will primarily be Designers, as energy efficiency/Passive House awareness always starts with the Designer/Design Consultant. In addition, other members of the industry (or pertaining industries, i.e. Real Estate) will be subject to the discussion/questionnaires; members such as: self-employed and small-scale contractors, property developers and builders as well as law-makers/local authorities and building authorities (i.e. a Building Inspector who operates in local Boroughs). This is to understand if a legislated approach to Passive House in all residential dwellings (but only mandatory for proposed alterations to an existing building), in their view, is the right way forward for the UK and its industries. This paper also delves into research already carried out on Passive House, looking into mandatory approaches and voluntary approaches boosted by incentives in the domestic sector. This will shift its focus, limited to the UK, on its barriers, potential implications (such as costs, freezing productivity in industries, etc.) and on what would be the best approach for implementation. This will, in turn, help structure the questionnaires and interviews more effectively (the goal is to add to existing research to find an answer, not take a step back). A total number of 28 individuals participated in the research. Descriptive data analysis was applied using frequency and percentage to report the results of the questionnaire.

3. Results and Discussion

The first half of this research paper, explored the potential barriers and implications of legislating Passive House and, flipping the coin, entertaining the idea of having a voluntary approach energised by incentives and additional support mechanisms. Irrespective of approach (and each approach will be appraised based on the data provided), feasibility – and its ease of incorporation – is what is imperative. The findings of the previous paper concurred on two barriers of effective UK Passive House implementation: ignorance/lack of awareness and lack of training/skill amongst the majority of the construction market – the self-employed. To steer an industry towards low energy design (limited to the domestic sector), enforced by advanced design & construction standards (adopting the Passive House principle; Table 6 & 7), ensuring the majority of its employees (the market itself being the ultimate employer) have the appropriate knowledge and skills to move the industry forward is the golden rule for this research to draw on noteworthy conclusions.

A questionnaire was designed to incorporate both collective answers for general questions (i.e. "Are you familiar with the term 'Passive House'?") as well as individual answers for specific questions (i.e. "Should there be better energy consumption standards in domestic buildings?" & "Would the legislation of Passive House standards harm your role and your job security in the industry?"). This allowed the data to be filtered out, ensuring the implications and barriers of a certain member of the industry can be addressed– and tackled – and not generalise the entire findings for one outcome.

Q1 of the questionnaire (Figure 4) asked the participants if they were aware of the term 'Passive House'. From the total 28 of participants: all (16/16) of the academic/young Designers said 'yes'; the only Quantity Surveyor participant said 'yes' (1/1); just one-third (1/3) of the Self- employed Contractors said 'yes'; just one-third (1/3) of the Property Developers said 'yes'; the only Design Consultant participant said 'yes' (1/1); and, not one person (0/4) of the Self- employed Tradesmen said 'yes'. This data shows quite an even split between those who design (or part of it) and those who build (or are part of it): the Academic/young Designers, Quantity Surveyor and Design Consultant were all aware of PH; and, out of all of the Self- employed Contractors, Self-employed Tradesmen and Property Developers only 2/10 were aware of PH. This clearly emphasises on the difference of awareness between those who design and those who build; this gap needs to be overcome. More alarmingly, not a single participant of the Self-employed Tradesmen knew of PH. If, say, one were a Plumber, technologies such as Heat Recovery Ventilation Systems are one of the 5 main factors of PH design and construction (Table 7) and, evidently, this would not be considered in the self- employed field.

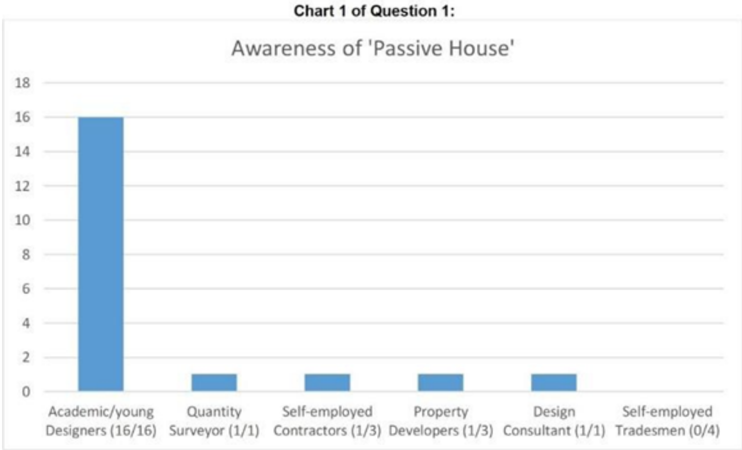

Figure 4. Question 1: 'Awareness of Passive House'.

Q2 of the questionnaire (Figure 5) asked participants if they were satisfied with the natural ventilation via prevailing wind orientation – during all seasons – in their domestic building. From the total of 28 participants: 10/28 said 'yes'; 7/28 said 'no'; and 11/28 said 'sometimes'. The goal here is to see how the participant would appraise the passive architectural design of their own home; entirely depending on the building's wind orientation, location and local climate (of the UK), 18/28 of the participants are not entirely satisfied with natural cooling (no mechanical systems).

Q3 (Figure 5) of the questionnaire asked participants if they were satisfied with the natural heating via solar gain – during all seasons – in their domestic building. From the total of 28 participants: just only 1 person said 'yes'; a staggering 23/28 said 'no'; and 4/28 said 'sometimes'. The goal here is to, again, see how the participant would appraise the passive architectural design of their own home; entirely depending on the building's solar orientation, thermal performance (i.e. materials that retain and emit heat), location and local climate (of the UK), it is, again, interesting to see that just one person out of 28 are entirely satisfied with the natural heating (no mechanical systems).

The result offers a correlation between insufficient ventilation and insufficient heating in UK domestic dwellings: in the absence of mechanical systems (air-con & boilers), the comfort of UK occupants are unsatisfied. This is down to both the inadequate design of typical dwelling models built in the UK, and, in turn, its incompatibility to the UK climate (i.e. the UK experience colder winters than the average European country, meaning occupants depend more on mechanical heating than, say, an occupant in Italy). This data shakes the shoulders of Designers, especially Passive House advocates, and should therefore shake the shoulders of Contractors/Builders too. If people are not satisfied/comfortable in anti-Passive House dwellings, why should we continue to design and build them?

Figure 5. Question 2: 'Natural Ventilation Satisfaction (Annual)' & Question 3: 'Natural Heating Satisfaction (Annual)'.

Q4 (Figure 6); From the total 28 of participants: all (16/16) of the academic/young Designers said 'yes'; the only Quantity Surveyor participant said 'yes' (1/1); two-thirds (2/3) of the Self- employed Contractors said 'yes'; all (3/3) of the Property Developers said 'yes'; the only Design Consultant participant said 'yes' (1/1); and, half (2/4) of the Self-employed Tradesmen participants said 'yes'. If we contrast this to Figure 1 of Q1, 'Awareness of Passive House', this is a big improvement all round. Limiting our focus to just Self-employed Contractors, Property Developers & Self-employed Tradesmen, we've gone from only 2/10 of them being aware of PH to now 7/10 accepting that the UK's domestic sector should be regulated by stricter energy consumption requirements. The recorded data in Q4 reveals a total of 3/28 participants not accepting the need for stricter regulation on energy consumption in domestic dwellings. The questionnaire provided the option for participants to explain their reasoning, if desired. 1 out of the 3 of these participants, a Self-employed Contractor, offered a reasoning: "If stricter energy consumption standards are put in place in the UK domestic sector, average home-buyers & builders are the ones who might suffer. This could have a knock-on effect, making homes more expensive to build and buy, therefore causing less homes being built and thus failing to meet the already high demand of housing." As explored previously, it is actually a common misconception of low-energy design to be more expensive than our current domestic models; sure, it requires the skill and utilisation of modern technologies (i.e. Ecotect, a daylight simulation software) but the costs of materials, plant and labour for construction offers no additional burden to project budget concerns. Concluding this, the importance of PH awareness – specifically its environmental and financial advantages/offsets – are in dire need of reiteration amongst the self-employed sector.

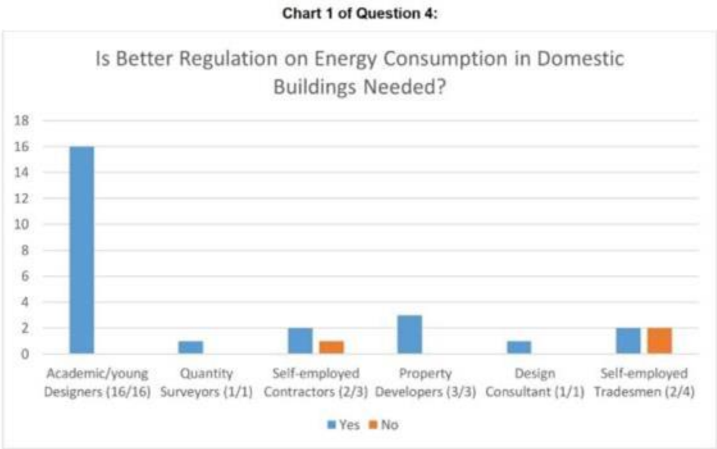

Figure 6. Question 4: 'Is Better Regulation on Energy Consumption in Domestic Buildings Needed?'

Q5 (Figure 7); The question presented the UK Government's 2020 proposal to Part L, this time acknowledging a fabric-first approach (i.e. lower u-values/greater thermal performance materials and lower air permeability/air loss). These are the main fundamentals of Passive House design, so putting forward these proposals to the participants allowed the research data to naturally evolve. From the total 28 of participants: all 28 participants said 'yes', accepting the fabric-first approach as the right approach to energy efficiency in domestic dwellings. No participants offered an additional reasoning. Knowing these participants don't represent the entirety of their role (i.e one self- employed Plumber doesn't speak for all self-employed Plumbers), it is hopeful to see all participating members to understand the key to enhanced energy standards is indeed utilising high thermal-performing materials. Contrasting this to Q4, having 3 participants not accepting stricter regulation/enforcement on higher energy standards, it is interesting to see these same 3 accepting effective fabrics to be the way forward for low-energy design; maybe this is because they are aware such materials exist on the market, but are not required to use them in their projects?

Chart 1 of Question 5:

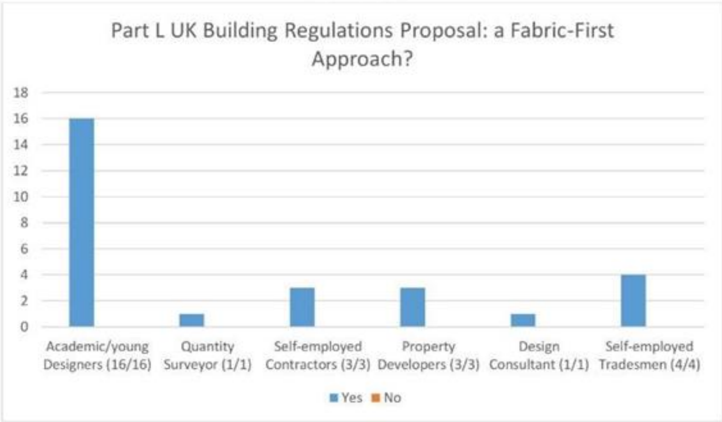

Figure 7. Question 5: 'Part L UK Building Regulations Proposal: a Fabric First Approach?'

Figure 8, Q5; continuing on from the UK Government's 2020 proposal to Part L requirements, the objective here is to see which participants from their respective roles believe the proposed standards are effective how they are, should be more effective (lower u-values etc.) or should be more relaxed (higher u-values etc.). From the total 28 of participants: 5 (5/16) Academic/young Designers said 'yes' & 11 (11/16) said they should be stricter; the one Quantity Surveyor (1/1) said 'yes, spot on' (not wanting them any other way); all 3 (3/3) of the Self-employed Contractors said 'yes'; 2 (2/3) Property Developers said 'yes' with 1 (1/3) actually wanting the proposals to be more relaxed/worse performing; the one Design Consultant (1/1) said 'yes'; and 3 (3/4) of the Self-employed Tradesmen said 'yes' with 1 (1/4) wanting stricter standards. This seems to offer quite a mixed bag of results here: everyone agreed with the fabric- first approach, accepting that the way to minimise energy consumption in the domestic sector is by using superior fabrics. However, not everyone agrees with the fabric standards put forward by the UK Government, from all different angles. When the participants were asked for their reasoning: the 11 Academic/young Designers & the 1 Self-employed Tradesmen supporting stricter standards believe the UK's domestic sector should be more in-line with Passive House criteria, but this should be a gradual progress (however, these proposals still fail to take us to the starting line); and, the 1 Property Developer opposing both the 2020 proposals as well as enhanced revisions believe such proposals can deter future Property Developers away from the market, expressing that this could be "intimidating" for such members to continue the building game. A somewhat valid reason in a sense, but reality begs to differ: support mechanisms, such as training and financial incentives, could relax such intimidation and strengthen the skills of the self-employed to build low-energy designed homes.

Chart 2 of Question 5:

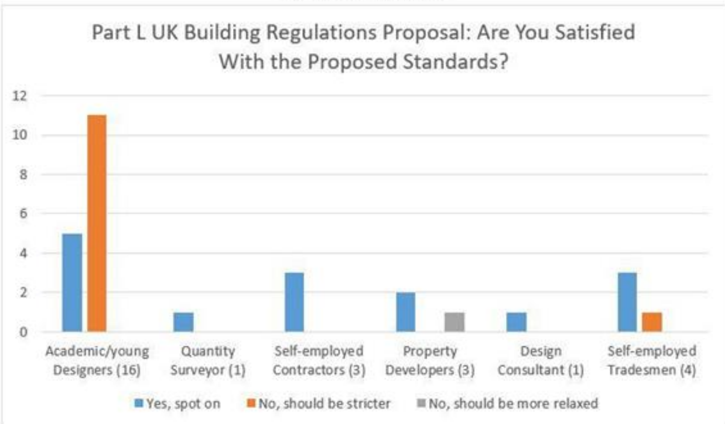

Figure 8. Question 5: 'Are You Satisfied With the Proposed Standards?'

Figure 9, Q6; from research conducted on Passive House criteria, specifically the u-values and air tightness spec required to be classed as a 'Passive House', this paper produced proposals of its own – exceeding the minimum Passive House requirements to aim for greater energy-efficiency outcomes (revisit Table 6). The questionnaire was the best opportunity to test the water; is it feasible? Would you welcome its enforcement? 11 (11/16) Academic/young Designers said 'yes' & 5 (5/16) said 'no'; the one Quantity Surveyor (1/1) said 'no'; all 3 (3/3) of the Self-employed Contractors said 'no'; one-third (1/3) of Property Developers said 'yes' with two-thirds (2/3) saying 'no'; the one Design Consultant (1/1) said 'yes'; and one-fourth (1/4) of the Self-employed Tradesmen said 'yes' with three-fourths (3/4) not accepting the legislation of stricter fabric performance. For the same reasons expressed in Q5, those who did not accept its legislation feared one of the following: it was not a gradual progression, meaning it's a big leap of change to demand sectors to comply to; and, others were intimidated by the change, meaning they fear the demanded enhancement of their skills and knowledge in the construction of low-energy design homes. Also, notice how there is 1 Property Developer who changed their mind (in Figure 8 of Q5, 2 Property Developers accepted the UK Government's proposals as they were and not desiring anything stricter, and 1 wanted them more relaxed. Now, after putting forward stricter requirements, one of these 3 Property Developers now accepts stricter standards). Unfortunately, no reason for the change of heart was provided, but the research assumes that one valued its proposal as feasible the way they operate.

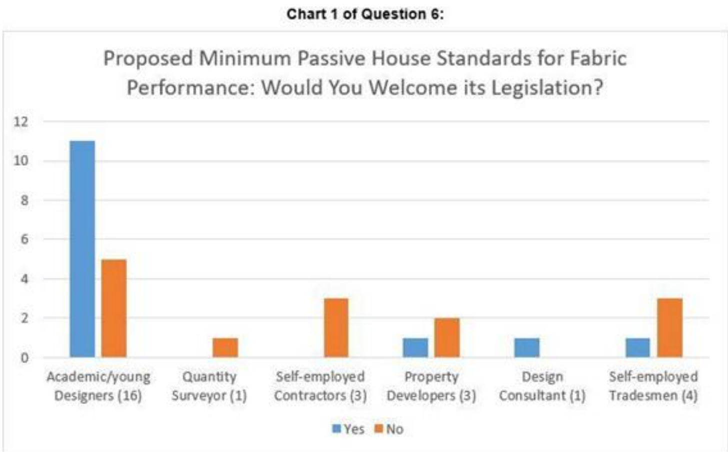

Figure 9. Question 6: 'Proposed Minimum Passive House Standards for Fabric Performance: Would You Welcome its Legislation?'

Figure 10, Q7; Support mechanisms for the self-employed – and all who require them – were proposed (Table 5), some supported by Government and some supported by local authorities. The suggestions respond to the lack of incentives and skills available to achieve Passive House standards amongst the self-employed in the UK industry, equipping them with the training required (once passed, they are 'PH qualified') and – in a sense – creating a hub/safe haven to expand their employment with other trained members (i.e. pairing a PH qualified Self- employed Contractor with a PH qualified Designer). The participants unanimously supported the proposed mechanisms. This data tells the research that all participants would in fact accept training – provided they were supported and incentivised – to become PH qualified. A few participants noted that, although these proposals have their support, it is also entirely dependent on the volume of funding catered by the UK Government (i.e. if insufficient funds were allocated, the scheme would not be sustainable).

Chart 1 of Question 7:

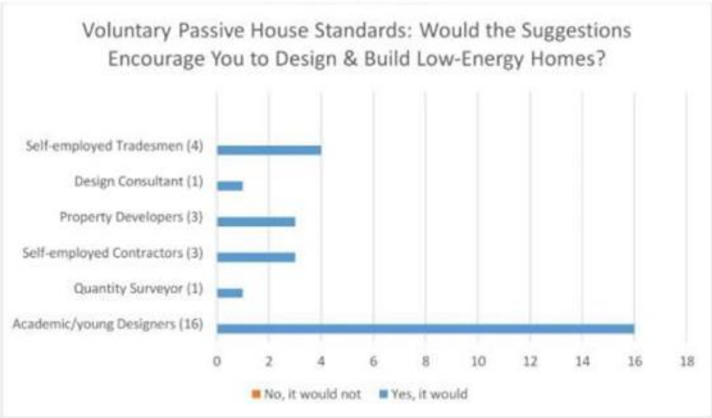

Figure 10. Question 7: 'Voluntary Passive House Standards: Would the Suggestions Encourage You to Design & Build Low-Energy Homes?'

Figure 11, Q8; The data recorded here conflicts with the assumption that each respective role of the industry holds their own opinions; this data shows each and every participant to have their own opinions, irrespective of their position. As you can see: 14/16 of Academic/young Designers, the one Quantity Surveyor, 2/3 of Self-employed Contractors, 2/3 of Property Developers & 3/4 of Self-employed Tradesmen all believe the post-Brexit economy is not an excuse to not go ahead with legislating Passive House; 2/16 of Academic/young Designers, 1/3 of Self-employed Contractors & 1/3 of Property Developers all believe it is an excuse but change such as this exceeds any other importance; remaining, 1/4 of Self-employed Tradesmen believe the post-Brexit economy has nothing to do with it but still does not want a legislative Passive House.

Chart 1 of Question 8:

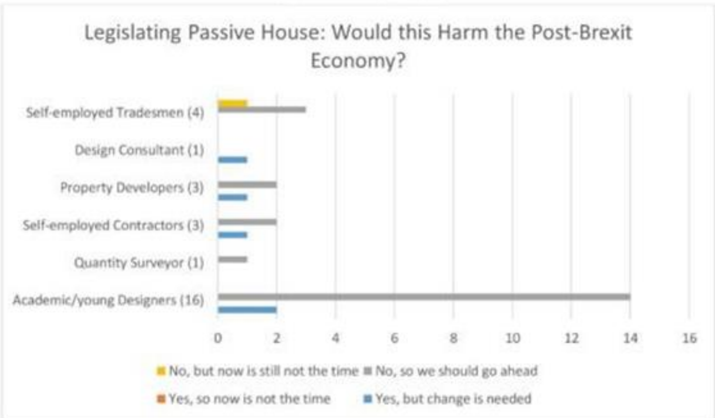

Figure 11. Question 8: 'Legislating Passive House: Would this Harm the Post-Brexit Economy?'

Figure 12, Q9. This follows on from the proposal of support-mechanisms (Figure 1 of Q7), this time asking the participant if it would harm the post-Brexit economy. The participants unanimously agreed on 'no, so we should go ahead'. This is an interesting contrast to the legislative approach to Passive House, revealing a commonality of the participants when it comes to a non-legislative/voluntary approach to Passive House standards.

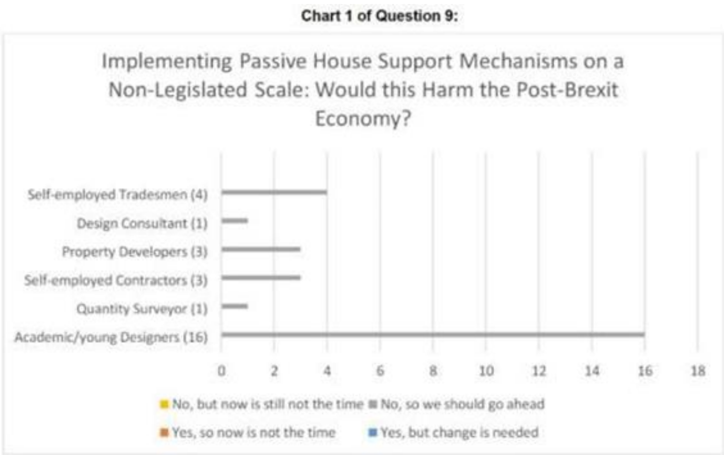

Figure 12. Question 9: 'Implementing Passive House Support Mechanisms on a Non-Legislated Scale: Would this Harm the Post-Brexit Economy?'

Figure 13, Q10. This question was posed to participants to understand if the legislation of Passive House would render their role obsolete – or make it too difficult to be profitable. From the 28 participants: all (16/16) Academic/young Designers said 'no, so we should go ahead'; the one Quantity Surveyor said 'no, so we should go ahead'; one-third of Self-employed Contractors said 'no, we should go ahead' with the remaining two-thirds accepting their job will be challenged, but the change is more important; one-third of Property Developers accept their job is on the line but change is dire, and two-thirds believe the legislation should go ahead; the one Design Consultant said 'no, so we should go ahead'; and, 2/4 of Self- employed Tradesmen admit their job will also be challenged but change is paramount, 1/4 stated that their job would not be challenged and thus legislation should happen, and 1/4 stated their job security will be affected and so does not accept its legislation.

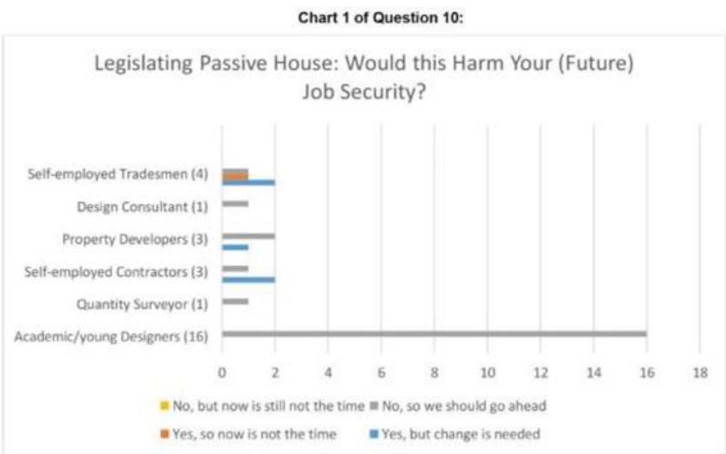

Figure 13. Question 10: 'Legislating Passive House: Would this Harm Your (Future) Job Security?

Figure 14, Q11. Following on from Figure 1 of Q9, this question was put forward to participants with the objective of understanding if the implementation of the proposed support mechanisms (Table 5) would harm their job security. Reminding this investigation that financial offsets were incorporated (ensuring participants enrolled on the programme would not be subject to financial loss), with the addition of expanded employment opportunities as well as future incentives, all 28 of the participants unanimously agreed that such implementations would not impair their role/employment. However, there was a commonality between those who are self-employed: although they all agreed (3/3 of Self-employed Contractors & 4/4 of Self-employed Tradesmen), they all noted that this acceptance was subject to one very important condition: exactly the same response as Figure 10 (Q7) – as long as adequate funding was consistently provided by The UK Government, and its local authorities, to sustain the programme and its benefits.

Chart 1 of Question 11:

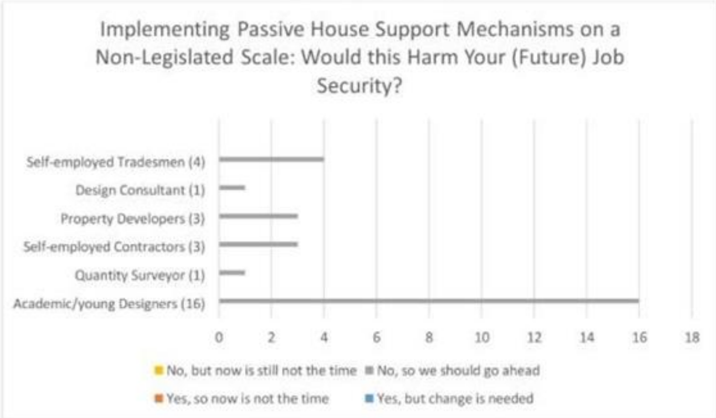

Figure 14. Question 11: 'Implementing Passive House Support Mechanisms on a Non-Legislated Scale: Would this Harm Your (Future) Job Security?'

The data recorded from Figure 10 (Q7) to Figure 14 (Q11) revealed an interesting response to the proposal of mandatory and voluntary approaches to Passive House in the UK. The research obtained through its 'qualitative: secondary evidence' explored The European Commission's response to zero-energy policy; having enforced only guidelines to meet energy-efficiency aspirations in the new-build sector of construction, and having those guidelines paired with a miserable outcome, The European Commission then responded with the enforcement, under the Energy Performance of Buildings Directive, of zero-energy legislation applicable to all new buildings from 31st December 2020. The research paper evolved from this understanding, assuming dire change – such as low-to-zero-energy homes (Passive House being the golden rule for such an approach) – can only be met by dire action: the enforcement of its legislation.

As it turns out, this is not the case. The 'qualitative: primary evidence' of this paper dramatically conflicts with its prior understanding; the voluntary approach to Passive House incorporation, propped up by the proposed support mechanisms, was met with profound positivity – almost the complete antithetical response to a mandatory legislative approach. Understandably, the self-employed members were concerned with their job security if such mechanisms were implemented (a voluntary approach) – however, such concerns would all be relaxed provided the UK Government cater the appropriate funding. In addition, some participants believed the UK's post-Brexit economy would worsen the landscape if Passive House standards were legislated, whereas not a single participant believed this would be the case if support mechanisms (again, a voluntary approach) were implemented into the UK's regulatory framework of the domestic sector.

On the other hand, however, it is imperative for this research to greatly consider its limitation (the COVID-19 outbreak) on not allowing the paper to fully conclude on such an outcome; the research, unfortunately, did not sit-down with other members of the industry to which this research question undoubtedly pertains to: members of local authorities (law- makers), Town Planners, Building Inspectors, Clients, etc. However, as previously concluded,

Self-employed members are far more at risk to such mandatory or voluntary implementations and, thus, considering their collective responses were positive, it is safe for this research to assume that a voluntary approach to Passive House with the proposed support mechanisms will steer the UK and its industries towards low-energy design homes. Q12 of the questionnaire concluded by asking participants if they have any recommendations on how to combat the energy-efficiency concerns in the domestic sector of the UK. Table 8 documents their recommendations.

Table 8. Recommendations of Participants.

Number:	Recommendation:
1.	The participants, specifically being the Academic/young Designers, Self-employed Contractors & Property Developers, noted that the approach to Passive House standards should be an approach with gradual ease and gradual progression. The reason for their recommendation comes with concerns that a sudden shape-up of standards – standards of which are far more superior than employees of its market are familiar with – can be intimidating, causing less attraction to domestic design and construction and, in turn, causing a detrimental disruption to the productivity of its market. This has been noted with utmost consideration and will play a great part to the ultimate conclusion of this research. ***Gradual change + gradual productivity/confidence = a gradual, yet effective, approach to Passive House standards. Noted.***
2.	The participants, specifically the Self-employed Tradesmen & Self-employed Contractors, recommended that, although the proposed support mechanisms of the voluntary approach to Passive House has their full support, it is entirely dependent on the fact that it has the full support and funding of the UK Government and its local authorities. Failing to entirely support the programme, and failing to ensure the sufficient funding required consistently, will cause the programme to collapse and, thus, disrupt the employment of the members concerned. ***Consistent UK Government & local authority support is paramount for the success of this operation. Noted.***
3.	The third and final recommendation from the participants is universal across the board; not a particular member/role of the industry put this forward, but rather some of each. This recommendation regards ensuring Passive House homes are more profitable on the market than those of traditionally designed and built homes (i.e those built to UK Building Regulations 2013 standards for example). Ensuring PH homes are more profitable on the market provides the following chain reaction: more Contractors, Property Developers, Builders etc. will shift their efforts to building PH homes if they're more profitable, meaning this is where the demand will be; Designers will design more (or exclusively) PH homes as this is where the demand is (more Contractors etc. are incentivised to build them); if PH homes are more of an investment than traditional domestic units, more people will want to buy PH homes and sell them (in the future), putting them back on the market; if more people are willing to buy PH homes (due to the demand and investment opportunity), the Real Estate industry will focus on PH homes as there are more opportunities for greater commission. Inevitably, a greater investment opportunity in property will induce more homes to be built (sustaining the need for more housing) and this will also result in the traditional built homes being refurbished to PH standards (as there will be a limited number of new build opportunities; i.e. land). ***Ensure PH homes are more profitable on the housing market than non-PH homes. Noted.***

4. Conclusion

The results of this paper reveal significant conflictions in two pieces of research offered when it comes to understanding the most effective approach. The European Commission's learning process, from implementing energy-efficiency guidelines to enforcing energy- efficiency policies was translated into a 'guidelines do not induce change, but enforcement/legislation does' approach. Fast forward to this paper's own data recordings and discussions, shifting its focus to those who know best: members of its industry, the response directly contrasts what was previously understood; enforcement of Passive House standards will deter its self-employed members (and others, such as Property Developers for example) from the more-advanced design and construction game.

A voluntary approach, however, paired with the proposed support mechanisms and its incentives will be the necessary – and trustworthy – force needed to push the UK's market into the right direction. On this note, the research paper has reached the following conclusion: *first*, the UK Government should gradually enforce (with legislation) stricter energy consumption standards in the domestic sector (turning to a fabric-first approach), ensuring there is no 'big-leap' from one standard to another as this could disrupt the productivity and confidence of the market; *second*, the UK Government, and its local authorities, should implement the support-mechanisms proposed for members of the industry to become Passive House qualified (and profit from it) and encourage those to follow stricter Passive House standards; *third*, the UK Government and its local authorities should work closely with the Real Estate agencies of the UK, ensuring PH homes are valued more (relative to its size, location, etc.) than its traditionally-designed counterparts.

As a result from implementing the above recommendations, there would be no harm caused to members of its market, and productivity will be sustained with gradual progress, whilst revolutionising the UK's approach to low energy design homes in the process.

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Potential of Virtual Reality Based Application for Students' Construction Planning, Sequencing, and Safety Planning Performance

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Abstract: This study examined whether Virtual Reality (VR) technology affects the planning, sequencing, and safety planning of engineering students with a construction background. The sample for the study consisted of 20 engineering students currently enrolled at United Arab Emirates University. To determine whether the 4-D VR simulation of a building helps students' learn construction sequencing and scheduling and detect safety hazards, students were initially provided only with 2-D drawings of a project along with a lecture on how to determine construction sequencing and potential hazards of the project. In the next stage, they were provided with an opportunity to explore construction sequencing via a 4-D VR-based simulation. A mixed-method survey approach was used to determine whether VR is effective in comparison to traditional learning equipment (presentations, animations, lectures, and 2D drawings). The final feedback of the students pointed towards the efficiency of digital tools such as VR in increasing awareness for construction lifecycle processes such as construction and safety planning.

Keywords: Virtual Reality (VR), 4-D Building Information Modeling (BIM), Construction Sequencing, Safety Planning

1. Introduction

The construction industry is heavily dependent on the usage of 2-D drawings at each phase of the project [13]. Relying on 2-D drawings usually leads to ambiguities, which may result in rework. Ultimately, rework results in the project extending its initially allocated budget or the project being delayed. Similarly, the process of safety management also gets hampered with the usage of 2-D drawings [14-16]. Most of the time safety managers use 2-D drawings along with their prior experience to layout safety management plans to be implemented on-site.

Industries other than construction have dramatically improved their Health and Safety (H&S) practices with increased productivity. This rapid development is due to the fact that those industries have leveraged the use of cutting-edge IT-centric technologies, which help in intelligent decision-making [17]. Similar to those tools, the construction industry over the last decade has also incorporated technologies into the conventional construction workflow. Digital tools such as Building Information Modeling (BIM) and Virtual Reality (VR) are rapidly improving the construction industry. BIM is the intelligent modeling technology that enables us to make rapid and efficient decisions based on the information we put, due to the help of visualization of a building model. 4-D BIM is the visualization of construction sequence to determine the flow of construction. VR is a tool that can help visualize the same BIM-based model, in an immersive environment. The usage of both these technologies has been very useful to the construction industry.

Similarly, construction academia has also not completely utilized the potential of digital tools for students' learning and capacity building. Typically low engagement (lectures, videos, or demonstrations) are used to inculcate these necessary skills to help them develop basic safety skills [18]. In comparison with these methods, digital tools are more effective [19]. Frequent real-time exposure with the construction sites is difficult to conduct during academia, the immersive approach helps students interact with the construction environment which resultantly inculcates the necessary skills in students regarding construction execution and safety practices.

The purpose of this research study is to explore the learning potential of the digital tools for students, and analyze whether they result in their capacity building. Little research has been done to analyze the potential of digital tools to evaluate their potential in the context of Middle Eastern academia or the construction industry. The study may serve as a stepping stone for the Middle Eastern academic circles to develop a curriculum based on technological usage to help students conceptualize construction activities.

2. Literature Review

Construction safety-based training is mostly conducted via lectures and audiovisuals demonstrations. 70 percent of this training constitutes theoretical knowledge while the remaining 30 percent is hands-on expertise [1]. With the advancement in technology, different industries including construction are benefiting from capacity building purposes. These training are expensive to develop and execute but save from the risk that comes from conducting these training on-site. Researchers have developed various training modules to evaluate their efficiency in training safety workers.

One such module is the Multiuser Virtual Safety Training System (MVSTS) which aims at providing a learning environment for tower crane dismantlement [2]. This system lets trainees participate in the virtual dismantling process of a crane. 30 participants from different backgrounds participated in this exercise and the results favored their training system as compared to the conventional method of training.

The construction industry is a multi-lingual industry, especially that of the Middle East, where human resources from around the world have gathered. Although this multilingual, multicultural environment promotes diversity but also results in the occurrence of safety hazards due to poor understanding of instructions. According to Clevenger et al. [3], 3-D visualizations can be very helpful in the training of Hispanic workers in America. Since the language in itself a great barrier in communication, they created a 3D visualization-based module especially for the needs of workers who understood Spanish. Visualization tools in BIM can help students devise construction safety measures, the information which is otherwise difficult to deduce from project documents (2-D drawings and specifications) [4].

The engagement of trainees during training is a key challenge [5]. Serious games are promising to help with the retention of trainees. Various games have been utilized for safety training purposes. One such game is Second Life, having the capability to address the lack of communication and interaction issues in traditional training programs [6]. Le et al. [7] inculcated the use of the Second Life (SL) game, which lets role-playing and social interaction solve the problem of real and virtual world communication gaps. Role-playing activities can effectively enhance the understanding of activity progression, coordination, safety training, and interface management.

The research in gaming for educational training pertains to a mostly case scenario like where the user interacts with particular cases or scenarios [8]. Dong et al. [9], developed a framework, which integrated real-time location tracking technology and BIM for lifting tasks. The case study showed that the work training could affect as-built work scenarios and improve operator capability in the virtual training environment. A scenario-based approach for learning has limitations concerning the variety and skillsets of trainees. Dawood et al. [8], approached this problem by combining 4D modeling and game technologies the improving the worker’s ability to identify hazards. The OpenSim platform was used to develop a training environment and the results proved to be beneficial for capacity building for construction safety for students [8]. Evia et al. [10], also developed a community-centric program helping their computer-based training (CBT) for Hispanic and Latino workers. Positive outcomes were derived for the capacity building of workers.

Many researchers have explored different domains within VR. For example, augmented 360-degree visuals offer reality and are low cost, easy to create, and close to a real depiction of the Jobsite [1]. Augmented 360-degree Panoramas of Reality (PARS) [11], were tried against four types of hazards to enhance the capacity of workers and their reviews testified to be helpful against hazard identification. Onsite training is insufficient and impedes the site activities and hence progress, whilst off-site training lacks the practicality and awareness that comes with hands-on experience [12]. The Proactive Construction Management System (PCMS), helps with train precast installation workers getting themselves aware of hazards [12]. PCMS uses real-time location tracking and Unity-3D as software for tracking people's equipment and materials to get real-time feedback and that can be helpful in appropriate decision-making accordingly. The rationale behind incorporating Virtual Reality in construction processes is that it provides the user with an immersive experience that might help stakeholders make an improved decision, which might prove helpful over the lifecycle of the project. VR in particular can be very helpful for creating construction scenarios specifically training and hazard identification. The existing research available in this domain does not utilize the multifaceted potential of VR in construction education. This study intends to explore the potential of VR in the context of academia, specifically focusing to

2.1 Preparation of 4-D VR Simulation

The VR headset used in this study is Oculus Quest. It is an improved version of prior what was known as Oculus Rift. This Head-Mounted Device (HMD) allows the user to have an immersive walkthrough experience in VR based environment. The components of Oculus Quest are shown in figure 1.

For this particular study, a 30,000 sq-ft residential apartment was developed in Autodesk Revit. Architecture, Structure, and MEP disciplines were modeled for this exercise. The model showed all the major components from all the disciplines to depict active construction sites. Hence the model served as the basis for investigation on construction and safety planning. This BIM-based model was then imported into a gaming engine software Unreal Engine, before cleaning it in 3ds MAX software, so that it is workable in terms of size for gaming engine. This gaming software was used for creating 4-D based VR simulations. The interface is such that the user is presented with an option initially, to walk through a building. The basic workflow of the whole process is shown in figure 2. The simulation starts at the discretion of the user. Color coding shows the construction underway in the simulation at a particular time.

Figure 1. Components of Oculus Quest (Source: https://www.oculus.com/quest/)

3. Research Methodology

Twenty engineering students; enrolled in construction engineering management electives at the United Arab Emirates University; participated in this study. These students were chosen because of their previous knowledge in the areas of project management. The students had already undertaken a course in “construction project planning and scheduling”, for which the major learning objectives were: 1) learning the overall process of construction through each phase of the project’s lifecycle, 2) read and understand construction documents for planning, 3) identify methods, materials and strategies involving in construction projects, 4) use different software (MS Project) for construction planning, 5) understand the process of control and monitor especially in terms of human and financial resources.

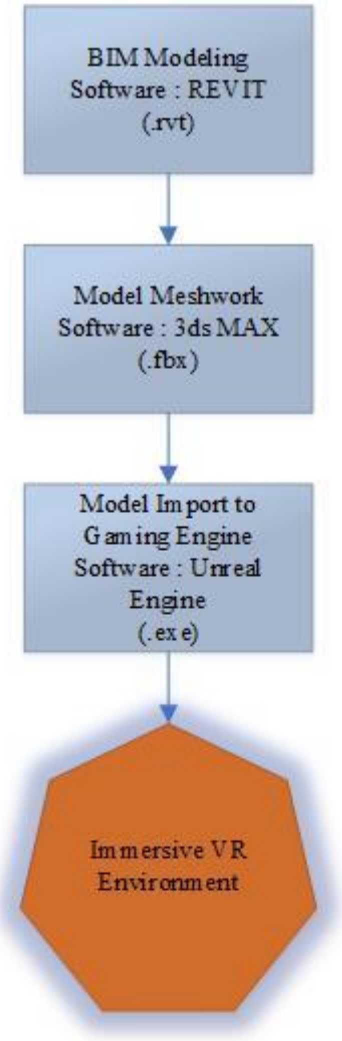

Figure 2. Workflow of 4-D based VR Environment

Before taking this course, students already had taken foundational courses such as construction project management and quantity estimation. The participated students had no prior construction industry experience.

Students, pre-and post-research designs were employed to determine whether VR helps in students' performance on construction and safety planning. The study was conducted in two phases, whereas initially students were provided with 2-D drawings, a lecture with animations and pictures, to establish a construction sequence based on Gantt chart and a safety management plan. Students were to produce crew entrances and exits, construction equipment delivery routes, possible threat spaces, potential congested spaces and predict future hazards and location of fire extinguishers. Then once their performance was evaluated, they explored 4-D based VR simulation. The same parameters were tested once the VR simulation was completed. After the assessment, a short interview was also conducted with the volunteers to record their feedback regarding the effectiveness of VR in their capacity building. For both of these tasks, students were given 20 minutes to finish.

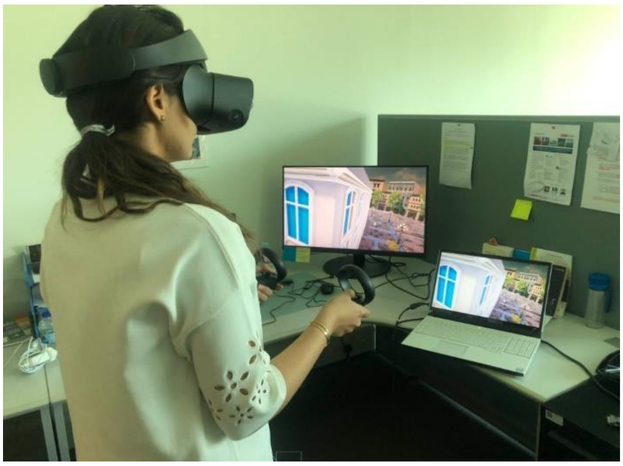

Figure 3. Test study being conducted

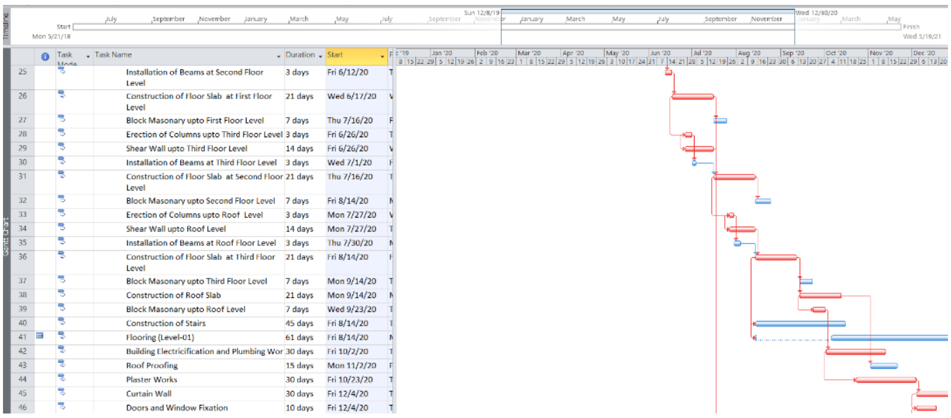

Figure 4. Gantt chart developed after the training

4. Results

During the first step of the evaluation, students were able to mention the basic architectural and structural activities that were to be held during the construction of the project. Although they missed many construction activities because of a lack of visualization and familiarity with 2D drawings. Similarly, students were able to point out few safety threats during the paper-based evaluation and missed many slip and trip, fall hazards, congested and difficult workspaces.

In the next step, students were provided an opportunity to experience the step-by-step timeline of the project in VR (figure 3). Once they were able to observe the project simulation. They were again tested for their knowledge to list down all the potential activities and potential safety lapses that may occur during the project. Given the activities, instructions, and period, the students were able to develop the Gantt chart (figure 4), of the project. With the VR representation students' performance for both construction planning and safety tasks improved and they were able to grasp project knowledge in a better way. After this step, the students were asked questions about their perceptions of the digital tools to improve their already knowledge. Students found the experience to be "immersive and interactive", "easy to learn" and "effective". As per the students, traditional learning strategies and 2D drawings do not provide the holistic scenario of the project. Students reviewed the technological use as per their experience with the real-time construction, which could also be the reason the students' performance was much better after the VR simulation. This way students can get a real-time grasp of the project without actually being on-site.

5. Conclusion

With the rapid improvements in digital tools such as BIM and VR, students can effectively learn complex construction concepts. Step by step VR simulations can provide a realistic experience of the project which may provide students with a better understanding of the project sequencing and learn about different safety hazards of the project.

This study evaluated the potential of VR against traditional learning techniques to incorporate construction planning and safety knowledge. The students were made to perform exercises based on 2D drawings and then with the VR immersion. With the VR immersion students were able to identify more activities and similarly more safety hazards.

The inculcation of the digital tools especially with the ongoing pandemic and virtual schooling could be a good measure that may help elevate student's capacity building for construction life cycle processes. Moreover, digital technologies can help replace students learning trips which are very difficult to execute due to the COVID-19 pandemic. Different measures should be taken at the academic level to establish a supplementary reliance on digital technologies such as VR which may result in increasing skills for construction students.

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Using Repertory Grid Technique to Investigate the Impact of Changing University Hostel Function During COVID-19 Pandemic on Students' Well-Being: A Pilot Study

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Abstract: COVID-19 pandemic alerts us about the future of the architectural design of our built environment. During this pandemic, buildings have functioned unexpectedly for different purposes and lengths of stay. Some student hostels have been transformed from their standard operations to become quarantine buildings, such as Maqam 4, one of the United Arab Emirates University (UAEU) female hostels. We were interested in examining the hostel design and function under this uncommon situation to explore a potential need for a new building typology for university students. Therefore, we sought to investigate the impact of the hostel design, during its both quarantine and standard operations, on students' well-being. Studies concerned with students' well-being during COVID-19 were mainly using standard psychiatric scales to gain quantitative measures for certain predefined mental disorders through self-reporting questionnaires. We aimed to implement a more intercave approach navigating students' feelings and gaining a rich insight of their perceptions about the built environment. For that, concepts of the Personal Construct Theory (PCT) and its associated Repertory Grid Technique (RGT) were targeted as a method for this aim in a small-scale research. RGT is a structured interview aims to find out how people make sense of their experiences. In this pilot study, perceptions of quarantined and non-quarantined students who stayed in the same hostel, case of Maqam 4, were gained through semi-structured individual interviews. The results revealed the good potential for the use of RGT in the full-scale research. These results articulated the kind of hostels that university students are willing to stay in normal and extreme events such as COVID-19. It also questioned whether there is a future need for a new building typology to emerge or a resilient design to cope with different living scenarios.

Keywords: COVID-19 Pandemic; Quarantine Building; Repertory Grid Technique; Standard Operation; Students' Well-being; University Hostel

1. Introduction

In March 2020, the novel Coronavirus (COVID-19) had been assessed and characterized as a pandemic by the World Health Organization (WHO). COVID-19 is not only a public health crisis as it is affecting multiple societal sectors, such as the higher education [1]. As an operating measure to control the virus spread, university education worldwide shifted from its usual face-to-face experience to become on-line. This shift in education delivery mode led to closures for university campuses, in turn affecting student housing operation as a place for living and studying together [2]. Besides, some student housing facilities were shifted from their standard operations to become quarantine buildings [3, 4, 5].

During this pandemic, as buildings have functioned unexpectedly for different purposes and lengths of stay, studying the impact of building design on occupants' well-being becomes more crucial. This effect was addressed clearly in a recent review paper concerning occupant health in buildings during normal operation and extreme events, such as COVID-19 [6]. According to the WHO, well-being is introduced in three aspects: physical, mental, and social [7]. Issues associated with the mental aspect of well-being were proved significantly among university students worldwide before and during COVID-19 [8, 9]. Mental health is defined by WHO as: "a state of well-being in which an individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and is able to make a contribution to his or her community"[10]. Different mental well-being measures are designed to evaluate certain predefined feelings and/or psychological functioning [11]. Warwick-Edinburgh Mental Wellbeing Scale (WEMWBS) is one of these measures which presents mental well-being as both feeling good and functioning well [12]. Besides, there are various mental illness measures designed to evaluate symptoms of certain mental disorders, such as depression, anxiety, and stress [11].

Mental health of university students in general and who are staying in student housing in particular is among the challenges arising from COVID-19 [13]. For example, students in health-related programs, such as medicine, dentistry, nursing, and pharmacy, were found with symptoms of anxiety in China. This study also proved that students who were living apart from their parents experienced higher anxiety [14]. Moreover, female students in the same health-related programs showed higher symptoms of anxiety and depression in Bulgaria [15]. They also showed symptoms of stress in India, where most majority of the sample size were living in the hostel [16]. Besides, students from various collages were found with symptoms of anxiety in the United Arab Emirates [17], anxiety and depression in the United States [18], and anxiety and stress in France [19].

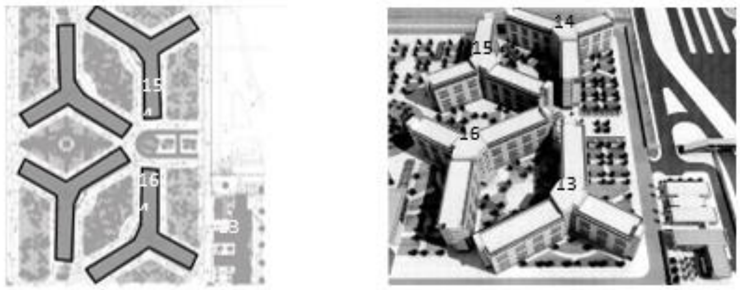
Studies which showed mental health issues among students during COVID-19 also proved the relation between these issues and the built environment where students are staying. For example, the availability of different types of greenery, such as a garden in houses, a green view in apartments, and indoor plants, was found associated with lower depression and anxiety [15, 19, 20]. Further, housing physical characteristics, such as the area and the presence/absence of a balcony was found associated with level of students' depression. Higher depression was also found associated with poor quality of indoor areas, such as lack of natural lighting, acoustic discomfort, and need for artificial lighting during the day [20]. This association between students' well-being and the design of student housing specifically as a place of residence is an area of research requiring further exploration. A recent scientometric review paper identified the main trends and gaps of student housing research. It indicated sustainable student housing as one of the research gaps [21]. As one of the characteristics of a sustainable student housing, it should minimize and ultimately eliminate negative impacts on students' well-being through the life cycle of the building [22].

The impact of COVID-19 on higher education facilities, such as student housing, opens horizons to think of an approach to design and purpose the new built facilities coping with normal and extreme scenarios, such as COVID-19 [23]. This research looks at the current continuous experience of COVID-19 as an opportunity to explore a potential need for a new building typology for university students. The aim of this research is to rethink about student housing design from the perspective of students' perceptions about the built environment and its impact on their well-being. Studies concerned with students' well-being during COVID-19 were mainly using standard psychiatric scales to gain quantitative measures for certain predefined mental disorders through self-reporting questionnaires. The qualitative research reported in this paper tried to overcome this shortcoming by implementing a more intercave approach navigating students' feelings and gaining a rich insight of their perceptions. For that, concepts of the Personal Construct Theory (PCT) and its associated Repertory Grid Technique (RGT) were targeted as a method. A pilot study concerned with shifting a student hostel operation from standard to quarantine was conducted to explore quarantined and non-quarantined students' perceptions through semi-structured individual interviews. A case study of Maqam 4 hostel, one of the United Arab Emirates University (UAEU) female hostels was considered for the study purpose. To achieve the study aim, the following questions were raised: (1) How did students make sense of their experiences in Maqam 4 hostel during its standard and quarantine operations? (2) What main design features of the hostel contributed to students' experiences and feelings? (3) what is the future vision for the student housing facility?

2. Materials and Methods

2.1. *Case study*

It was needed to select a case study of a student hostel that had been operated for both standard and quarantine purposes. Therefore, Maqam 4 hostel was selected taking into consideration the applicability of the researcher's accessibility. Maqam 4, shown in Figure 1, is the latest built hostel among the five female hostels of UAEU. It has four typical G+5 buildings labeled as 13, 14, 15, and 16. It can occupy 1000 students; 250 students in each building. Figure 2 shows the typical ground and 1st to 5th floor layouts. The typical room module, shown in Figure 3, has two individual bedrooms, labeled as A and B and shared bathroom in between. During COVID-19, the capacity of the hostel is reduced to 50% by operating rooms A's only and closing B's as one of the health precautions. In respond to the need for a quarantine building for students who contacted positive COVID cases or returned from a travel, UAEU assigned two buildings of Maqam 4 hostel for this purpose. For that, buildings 14 and 15 are being used as quarantine buildings while buildings 13 and 16 are continuing their standard operations hosting students whom their presence in the university is required.



(a) (b)

Figure 1. (a) Site layout; (b) Views of Maqam 4 hostel.

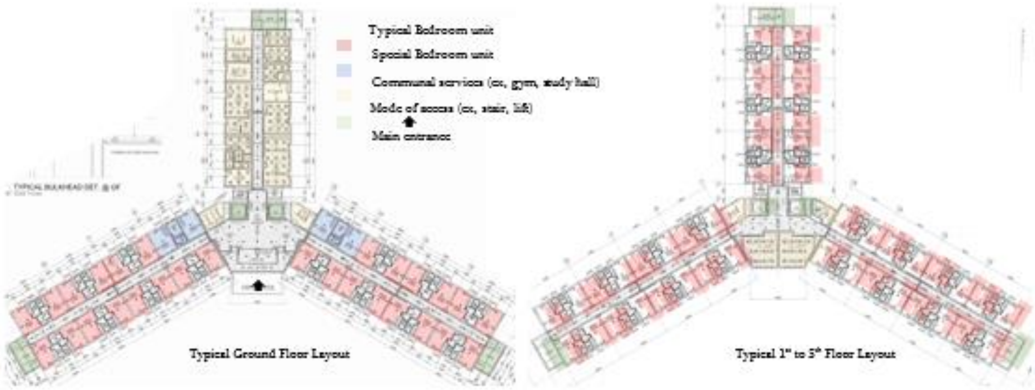


Figure 2. Typical ground and 1st to 5th floor layouts of Maqam 4 hostel.

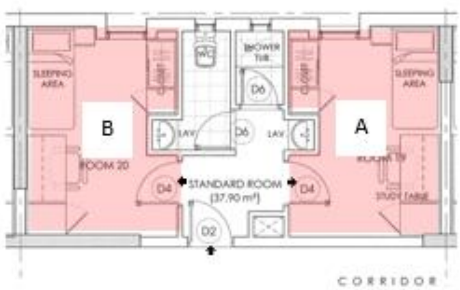


Figure 3. Typical standard room (1 student / room A or B) of Maqam 4 hostel.

2.2 RGT

RGT can be defined as a structured interview in which interviewees' responses are placed in a grid form. It was devised by George Kelly in 1955 and is based on his Personal Construct Theory (PCT). The components of RGT are elements, objects of the topic under investigation, constructs, people's perceptions about the elements, and a rating grid, with elements at the top of the columns and two poles of each construct at the far ends of each row. RGT can be designed in four forms: real repertory grids in which elements and constructs identified by participants, grids with fixed elements, grids with fixed constructs, and grids with fixed elements and fixed constructs. These common forms are types of quantitative grids in which each element is rated by the interviewee based on each construct using Likert scale. On the other hand, there is a qualitative grid in which people's perceptions, that carry their constructs, are placed directly by their own individual used words as answers of the perceivers towards questions or elements of investigation. Choosing the suitable form of RGT depends on the focus of the study [24].

The elements are the objects of people's thinking to which they relate their concepts or values. There are common characteristics for the elements. They should be homogeneous, all the same type, discrete and representative, a reasonable coverage of most aspects for the topic of investigation, short and brief, specific and easily understood by the respondent, and finally previously experienced by the interviewee [25]. Elements can be supplied by the researcher or elicited from the participants. If they are supplied by the researcher, their number is correlated to the topic under investigation and time allocated for the interviewees. On the other hand, to elicit the elements, direct or indirect questions can be asked to generate a list of elements. This approach lets the respondent nominate what is considered the key elements that make up the subject matter to investigate [26].

The constructs are the discriminations that people make to describe the elements in their personal individual words. The constructs should be a bipolar phrase in which opposite phrases are available in each. The bipolarity emerged from gaining similarity and difference statements from interviewees. Jankowicz summed up the qualities of a good construct to be clear, appropriately detailed, and relevant to the topic [27]. Methods of eliciting constructs differ widely based on the nature of the study and the matter of investigation. The traditional way of eliciting constructs is by comparing the elements in a monadic, dyadic, or triadic form. However, constructs can be elicited in ways other than from direct elements. One of these other ways is eliciting personal constructs by interview in which a talk is elaborated about the elements to reveal the constructs. This method helps the interview to be a conversation rather than a boring task to the interviewee [24]. Considering the focus of this study, individual semi-structured interviews were conducted to elicit students' perceptions grounded in the substance of RGT.

2.1.1. Individual semi-structured interviews

As PCT focuses on people perceptions from their individual experiences with the same event, place, or object [24], it was important to consider whether students have differences that might affect their perceptions. After interviewing the student housing specialist, it was found that students who experienced the stay at the same hostel of Maqam 4 can be classified into three main categories. The differences in these categories refer to multiple factors: nationality (local versus international), academic level (undergraduate versus graduate), purpose and length of stay (standard versus quarantine), and purpose of quarantine (contacting positive COVID case versus returning from travel). One other important factor is the place of residence that students experienced before and after their stay at Maqam 4. The significance of this factor comes from the concept of comparison which represents the core of the PCT. This concept indicates that people are more capable to describe their perceptions about a certain element when they compare it with others [24].

First category is non-quarantined students who are staying at Maqam 4 hostel, buildings 13 and 16, for their recent academic semester of spring 2021. These students are mainly local freshman undergraduates. They came from their original homes, stayed for the first time in Maqam 4 for around three months, and then returned homes with the end of the semester. Second category is quarantined students due to return from travel. These students are mainly international graduates.

They came from their original countries, stayed for the first time in Maqam 4, quarantine buildings, for around 10 days. After their quarantine periods, they moved to another hostel which is Maqam 2 to pursue their stay and study at the university. Last category is quarantined students due to contacting positive COVID case. These students are either internationals from Maqam 2 hostel or locals from the new-campus or Maqam 4 hostels. If they contacted a positive case of COVID-19, they will be shifted to the quarantine buildings of Maqam 4 for around 14 days. After this period and the negative result of COVID-19 test, they are returned to their original hostels. Concerning the above categories, three individual semi-structured interviews were conducted, and the following set of predetermined questions were defined in each:

(a) How were your feelings towards your experience in Maqam 4 hostel?
(b) How did you perceive the used spaces during your period of stay in Maqam 4 hostel?
(c) How did you perceive the used spaces before/after your residency in Maqam 4 hostel?
(d) What coping strategies did you use to overcome any negative feeling?
(e) What kind of future space would you expect to suit hostel students' activities?

These questions were not following a specific order as the interview was taking a conversational mood. To guide the interview on its focus about the hostel design and to help students reflect on their experiences, students were encouraged to think of these questions in relation to their experience in other hostels of UAEU. Two of the interviews were conducted in a long approach, lasting for around 35 minutes. Props were provided continually to explore students' meanings, and also detailed questions were raised to generate detailed data for further investigation. While the third interview was conducted in a short approach, lasting for around 16 minutes, with minimal inference by the interviewer. All the three interviews were audio recorded.

2.2. Sampling

In respond to the nature of the study, purposeful sampling technique was important to be used to interview a representative student from the three discussed categories. After getting UAEU ethical approval, it was required to know the willingness of students for being interviewed prior to contacting them. Therefore, an online survey was created through google form and sent to two groups of students during spring 2021 academic semester. It was sent to 165 students of Maqam 2 hostel through hostel what's app group and to 124 residing students in buildings 13 and 16 of Maqam 4 via email. The number of possibly contacted respondents for the interview purpose was thirteen from Maqam 2 and twelve from Maqam 4. Two long approaches interviews were conducted; each was with one of the respondents of the two groups. Third short approach interview was conducted with a student representative for the category of local students who are residing in the new-campus hostel and stayed in Maqam 4 for quarantine purpose after contacting a positive COVID case. Figure 4 illustrates the differences among the three interviewees, perceivers.

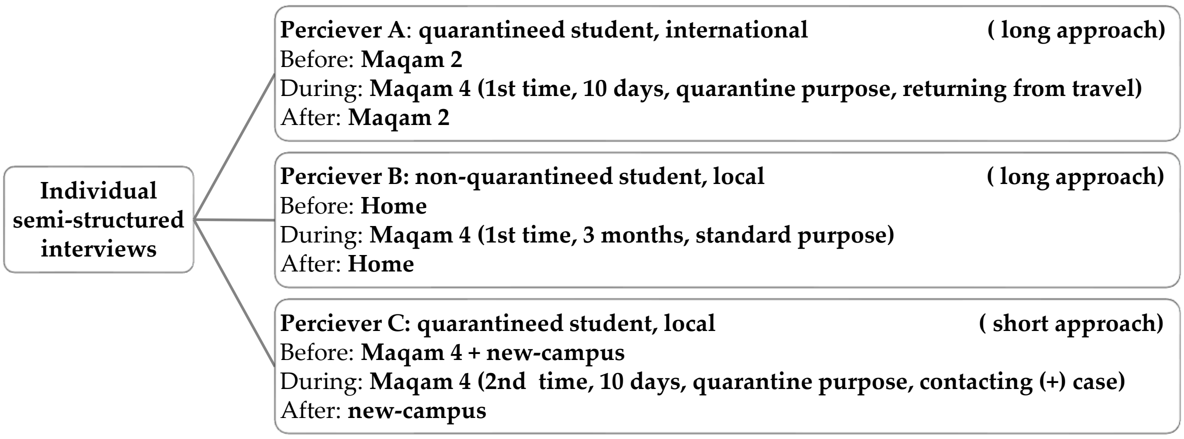


Figure 4. Differences among interviewees.

2.3. Data Processing and Analysis

To categorize qualitative data, the elicited statements can be grouped into clusters. This grouping is based on commonality in wording [28]. Further, categories should feature internal homogeneity and external heterogeneity [29]. Thus, interviews were transcribed and, in case of Arabic participants, translated into English. Then, the transcripts were analyzed to generate categories of students' perceptions answering research questions and placed in qualitative grids.

3. Results

Interviewees' perceptions of their feelings towards their experiences in Maqam 4 hostel and towards the future space for students are shown in Table 1. Perceiver B, non-quarantined student, showed positive feelings of being comfortable and having enjoyable experience in Maqam 4 hostel. She explained how the experience in the hostel helped her to feel more responsible by managing her own time and tasks individually. She also explained the availability and sufficiency of her daily needs. On the other hand, perceiver A and C, quarantined students, showed dissimilar feelings. Perceiver A showed an overall positive feeling of being good and comfortable. This feeling was mainly associated with the availability of friendly people around. Perceiver C, quarantined due to contacting a positive COVID case, showed an overall negative feeling of being lonely and scared. She also showed some positivity due to availability of cooperative people around.

Table 1. Interviewees' perceptions towards their experiences and the future space.

Perceiver	How were your feelings towards your experience at Maqam 4 hostel?	What kind of future space would you expect to suit students' activities?
A	- *"first two days you knew new country outside the box. You do not know much what is outside the wall. You knew, you just came from airport. They just taking you from the taxi and dropped you here."* - *"I actually met one of my neighbors, she was also staying there. She was also in quarantine. We knew each other. We got to know each other so I did not feel so much of, and the building management people whoever there you knew those nurses, other workers, they were nice. They were very communicating, they made us to be in home you knew."*	- *"I would say this space would be like we can have group activities. Something like you know to get to know each other, cook together, having some cultural event, or sports even. Everybody can come together; we can have some fun, or we can have like a competition like. You know… to have social life, I would say in the future. You come to know who beside you. You know what she likes, what she does not, you know… start communicating instead of sitting in the room, full box"*
B	- *"The hostel frankly, the hostel experience was very nice for me. I could even know organizing my time, I wake up from the early morning, al Fajar time, I start walking then I go to study then I attend my classes. I even start knowing washing my clothes alone. I know doing everything; there is nothing I cannot do, and when I am missing something, the supermarket of the hostel is here. I do not feel there are too many things I am missing when I am here."* - *"I did not feel at any time I do not want to stay in the hostel and want to come back home. The opposite, when I was at home, I missed the hostel. I want to come here."*	-*"I expect the space to be like B3 building of the university; it is for example have everything.. there is salon, library, there are many things, but we could not use because of corona, they are closed. I feel the space would be like this one; it suits all students, like there are various activities suiting all people, all girls inside. Something suits for all of us. For example, to have a gaming area, movies area; areas that are different so each student can visit what she wants"*
C	- *"I get tired psychologically."* - *"I was scared. What if I have the virus?"*	- *"I feel the building must be sound proofing."* - *"if there was a building or at the same time more studying rooms than the existing ones and*

- *"It was something scaring a lot and you feel alone. But later, it was fine."* - *"They were understanding a lot in case if someone wants to ask for delivery, they bring the food, we do not go. They bring the food, cooperative. From the emotional side, I mean it was a little mixed."*	*at the same time halls for I cannot say for students to gather; it is quarantine currently, but a space for activity or something for people who want to make activities."* – *"The furniture, I feel, it has to be designed for the room, not like putting a table that is very big in a very small room. Even if they told me, you could move it, there are many limitations. The bedroom is very tight comparing with the furniture in it. If they have a better use of furniture; that would be better a lot."*

Interviewees' perceptions towards the used spaces at Maqam 4 hostel comparing with the used spaces in other hostels before and after the quarantine were summarized in Table 2.

Table 2. Interviewees' perceptions towards the used spaces at Maqam 4 and other hostels.

Perceivers A &C	Perceiver B
1. Bedrooms were perceived small and might not be convenient for long term use. Comparing the bedrooms size with Maqam 2 hostel, students prefer bedrooms of Maqam 2 hostel for its wider areas.	1. Bedrooms were perceived convenient and sufficiently satisfying the needs. Comparing the bedrooms sizes with new-campus hostel, students prefer bedrooms of Maqam 4 hostel for its wider areas.
2. Natural lighting was perceived satisfying the needs in bedrooms and other spaces.	2. Natural lighting was perceived satisfying the needs in bedrooms and other spaces.
3. Inside bedrooms, the artificial lighting was perceived suitable and convenient for. Comparing the artificial lighting of bedrooms with Maqam 2; students prefer the lighting in Maqam 4 as it looks white while in Maqam 2, it is yellowish	3. Inside bedrooms, artificial lighting was perceived suitable and convenient for different purposes.
4. Single use of bathroom was perceived positively comparing with the shared bathroom among each three bedrooms in Maqam 2 hostel.	4. Bathroom arrangement in relation to bedroom was perceived positively comparing with its arrangement in new-campus hostel.
5. Views of windows were significantly contributing to students' moods.	5. Views of windows were perceived positively.
6. Th architectural style of the hostel design was perceived positively and preferred more than Maqam 2 due to its modernity (newly built) and building colors.	6. Th architectural style of the hostel design was perceived positively.
7. The hostel was perceived as being isolated.	
8. Rooms distribution along a corridor was perceived negatively comparing with its distribution in Maqam 2 hostel.	

4. Discussion

The interviews revealed the main differences between how quarantined versus non-quarantined students perceived their experiences in Maqam 4. It also revealed the differences in feelings due to the purpose of stay and to different factors associated with each individual experience. For example, although perceiver A was experiencing not only Maqam 4 hostel but the overall country for the first time, she was more satisfied with her quarantine experience than perceiver C. Besides, perceiver C, showed less satisfaction, although she was experiencing the residency in Maqam 4 hostel for the second time. Using PCT concepts helped to find out that feelings that students were expressing can be related more to their emotional well-being than the presence/absence of certain mental concerns. Being emotionally healthy does not mean the absence of negative feelings, such as being stressed, depressed, or sad; however, it means the awareness of these feelings and the capability of handling with them [30]. Therefore, further investigation is recommended towards students' emotional well-being and its linkage to the built environment.

Moreover, the interviews showed how students' perceptions towards the design of Maqam 4 hostel were associated with their experiences of other hostels and to their purpose and length of stay as well. The three perceivers were generally satisfied with the overall design of Maqam 4 hostel. They highlighted common factors affected their experiences positively such as, availability of sufficient natural daylighting in bedrooms and other common spaces, suitability and convenience of artificial lighting, good quality of views from windows, and the new and colorful look of buildings. However, quarantined perceivers highlighted some shortcomings related to bedroom size, floor layout, and allocation of the hostel. These physical design features of the hostel design were found affecting students' mental well-being in the reviewed studies.

Aside from the differences in the perceptions of the three perceivers towards their experiences in Maqam 4 hostel, they all perceived a future facility for students with a similar characteristic of having multi-functional recreational communal space. They are expecting these communal spaces to occupy various functions and to suit various students. This can draw an attention to two points. First, it can justify the main missing design aspect that affected students' experiences and feelings differently. The non-quarantined students have the capability to reach the nearby communal building, B3-the village, within the university campus in contrast to quarantined students who are not allowed to go out of their rooms or buildings. This absence of recreational activities and physical exercises were found among the associated factors with different problems of mental well-being during COVID-19, such as stress, anxiety, and depression [31]. Second, if quarantined students cannot access the current multi-functional communal spaces, how their individual spaces can be different to satisfy this need. The need for a multi-functional recreational communal space in normal and extreme scenarios similar to COVID-19 can be the milestone of envisioning a new building typology or designing a new kind of resilient hostels.

This research is conducted as a pilot study on a small-scale in order to help designing the full-scale research later using the RGT technique. The results showed that the main study is feasible with close monitoring to the interview tool that requires less inference from the interviewer.

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Session 9:

Environmental Sustainability and Policies

Sustainable Approach: Smart Grid System Challenges and Opportunities in UAE Building Regulation Codes

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Abstract: The rapid extreme economic evolution of the United Arab Emirates (UAE) has followed in giant power plans. Numbers have revealed that, two years ago, the total electricity consumption in the UAE was more than to thousand GWH, which reflected an increase of 1.5% compared to previous records by using the standard model of electricity generation. Governments have realized a necessity for updating the electric energy system and creating such Smart Grids around the planet. UAE set various guidelines and tactics matching with the recent sustainable international projects in terms of decreasing energy consumption and gas emissions. Currently, green energy and new technology assisted to reduce these matters. The Smart Grid System (SGS) is a combination between the connected networks and the technological era, which provides several methods to produce power from several sources. Currently, the energy production witnessed a huge interest in SGS in UAE. Most likely, SGs implementation problems are different from one area to another as each place has its own nature and economic circumstances. This paper highlights the UAE challenges in smart grid development policies and explores the smart grid plans to determine creation difficulties in the UAE. A focused study has been applied, where significant factors were reviewed and analyzed as well as a questionnaire survey and interviews with specialists from diverse settings. To determine the aids and drawbacks, four main features of SGS will be considered nature, sponsor support, government responsibility, and marketplace expansion.

Keywords: Electrical consumption; Energy efficiency; Smart grid; New technology; UAE policies and regulation

1. Introduction

The massive reduction in the energy became a major concern for using the energy resources and many eco-friendly issues like poisonous fumes and whether change [1]. The global energy companies' point of view, the energy use will exceed the double by the year 2025 [2]. To prevent such troubles, building capabilities should be built by consuming the least amount of the energy. This demands an adoption of energy efficiency and preservation systems. Energy utilization is a open expression with many statistical measures that have many guides to gauge the changes in the energy consumption. Similarly, power consumption reduction is about cutting energy use compared with the current condition of the same issues [3].

Constructions are the biggest energy consumers among all type of facilities which makes approximately half of the globe power [4], which produces a high percentage of carbon that is above thirty percent [5], as the International Energy Agency (IEA) Guesstimate, the energy loss will be more than fifty percent before the year 2025 [2]. As presented in Figure1, power consumption will grow in buildings with more than forty percent compared to other facilities. Subsequently, it is significant to search for answers to decrease the energy consumption in all building types (UN Environment Program (UNEP) [1].

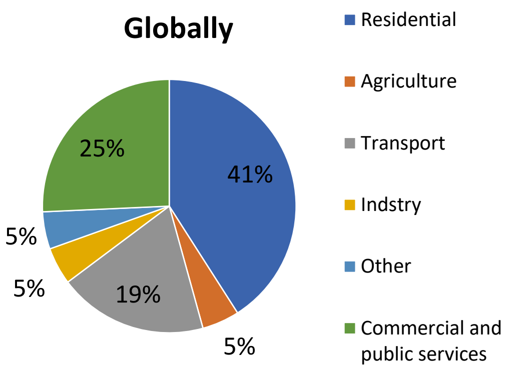

Figure 1. The GCC Electricity Consumption, 2015 [1].

Facilities in the UAE consumes around three hundred kWh per year (EMS, 2020), because of cooling of the unusual hot weather which is about eighty percent of the total energy consumption [2]. That's why, reducing energy consumption in buildings is very essential (United Nations Environment Program, 2016) [5].

Fuel is the only source of energy in transportation and other industrial issues, which had its bad influence on the earth due to the poisonous fumes that will be increased a lot in the coming few years if no strategies are implemented [6][8][9]. One of the best solutions is the use of the green energy resources to produce power. Solar energy compared to the traditional indefinite benefits [10,11].

2. Smart Grid

The clean energy supplies had a random action, to overlook this issue the smart grids were developed to enhance the energy production amount. The smart grid had a two-way communication process that allows the consumers not only to get their energy source but also to contribute to the grid efficiently [12]. The main goal for the smart grid is to produce and move the energy between various nodes straightforward, in addition to increase the energy production amount and ease its distribution process, using clean energy sources to attain the consistency between generation and consumption the consumers to obtain efficiency [9]. Smart electrical network (smart grid) is a combination between the electrical setup and the new state of the art technology, it has a vast power to generate and manage electricity from several distributed supplies [13], considering renewable sources, such as turbines, solar power projects, windmills and others as explained in Figure 2.

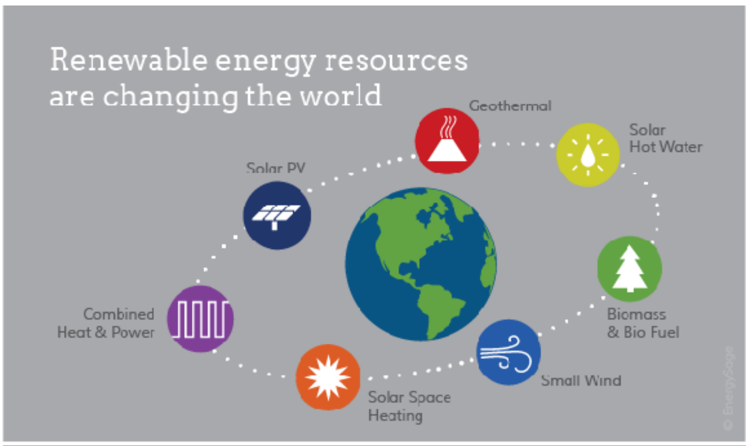

Figure 2. Renewable Energy Recourse Alternative [13].

SGS has many modules, each with an exact task to accomplish the process as presented in Figure 3. The bright apparatus is ready to set the time to consume energy based on the user pre entered and managing the highest load energy and price, i.e., the intelligent sensors. The smart power measures direct the 2-way communication delivering bills collection and discovering the system problems in any exact location. The job of smart substations is following up and managing the power standing and power functioning. The voltage is converted in the stations various times to get to the consumers and split the energy stream in all ways. The combined communication in the smart grid is the main point, and it must be very fast to give outputs promptly there is some technology to practice in the smart grid interaction based on the need [14].

Figure 3. The Process of Demand Side Management [15].

The electrical distribution market requires to be precisely controlled to assure the electricity is unchanging, though, with the development of renewable energy this changes due to the few sources of the energy creation because of the limited energy source [15]. The demand side management DSM had reviewed this matter to find out more choices in energy manufacture. The aim of using DSM is to push the clients to use less energy whether they are at home or not, which reduce the demand completely. Various methods were used within the electricity systems by providing the conventional power plants with the switching option with the renewable energy systems, the DSM influence the consumer behavior as presented previously: incentive based, and price based [5].

The energy management activities are divided into two key parts: the supply side management SSM and the demand side management DSM that involving the usage of effective devices that may have less power waste, which decrease the energy bills [1]. Several scientists who specialized in green power production, stated that DSM as technical control of usage in electricity needs to achieve less energy consumption [3,16]. DSM's focal point is to provide the energy to all consumers with competitive price with additional free services, and Power failure [17]. When the systems store and analyze the data, many features can be beneficial to the market growth, looking for flexible energy forms and low costs, analyzing the over-all cost of the expansion and eventually force the consumer to use less energy and contribute to the awareness [18].

2.1. Safety and security

Energy management is a key point which can be achieved thru smart grid plans. Lots of nations have improved their energy throughput, based on new technological power production and consumption method and strategies, to recover the demand and supplies in line with the financial and political burden by developing smart grid directives through its policies. Figure 4 shows the three key points that are affecting security in the smart grid system operation.

Figure 4. Factors Affecting Safety and Security in SGS [19].

The project of smart grid provides a large amount of data via and from consumers, public facilities that required advanced technological hardware and software that require conservation and control from its fitting date to end of its lifespan [19]. Internet security is considered as the greatest issues in the smart grid projects. Houses, public facilities, and governing specialists are all vulnerable if a digital attack could breach the smart grid network system. Several attacks had been done like access the local energy consumptions, where many features can be extracted from this data and give some details whether these places are occupied, or how many people are at homes [5]. Places may be wide-open to information theft in terms of the amount of production and energy consumption that may affect some privacy issues. Guidelines should be set by the governments to ensure the security of smart grid that assist in the safety issues such as smart gauges [20], with a strict social that manages these networks and follows up them. For inspiring the expert consultants to form internet-security and related rules [21].

3. Challenges of Smart Grid Policy

3.1. Socio-economic factor

Combining social and cultural factors, many problems will raise, mostly the troubles of consumers such as the difficulty that exists today is the lack of knowledge about the function and degree of profits as well as drawbacks of the smart grids. Familiarity with energy consumption and evaluating should be freely available to the users. Consumers must know about the cost benefits that could be added from the use of automatic pricing systems enabled by smart grids in preservation chains [14]. Most places in the world where prices of petrol are low; there is little interest of the consumer to reduce usage of even think about energy having an hourly cost. That allows consumer understanding and involvement is key factor to the success of energy and power projects. Thus, it is necessary to cover all aspects of the consumers in the building process so that any issues can be solved, and new thoughts can be considered in the early phases of the project.

3.2 Stakeholder collaboration

For the smart grid field, the key concept mainly depends on technological challenges, but integration and studies are running is slowly but surely connecting the theories and real and successful smart grid projects. However, the industrial challenges have radically enhanced recently, a lot of smart grid project were initiated, like BESCOM plans in India, continue to fail [22,23]. Lately, all electricity network projects have a linear concept in their integration [25]. For smart grids to survive, a more consistent and bidirectional network is required to link several types of association. Further, to increase the development of smart grids, plans implementation structure must include as many as possible stakeholders via a close associate such that a bidirectional interactive network is also founded during the early phases of the system. A new structural layout of smart grid stakeholder could output a positive development in enhancing the execution division which is most likely an issue in the smart grid development [24].

3.3 Government role

Smart grid system offers critical advantages compared to the traditional electricity system, but the key factor is that the regulators need to control electricity valuing and the profits that come from smart technologies. Many research papers addressed the difficulty of keeping that smart grid businesses are trustworthy by talking to one of the managers at Florida-USA Power and Light facility [26]. While there need to be a change in policies that will encourage smart grid development directly, there are also possible changes to secondary policies that could be made to promote the growth and development of smart grids indirectly such as: promote renewable energy, increase energy security, and increase energy efficiency measures.

Projects of smart grid will return values for the overall network of the electricity starts from the creation process to the end, just the most wanted part of the investments will be in the distribution part which is the most expensive [27]. Likewise, this type of growth needs the collaboration between the privet and public sectors to give a complete economic plan [26]. As green energy usage increases, a durable need of the smart grid projects is hardly needed; variable sources of renewable energy required an accurate energy management strategy with smart procedures that supports bidirectional communication networks.

2. Materials and Methods

In order to cover the issue of smart grid future and guide lines ,a traditional method of "Policy Delphi" and an advance survey software that called Qualtrics which was adopted to a bias group of opinions of specialists who are involve and expert on the field of SGS implementation and development ,the experts were chosen through a precise research via network ,phone calls and emails approximately 40 experts were chosen that were located in UAE generally and in the city of Abu Dhabi most of them regarding that Abu Dhabi city was our key of interest. These specialists came from different sectors of industrial sector, academic field, urban authorities' representatives and policy makers. In addition, were invited to participate on the survey through emails and video calls. The survey aims to extract, analyzed the main significant guideline, and issues that impact the progressive smart grid implementation development in Abu Dhabi city. In order to provide unrestrained opinions data were collected from field experts to avoid any contrasting data from academic dissemination or a controlled group.

The online survey was conducted on two rounds in row the first round was completed by April 2020 this phase of online survey aims to identify the main keys of SGS barriers and drivers and their functions that could have a magnificent influence the smart grid implementation. Furthermore, the survey was developed according to the main SGS keys, technical issues and policies that was defined through literature reviews examination and experts' opinions. The survey involved 40 specialists, around half of them were academics, network engineers and operators, with consideration of policymakers, governmental representative and electrical sector department administrators and other interest group the same group were included in the second round to participate in in September 2020 with higher participants of industry and engineers (see Figure 5) which reflect that SGS specialists are academia and industry than other sectors

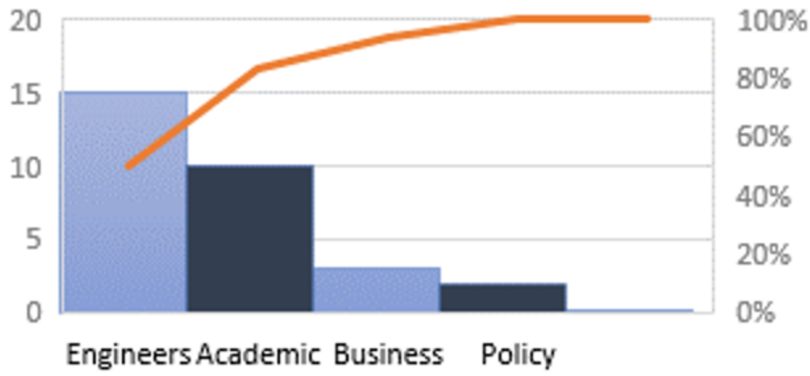

Figure 5. Expertise Classification – Conducted Survey

Figure 6 shows the schematic diagram for this paper starting by analyzing international case studies to obtain the learned lessons, then chose a local case study which implement the smart grid concept from two aspects, the local side and government side.

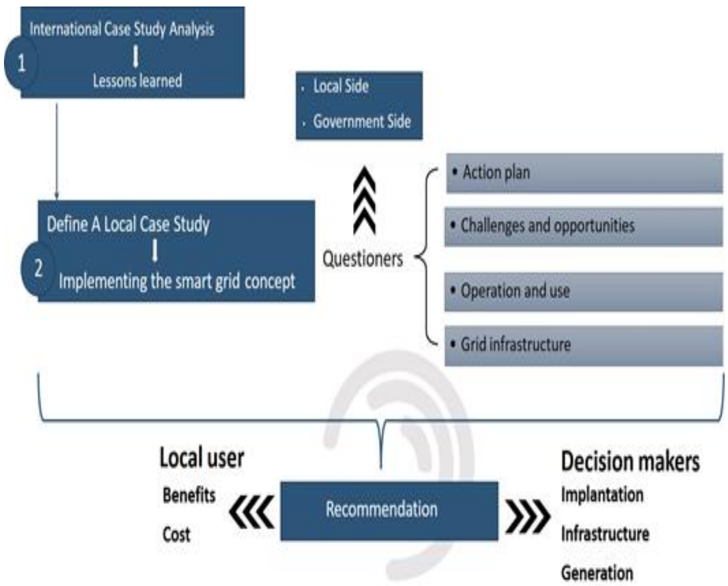

Figure 6. The Schematic Diagram

4.1 The Delphi method

The Delphi method applies a repetitive aspect; the participant's responses results are summarized [28]. The purpose of integrating a wide range of responses and point of views to fewer the differences and to reach a realistic ideal compromise. Therefore, data is collected anonymously to constringe the unrestrained opinions of participants [29]. Numerous projects with different sizes [30-32] have used the Delphi approach to summarize the stakeholder and decision maker's views on energy usage futures. However not all the energy expected scenarios are conducted through Delphi approach [33], As a main point the most cited advantage of Delphi helps the policies and decision guidelines research as it utilizes a wide range of views in new presented field which rapidly developing sector [35]. However, Delphi is usually integrated with other method [35,36], in scenario structuring and future strategies in energy field [31,35] as in our case study [37] for full project report. This approach assists authors to define the main significant gaps issues and examine them comprehensively to draw the main guidelines to follow as in our local case study for Abu Dhabi.

3. Results and Discussion

The main findings of the survey SGS drivers, barriers, including the most significant factors that affect the smart grid, and the variables that should be addressed to enhance the functionality of the smart grid. The participant's responses were coded comprehensively in accordance with McLeod's four-phase model [38] all the open-end answers were coded into an objective section. Then this procedure was repeated four-time (hanging on depending on the question and the variability of the answer) in order to clarify each category then they were classified by their frequency.

The results of the responses showed that the top three ranked drivers which counted for 32 % of the responses, were energy efficiency and loss reduction, which are considered the most important variable. In the second place by 20 % of responses, participants consider saving is an important variable of smart solution. As shown figure 7 shows the expected drivers of SGS, moreover participant's answers focused on extending the assets lifetime to reduce the cost could be a smarter solution than developing and reinforcing the network. Furthermore, enhancing the energy efficiency would provide a better solution for the main time and future, power delivery, and the utilization of assets. The third significant driver of SGS technology and functioning was categorized as active network management by 15% of responses. Which deal with fault management, network flexibility, reliability, controlling and improving technology, the reduction of CO_2 emissions, and renewable energy occupied fourth place by 10 % of the comments. The responses showed the importance of renewable for the generations as smart grids.

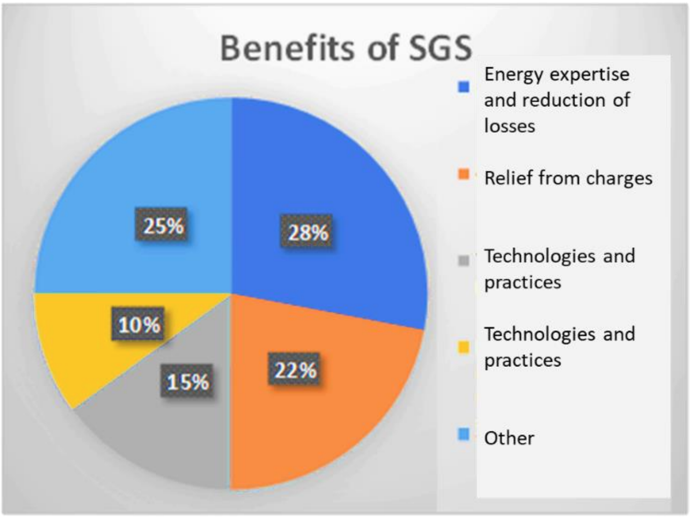

Figure 7. Benefits of Smart Grid System

Figure 8 shows the percentages of the different obstacles for the SGS. The most frequently cited stumbling block to SGS implementation was operations and connectivity, at 30%. These include prohibition, cost, and capital, and the amount of capital required in a comparatively short period of time. Others shown that SGS technologies were expensive to build, so the income of the business was not encouraging. Also, the most critical perceived drawback was a problem for both customers and technical investors in the power system, with 25% of respondents. They considered SGS planning, application, settlement, and regulation to be complex. Third was the risk that 15% of clients, both residential and commercial, would not be reactive or helpful. Although, it was obvious from the replies why customers were not appealing or what accurately would be the result of a lack of arrangement, the feeling of customer reflection to engagement policies was cited as a concern - the concern of customer engagement was declared as a factor touching SGS implementation and running. The drawbacks mentioned approximately 70% of replies.

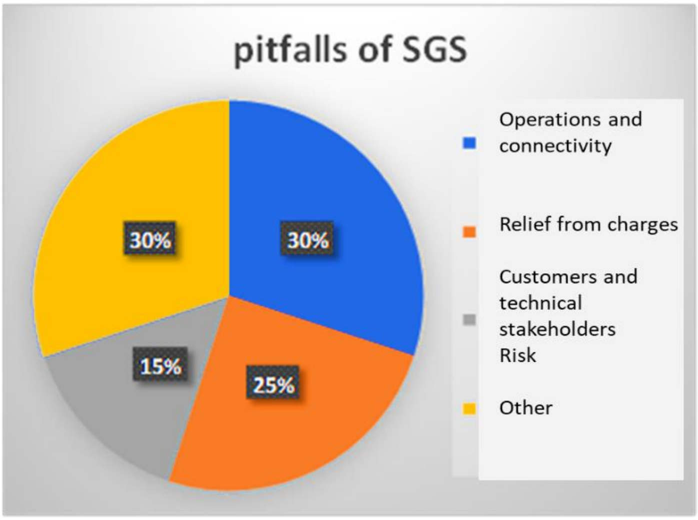

Figure 8. Pitfalls of Smart Grid System

5.1 Factors for SGS development

The study of the motivation for smart grid and the rated survey outcomes for the main drivers that will empower the construction of SGS are presented in Table 1.

Table 1. Summary of essential responses for the factors that influence SGS development

Standards
Smart metering
Communication protocols
Technical issues
Communications
Active network management
Condition and voltage monitoring
Data handling
Data protection/security Privacy guarantees
Public acceptability/trust
Market structure
Government intervention to enforce changes
Development of demand/storage/EV/cooling markets
Regulation to encourage energy department participation
Regulation
Increase renewables integration
Effective commercial arrangements and pricing
Transform structure/operation
Incentivize cooperation and alternative revenues
Customer engagement
Customer and public education/awareness
Customer willingness to comply/share data/shift demand
Pricing
Investment
Long-term regulation/policy certainty/objectives
New modes of financing/business models
New value delivery mechanisms

Starting with the most important challenge, standers accessibility, the top two themes for this category are smart metering and communication protocols. Initially, the first issues such as the development, design, and running of smart measures. The second issue spanned the requirements at all levels of SGS, including substation communications. Noticeably, these results (showing 66% of responses) reflect that the smart meter future in the UAE.

However, data security, protection, and privacy were ranked as secondary concerns for the participants. As the limits that the government will apply to the size and the nature of data that is allowed to be collected or controlled by consumers and the accessibility for these data. Also, the government affects data network operators, consumers offered services, and their energy demand control. On the educational and awareness category, customer engagement was the most cited comments. Involving the media influence, responses to tariffs, and cost-pricing effect on behaviors. Participating in demand change, understanding the advantages and disadvantages of SGS, these issues were found as the most important concerns of participants. Which shows the importance of public engagement in the policy-making factor. These items were 70 % of responses.

5.2 Smart Grid Challenges in Abu Dhabi

Recently, Abu Dhabi has implemented renewable energy projects and smart grid operations such as Shams 1 Solar Power Station Project. With the increasing demand for breakthroughs in renewable energy generation, customers would need to change the way they use and manage electricity. The new SGS technologies can manage the use of electrical energy during peak and non-peak hours, as well as control the preservation of stored energy from any outside intrusion or leakage.

Electricity generation, combined with demand-side management, influences, and determines the supply of electricity to customers. The facts and indicators presented show that it is necessary to adapt the current electricity market and generation regulations to manage different market models with completely new demand and supply, and to consider the flexibility and adaptability to bring together new technologies for the operation of the smart grid.

The government will struggle whole fossil fuel burning elimination, then maintain low electricity charges. When energy markets are reasonable, prices will be more stable and lower, and more green energy will result in lower market pricing. Hence, boosting participation of private businesses in power production is a great barrier because of a fair support in prices. An increase price of electricity would arise if subsidies would be being removed and the integration of green technology for smart grid operations is being improved.

Economical influence is the key point of renewable energy and smart grid process. However, in order to adequately assess and carry out the cost breakdown of power generation employing alternative technologies, a high level of transparency is required. The smart grid network, various technologies would be adopted by the information and communication services. These communication facilities are guaranteed to be exposed to data stealing.

The lack of consumer involvement could lead to many unexpected difficulties during the final stage of implementation which would affect the duration, cost, effects and overall success of any smart grid system. It is important for the consumers to share their opinions and ideas during the implementation of a smart grid system. Figure 9 shows the main factors that affect the implementation process of SGS.

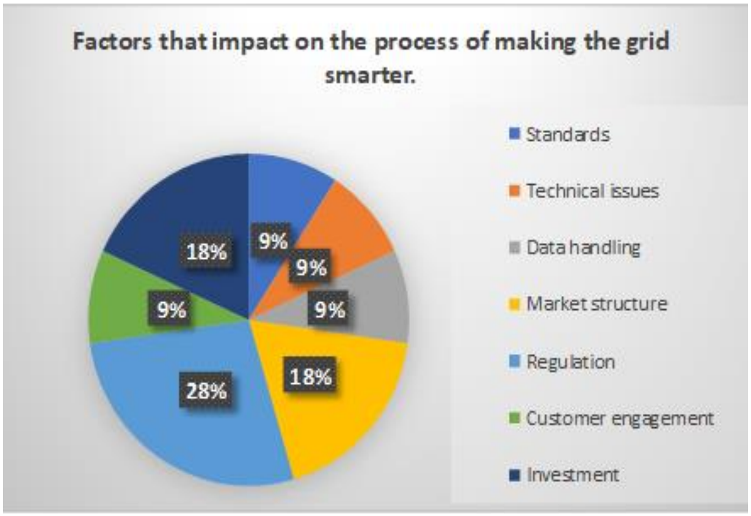

Figure 9. Factors affect the implementation process of SGS.

5. Conclusions

Abu Dhabi is one of the most fast-growing cities worldwide. Therefore, there is a need for additional power sources and demand, as well as potentially low electricity rates. It is essential to manage the way that the electricity production, supplied, and used for ideal and well-organized performance, by applying the smart grid technologies. The emerging technologies of the renewable energy sources will provide a plenty of power and energy sources, which support the chance of smart grid integration in the area. The solar and wind power are the only known energy sources in the market. Thus, there would be required to implement more participation by private sectors. The successful development and integration of smart grid technologies and other additional services would assist to build a more advanced and civilized beloved Emirates of UAE. Furthermore, an appropriate implementation of smart grid technologies and smart cities, would serve to a green power supply of electricity in the country, in addition to encouraging the economic development. Furthermore, there are certain challenges like green energy businesses, which requires for new agreements on managing the electricity. The smart grid technologies would be implemented in the UAE, far in spite of the challenges. Ultimately, the growth in power sector cannot be ignored, because of the large investment of money that will be offered in building new energy production projects and smart grid technology systems.

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The Impact of Light Rail Transit on the Urban Development in Dubai, UAE

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Abstract: The United Arab Emirates (UAE) has seen significant growth in urban development over the past two decades. To overcome the implication of this development, Dubai's Roads and Transport Authority (RTA) has called for sustainable transport development at all levels, including the Light Rail Transit (LRT), which is a friendly mass transit system to satisfy the requirements of urban mobility, environmental sustainability, and green power efficiency. The shift towards sustainable mass transport systems has become the ideal choice to overcome the challenges accompanying the growth and development facing cities such as Dubai and to convert them into sustainable environmentally friendly places. Dubai is arising an extraordinary development of urban projects and strong attention targeting infrastructure and transportation systems. Therefore, the most sustainable transport system used to enhance the rabid development is the light railway system that plays a major role in shifting the city toward sustainability. Consequently, the Metro and Tramway systems are recognized as optimal provisions of public transport mode for high-capacity public transport systems in Dubai. This helps to improve the infrastructure by promoting connectivity, economy, and a sustainable environment. The paper investigates the impact of Dubai Metro in accelerating the Urban Development in Dubai. Urban transformation pattern around the main Metro Stations is studied. Population densities, connectivity, and land use pattern are examined. Three main Metro Stations have been selected for this study, namely: Jabal Ali, Al Barsha First, and Business Bay. To achieve this aim, the following objectives are covered: to investigate the needs of the sustainable transport system to cope with the urban development requirements; to examine the population density, connectivity, and accessibility around Metro Stations; and to analyze the impact of Dubai Metro on urban land use. The research methodology focuses mainly on qualitative analysis of the use of a light railway transport system. GIS and Spatial Maps, interviews, case study analysis, and land use investigations have been used to reach the finding of this research. The study indicates an overall positive impact of Dubai Metro on commercial and residential land uses on one hand, and connectivity and accessibility on the other hand.

Keywords: Sustainable Transportation, Light Rail Transit, Urban Development, Dubai Metro

1. Introduction

Transport plays a vital role in shaping the city's physical, social, and economic structure, and without an infrastructural foundation, economic activities cannot occur. Transport driving force changed land use and influenced growth trends and economic activity by offering land accessibility [1]. Sustainable transportation aimed towards providing and meeting the different requirements. It improves the air quality by reducing cumulative emissions from cars and smog-creating pollutants. It decreases the need to build additional road networks, manufacture new cars and extract further fuels, which allows more energy savings and fewer environmental impacts. It connects the people to businesses, shopping, and services, which increase the economic development. Additionally, it facilitates higher density by moving a large number of people on one single trip that decreases distance and time taken for people to travel to their destinations [2]. One of the sustainable transport modes is the Light Rail Transit (LRT), which has all these features with the potential for economic growth that helps the city grow faster. Therefore, to meet high transportation demands, Dubai city has introduced steps to facilitate public sustainable transport. Road and Transportation Authority (RTA) in Dubai implemented a comprehensive strategy to link the various transport modes as part of an Integrated Public Transport Plan. Dubai's Transit Oriented Development Plan was implemented to upgrade and enhance transportation system within the city. These include a project to the public transit system to build the first Arabian Peninsula's urban rail transit system and the world longest fully automated train system, Dubai Metro. Dubai is well-known for its impressive architecture and urban developments. Due to the existence of a high density of vehicles, Dubai is mainly concerned with vehicle-related movements. Car, street networks and large parking lots surround most buildings [3]. Dubai authorities have recognized the serious limitations of these practices and the fact that they affect sustainability and established a system to restrict vehicle movement while also developing an integrated transit system that centers on the Dubai Metro. The RTA established Dubai Metro in 2009 to cope with urban development and moving extending urban land within and outside the city. By introducing the light rail transit, it functions as nodes in transport networks that paving the way for more sustainable transport which has various positive effects on the local economy. There are many studies investigating impact of light railway on property values, both in terms of the whole effect on property values and to localize differences among properties located nearer and further away from a Metro station [4,5,6]. For example, there is study indicate the growth in urban land use is directly formed by the expansion of LRT and land use integration [7].

This paper aims to investigate the influence of Dubai Metro as a light rail transit system on the urban development through spatial, temporal indicators for Dubai city, UAE. Such temporal, spatial measures of urban development and transportation are utilized and assessed using remote sensing techniques and GIS. Three main Metro Stations have been selected to investigate the impact of Dubai Metro on the surrounding land use and population distribution pattern. the first station is Jebel Ali which is located 35 kilometers out the center of Dubai and serves mainly the Jebel Ali Free Zone and surrounding urban development. Al Barsha is the second metro station that bounded by Al Sufouh to the north, Emirates Hills to the west, Al Quoz to the east, and Dubai Sports City to the south. The third metro station Is the Business Bay, one of the popular residential and professional districts that was developed as mix land use and business cluster along a new extension of Dubai Creek from Ras Al Khor to Sheikh Zayed Road. The prepared satellite imagery from the Lansat 8-OLI and the external sources (OSM, Google Earth Pro) were used to identify the changes that occurred around the three stations in 2008 (before establishing Dubai Metro) and 2020 (11 years after establishing Dubai Metro), using ArcMap as a primary software.

2. Light Rail Transit (LRT) as Sustainable Transport

Transportation modes include how people drive around to get to and from a destination. They are infrastructure and communication assets that fall into three main categories: individual, public, or air. Public transportation is a form of travel that enables more people to travel together on a single trip. The most common types of public transport are buses, metros, and trams. While large numbers usually use public transportation, private transportation would not share the trip with strangers. The only people you are willing to share it with is the driver and your friends/family/colleagues. Therefore, public transport is a valuable transport mode because it is a green and economical transportation method [8].

One of the modes of public transportation systems is Light Rail Transit (LRT), and it is a type of urban passenger transit characterized by both trolley and subway characteristics. Since its rolling stock is more similar to a conventional tram, it runs at a greater capacity and speed and sometimes on a small exclusive right-of-way.

The "light" refers to the lower passenger capacity compared to commuter trains. The LRT is built as a framework to serve smaller, more metropolitan cities rather than larger, less metropolitan ones. It can also act as a feeder for higher capacity metros and commuter railways [9]. The LRT is six times safer than car travel as they can operate relatively unimpeded even in adverse conditions such as snow, rain, or ice, which otherwise affect automobiles [10]. Light rail can positively affect by reducing dependence on private vehicles [11]. While it has long-term benefits, its success depends on the extended participation of the commuters. It can be successful if only integrated with other modes of public transport.

LRT, as a sustainable transport ensuring safe, reliable and secure access to transport while also considering social, environmental and economic aspects [12]. To achieve sustainability, Banister argues that pedestrians and cyclists are at the top of the sustainable transport pyramid, followed by public transport users and car users. The definition of sustainable transportation is to retain the hierarchy of transport participants. Pedestrians are the most vulnerable, the most vulnerable and endangered group. The second group is cyclists, followed by the public transport network. At the bottom of the classification are car users, who are the most troublesome group—throughout traffic congestion and blocking the streets. As shown in Figure 1, the pyramid illustrates the current levels of sustainable modes of transport. The accomplishment of this aim lies in slowing down city traffic and ensuring safe and adequate public transport.

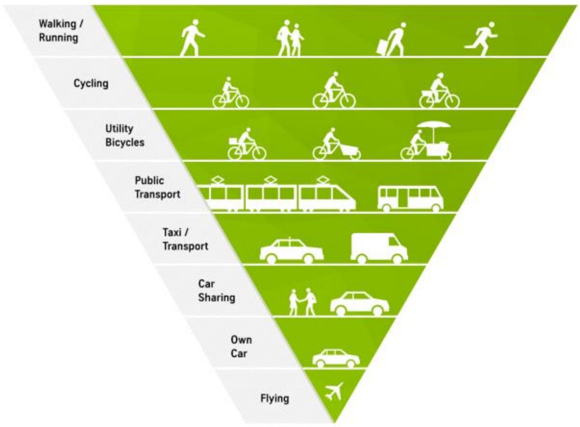

Figure 1. The pyramidal structure illustrating the level of sustainability associated with different modes of transport [13].

3. Dubai and its Urban Transformation pattern

The rapid transformation of Dubai and its wider urban region during the last few decades demands great attention from urban planners and researchers. Three issues motivate its urban pattern [14]. First, the city of Dubai is an international trading center "Global city". The second motivation concerns the dramatic nature of the city development. Population increase, spatial expansion, and economic growth over several decades are part of this motivation. The most spectacular of all is the development of the new center of Dubai (Sheikh Zayed Road), which includes one of the world's fames tallest buildings, Emirate's twin towers. The third theme demanding attention in Dubai is its emerging status as an urban region. Urban development in Dubai can be divided into traditional, conventional, and modern patterns. The traditional process reflects architectural and planning ideologies of the pre-modern era, characterized by courtyard, wind-towers, low-rise buildings, walkways, and narrow streets. The modern process was established during the second half of the 19th century, with fast urban development following the discovery of oil. Dubai became one of the most modern cities in the world, boasting the highest glass towers in the Middle East, including the second tallest twin towers in the world "Emirates Twin Towers", the world's tallest hotel "Burj Al-Arab", and the world's tallest tower "Burj Khalifa".

The city of Dubai has seen a range of unexpected and anticipated changes due to the rise in population. The Dubai economy has seen exceptional growth since 1990s, hitting a rate of 16.7% in 2004, with most of this growth fueled by significant regional net migration [15]. The city made a strategic decision to emerge as a major international-quality tourism destination during the early 1990s [16]. As shown in Figure 2, since the late 1990s, Dubai has seen tremendous urban development, with the developed area growing from 149 square kilometers in 1993 to 224 square kilometers in 2005 [15]. New urban development occurred by building nearly 100 km2 of three artificial islands of Palm Jumeirah, Deira Islands, and Palm Jebel Ali were constructed on the coast of Dubai [18]. Every island was constructed to have a number of residential, leisure, and entertainment complexes.

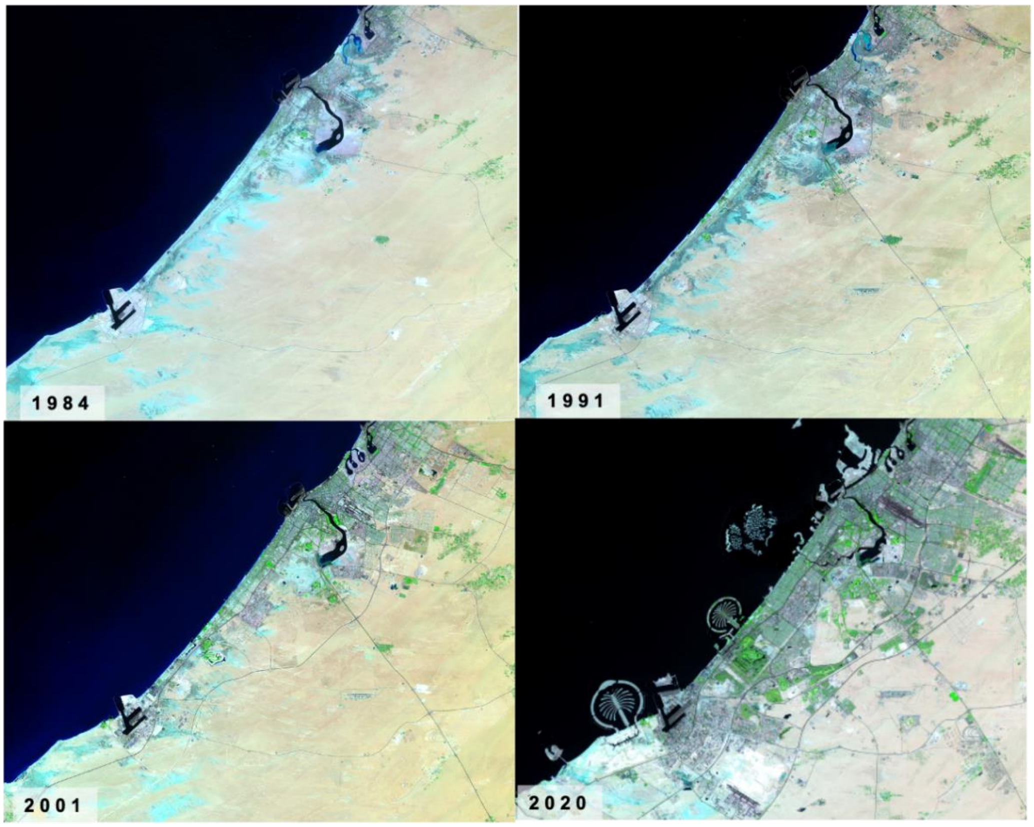

Figure 2. The development change over time in Dubai 1970 to 2020. Satellite Image from USGS.

In the past few decades, Dubai has seen an unprecedented rise in population. Dubai's population grew rapidly in 10 years, from 1.732 million in 2009 to 3.331 million in 2019 [19], with a rise of 91%.

Dubai has a unique land use pattern with area size approximately 4,114 km² and divided into six sectors. The population of Dubai city presents nearly 34% of the total population of UAE. According to Dubai's population distribution structure map, cities grow around several points instead of one in the central business district, which is due to urbanization. There is a strong correlation between the economic or residential activity distribution and land use. The number of people in an area has changed how land is used in two ways: using the land in more productive ways and developing new land. The lower-class neighborhoods prefer to live close to where the CBD activity, making it easier to travel. The highest population concentrated residential areas are located close to transit lines in "Muhaisnah," located in eastern Dubai in Deira. In contrast, high-income residential regions are clustered in low-density across the city's boundaries in areas.

3.1. Dubai Metro

Due to economy increasingly, air transport, property development and tourism, Dubai Municipality identified the need for a rail system. To mitigate the heavy traffic flow of Sheik Zayed Road connecting Dubai Creek to Jebel Ali and to meet the rapid urban expansion of Dubai, the government established the light railway "Dubai Metro". Dubai Metro, the world's longest automated driverless system, was developed in two phases (see Figure 3):

- Phase-1: The first Metro Line (Red line) was opened in phases from 2009 to 2011. It covers 29 stations and handling 32,000 passengers per hour, which is almost 10% of the population of Dubai that uses the metro [20]. The total length of the metro system is 74.6 km, within which 13 km metro line has been build underground. Seven monorails are also scheduled to be built to help feed the Dubai Metro, connecting various places such as Dubai land, the Palm Jumeirah and other districts near to the main track. The catchment area around the red line contains of new and old service centers, newly established mixed-use land, at least four of the most important shopping malls as well as 2 of the busiest stations of the Dubai International Airport. On the other hand, the majority of the 18 stations on the Green Line are in the old CBD area along double sides of Dubai Creek. More than 329,365 people used the Dubai metro service per day [21]. In September 2017, RTA declared on its website that passenger numbers reached 1 billion. The increasing in number of passengers reflected to the increase in population and business in Dubai.

- Phase-2: The RTA expand the two lines and construct new line: The Route 2020, extending the Dubai Metro Red Line from Nakheel Harbor and Tower Station to the Expo 2020 location. It now serves a new area with a population density of around 270,000 residents including the Gardens, Discovery Gardens, Al Furjan, Jumeirah Golf Estates. Seven additional metro stations would be included as a result of the extension. The travel time is also improved to be 16 minutes from Dubai Marina Station to Expo Station [22].

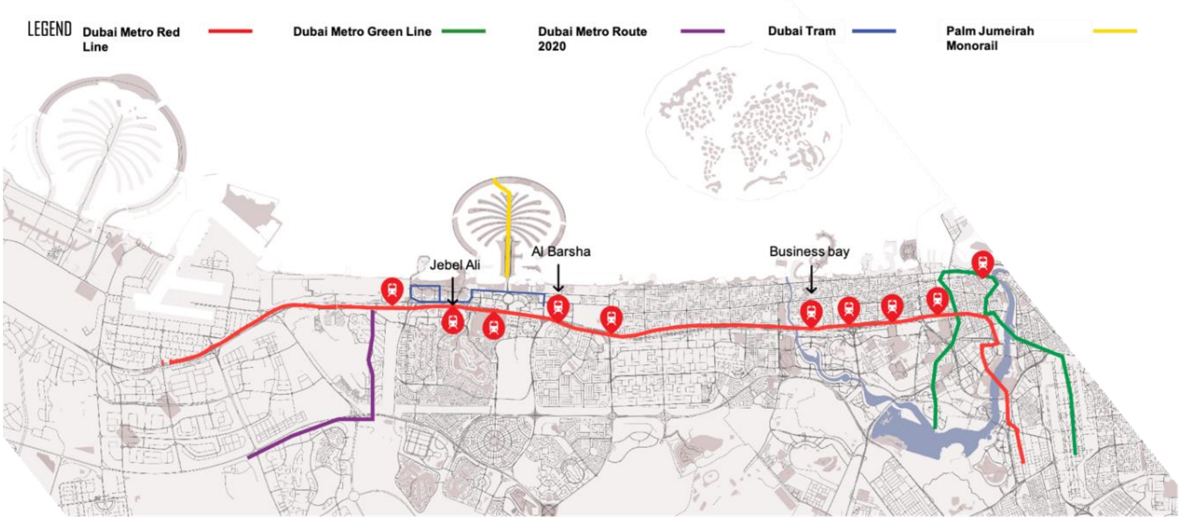

Figure 3. Metro Network in Dubai, adapted from the Roads and Transport Authority (RTA), 2020.

4. The Impact of Dubai Metro

The impact of Dubai Metro is huge due to the interest given to it by people because of the offered accessibility, as well as economic agented. Investors see a great opportunity to develop new businesses around metro lines. The land use pattern has been affected in areas where new metro stations, new public bus stations, tramlines and stations and other service facilities are built.

Dubai is a relatively new city, built on a very well-developed model, in a huge development point, many impressive buildings being at the design stage [24]. Dubai's land use divisions include the built-up, commercial, residential, industrial, waterbody, and bare ground. The two most prevalent land use types are commercial and residential areas. Dubai's rapid development has resulted in a decline in desert areas and green spaces. In the case of the Dubai metro, the metro is one of the fastest and easiest means of transport in cities to get to work or to travel for any other purpose from one part of the city to another.

4.1. Population Density

Dubai, the recent urban growth has led to two significant factor, population development and urbanization. Urbanization can be characterized in terms of population concentration in larger urban settlements within a specific area, as well as growing population density within urban settlements

[25]. The Dubai population growth has increased from 1,645,973 in 2008 to 3,335,990 in 2020 because of its urban transportation development in general and its light rail system.

One of the main effects of the impact that the Dubai Metro has had on the territory it annexes has been a relatively large increase in population in this area. This population growth can be characterized of all by the urbanization phenomenon that occurred as a result of the development of the transport infrastructure, thus capitalizing on the potential of the place through accessibility, increasing its value. The population growth affected by the rapid increase of transportation infrastructure, the new lines of Dubai metro and topographical factors. Thus, the result of the infrastructure development process, through the appearance of new means of transport in the case of new metro stations in Dubai, rapidly increased the number of inhabitants in this place, particularly around metro lines, by urbanizing the area, enriching it with social and economic facilities. This can also be shown in Figures 4 and 5 that characterize the difference in population density before building Dubai metro in 2008 and after (in 2020).

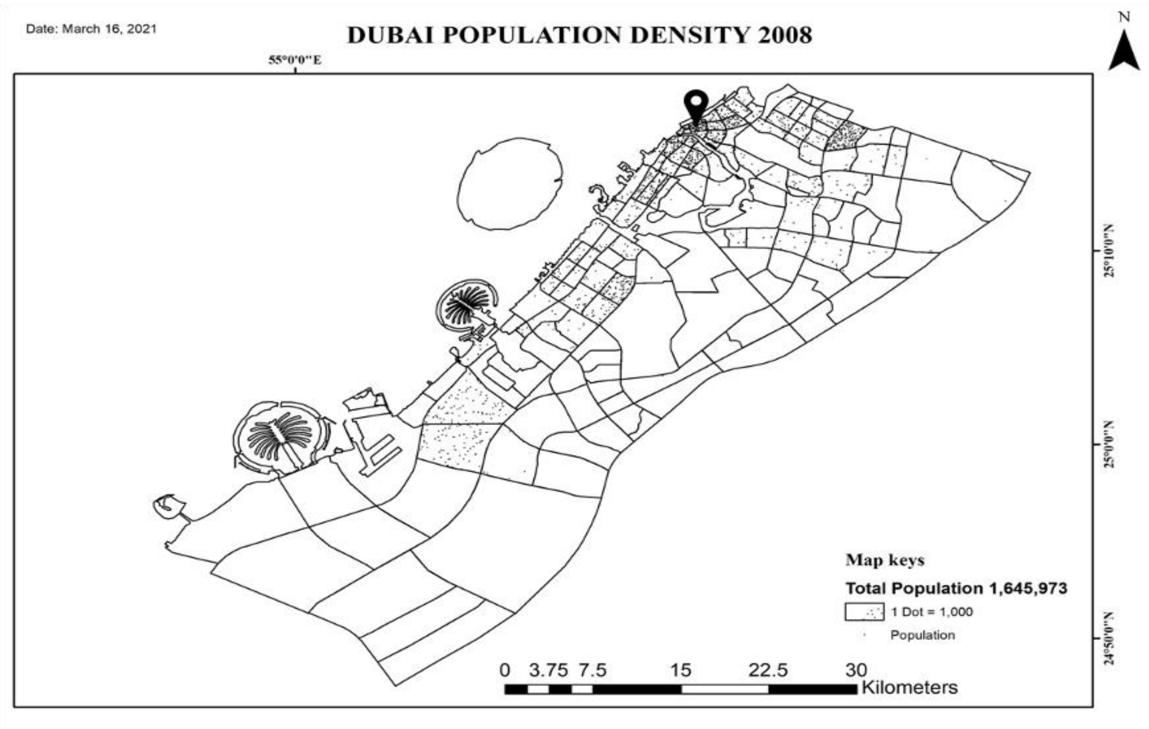

Figure 4. Population distribution pattern of Dubai in 2008

In 2008, as shown in Figure 4, a concentration of the population mostly found in the coastal area in Deira and Bur Dubai, with inconsistencies at the middle level of the area where the population density is very low. The most populated area seems to be the one in the northeast of the area, continuing timidly along the coast near Palm Dubai. This low population density in the area is given by the underdeveloped areas in terms of infrastructure in the surrounding areas, where primary needs such as transportation, whether fast or not, is currently non-existent. This lack of an easy transport method such as the metro is not of interest to the population and implicitly to economic developers.

Twelve years later, after developing Dubai Metro, the development of Dubai metro infrastructure is very visible by extending the high population density in the bordering areas of Khor of Dubai and along the metro line areas as shown in Figure 5. The new metro lines appeared led to the creation of new residential centers where the population felt comfortable to live with fast transportation facilities provided.

Thus, the relationship between the development of new metro lines and the increase in population density is validated by the impact that the Dubai metro has had on the city and especially on the increasing areas of residential and economical type.

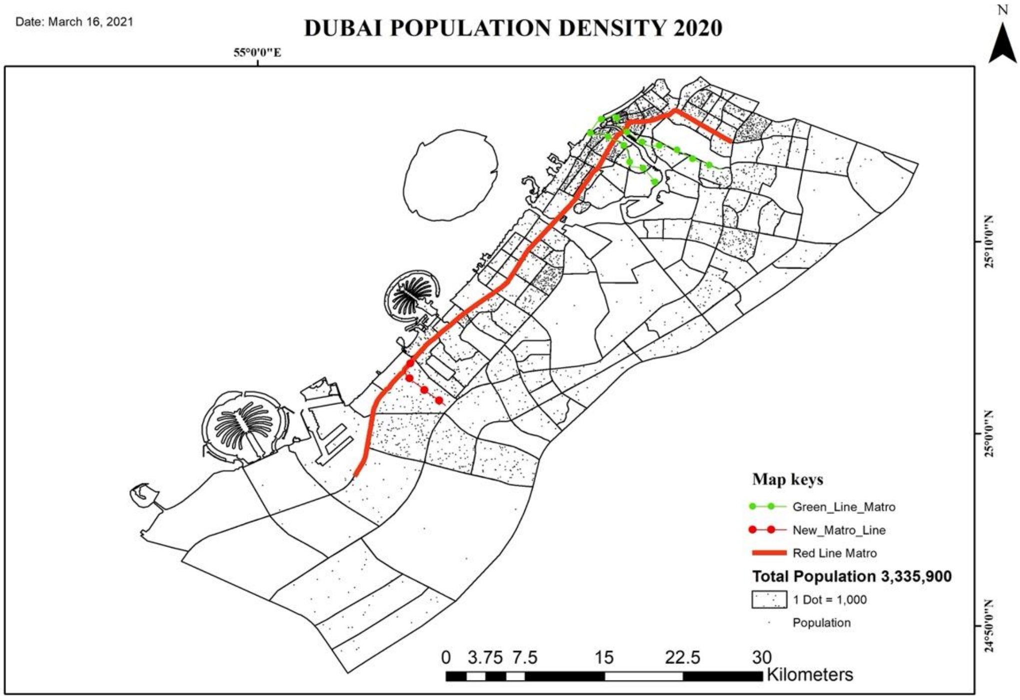

Figure 5. Population distribution pattern of Dubai in 2020
Source: the authors, based on the database produced by ArcMap

4.2. *Land Use*

Land use change mainly depends on many reasons. Among them increasing population or population accessibility is a driving tool for the change of land use [26]. Dubai has seen major spatial expansions along the transport infrastructure with a typical pattern of infill, extension, and leapfrog growth. Residential development has driven more than commercial and industrial growth in Dubai.

4.2.1. Jebel Ali

Jebel Ali was built in 1977; serve as a free zone and commercial port and center for trade between Dubai and the rest of the world; linking eastern and western markets with North Africa, the Middle East, and South Asia. Land use analysis were applied to Jebel Ali and Jebel Ali 1st in Dubai to see the differences of land use between 2008 and 2020.

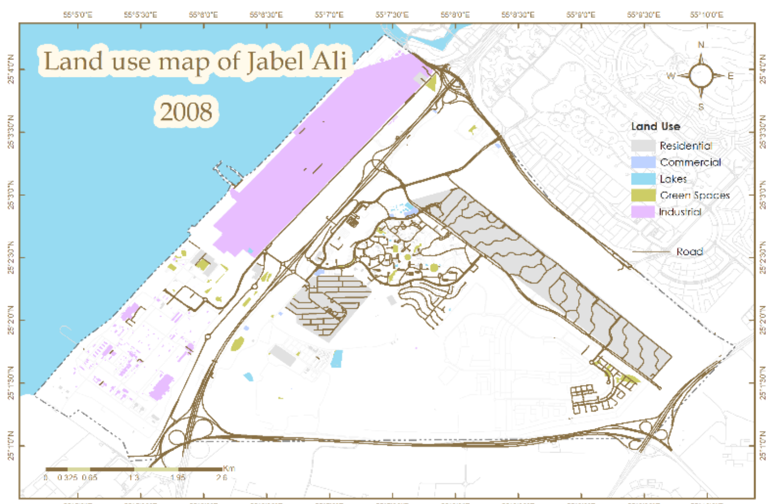

Figure 6. Land use of Jebel Ali after Building Dubai Metro in 2020

Source: Dubai Statistics Center, based on the database produced by ArcMap

Figure 6 represents Jebel Ali area of Dubai in 2008, which shows a dominance of industrial areas, residential areas, but with very few roads, green spaces, recreational and commercial areas. The lack of service facilities indicates that the area lacks a transport network that can support a large influx of people, implicitly a more accentuated development. The year 2008 surprised Jebel Ali in full development, but still with much to bring to attract the population that was to live there in 2020 (Figure 6).

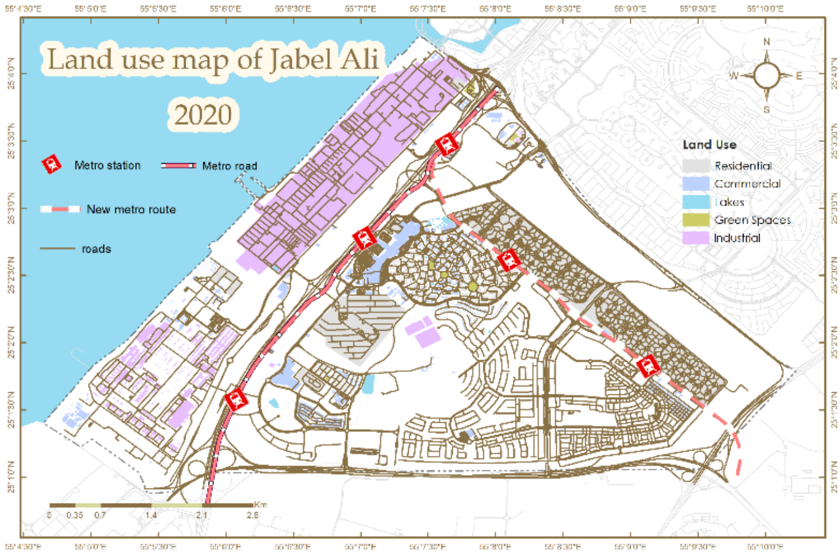

Figure 7. Land use of Jebel Ali after Building Dubai Metro in 2020

Source: Dubai Statistics Center, based on the database produced by ArcMap

After 2008, with the establishment of Dubai metro, much of urbanization increased and residential buildings spread over the area in the form of apartments, residential buildings, and villas. Due to the rapid growth of urbanization, roads also constructed and increased almost 40% by the 2020. Most of the urbanization increased along the main road and metro line, and new society which are skyscraper buildings comprising on apartments and flats. Due to the urbanization commercial area also increased to the large extent. Many hotels, malls, shops, and related commercial buildings enlarged along the housing areas as well as along the main road. As green spaces are integral part of urban area so along the residential area, green spaces and parks also increased. The water bodies like Lakes did not construct new on the ground level but increased on the top roof of skyscraper buildings. The part of Industrial buildings has not changed much but little more industries constructed along the pre-existed industrial area in Jebel Ali 1st. Because of rapid change of land use, the open area and sandy area decreased as fast as urbanization exceeded. Most of the open area covered by roads and residential buildings like villas and new industries as well.

Table 1. Change in land use areas at Jebel Ali 1st.

Land Use (ha)	2008	2020	Changes %
Residential	36.75	273.21	643%
Commercial	73.85	474.15	542%
Industrial	252.1	299.11	18%
Green space	28.15	13.580	-51%
Lakes	7.8	7.8	0.00%
Main Streets (km)	192.34	542.87	182%

The urban development of Jebel Ali and the changes to land use pattern are presented in Table 1. It shows that the development of Dubai metro has a great impact on the surrounding land use pattern in Jebel Ali. In 2020, residential areas have increased from about 36 hectares to 273 hectares, an increase of 643% compared to 2008. In line with the increase of residential spaces, implicitly of the population, the commercial areas increased by approximately 542% from 73 hectares in 2008 to 474 ha in 2020. Following the same trend, the industrial land use increased by 18%, as well as main road network with an increase of 182%. The only land use that has been decreased is the public green spaces, which have been decreased by about 51% due to the constructions that followed in this area within the residential, industrial, and commercial ones, the lakes have remained unchanged.

4.2.2. Al Barsha First

Land Use change and pattern identification were also applied to Al Barsha First, Dubai. As shown in Figure 8, prior to 2008, the area was characterized by a medium developed street plot in which commercial buildings and few residential spaces dominate, in which the main means of transport is represented using personal car or public transport at road level.

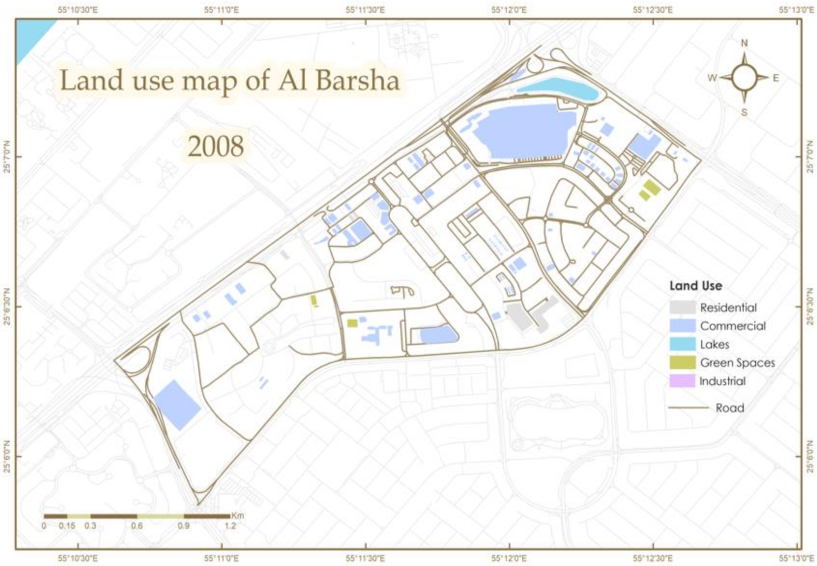

Figure 8. Land use of Ali Barsha before Building Dubai Metro in 2008
Source: Dubai Statistics Center, based on the database produced by ArcMap

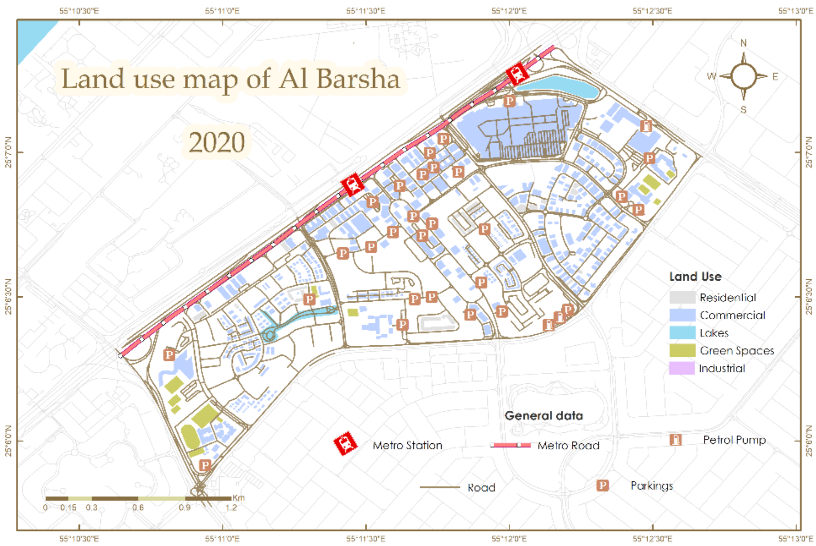

Figure 9. Land use of Ali Barsha after Building Dubai Metro in 2020
Source: Dubai Statistics Center, based on the database produced by ArcMap

The year 2020 comes with major changes in the area of Al Barsha 1st due to the appearance of the new metro line that connects this area with the other important districts of Dubai, now making possible a fast and direct connection with any important areas and facilities. A significant increase of the residential area can be observed in both Figure 9 and Table 2, implicitly an increase of the population that needs the commercial spaces that are seen at the level of 2020.

Table 2. Change in land use areas at Al Barsha Frist.

Land Use (ha)	2008	2020	Changes %
Residential	10.057	22.6	125%
Commercials	34.41	296.1	760%
Industries	-	15.49	-
Green spaces	1.56	9.876	532%
Lakes	4.03	4.032	0
Roads (Km)	61.74	101.38	64.20%

The change pattern has occurred in the features of Residential, Commercial, Industrial, Green-spaces, Lakes and Roads, listed in Table 2. Due to rapid urbanization, the land use features also change swiftly over the area. The rate of Residential buildings was increased by 125% from 2008 to 2020. The area occupied by the residential building in 2008 was only 10 hectares but in 2020 it was 23 hectares. These residential buildings were increased as apartments, rental flats, and villas also but in 2008 there were mostly villas and flats. Very few buildings were comprised on apartment skyscraper building. Along the residential, there was huge change came in the commercial buildings. The commercial land use area has been increased from 34 hectare in 2008 to 296 hectare in 2020. Many new buildings including offices, hotels, restaurants, religious buildings, and other commercial buildings were constructed nearby the metro station. The details of the land use changes are summarized in Table 2. It is noted that the industrial land use has been developed after 2008, and road network was increased by nearly 64%, however the lakes development remains the same.

4.2.3. Business Bay

Business Bay is most likely the least developed area of the three in 2008. Most of the area was uninhabited and the only shopping and residential centers being developed in the northwestern part of the area (see Figure 10).

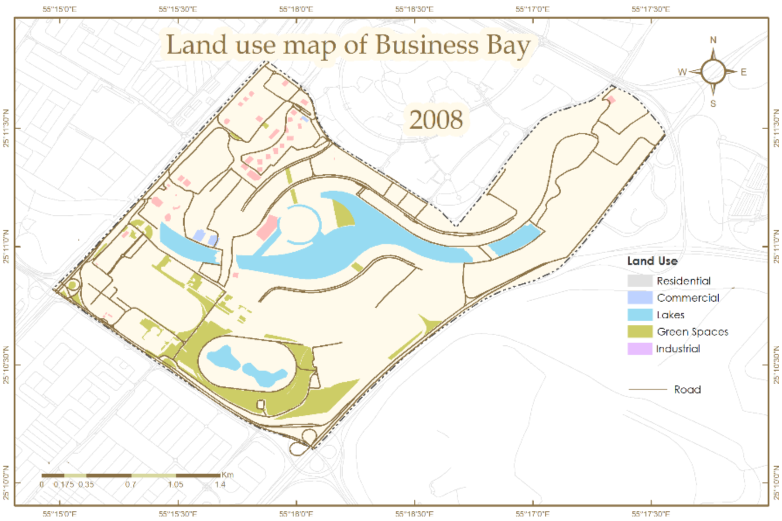

Figure 10. Land use of Business Bay before Building Dubai Metro in 2008

Source: Dubai Statistics Center, based on the database produced by ArcMap

With Dubai metro and other recreational facilities established by 2020, major changes to the land use have been developed in this district, attracting more population and investors of residential and commercial spaces to move to this area. Residential and commercial areas are now developing along the water arm, causing major changes especially on the left bank of the water arm. In Business Bay area, the land use pattern is slightly different compared to the other two areas. As shown in Table 3 and Figure 11.

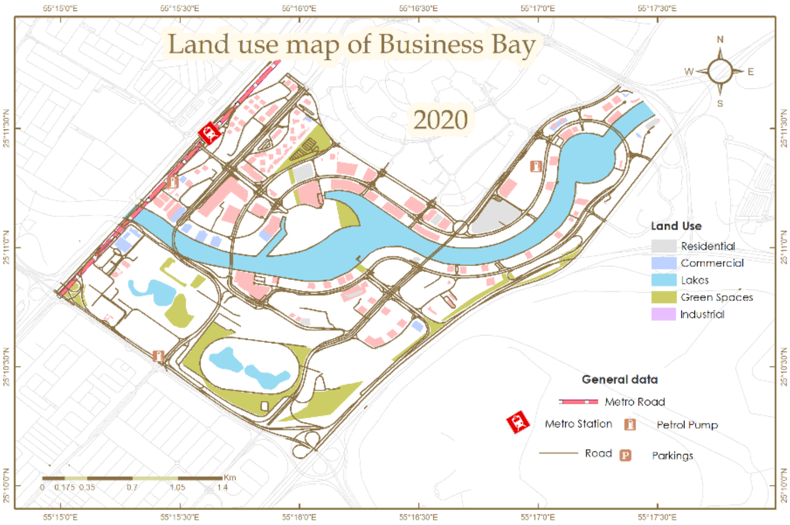

Figure 11. Land use of Business Bay after Building Dubai Metro in 2020

Over the period of time from 2008, land use has experienced a rapid change in man-made earth feature. Almost 0.048 km^2 area was occupied by Residential buildings in 2020. These residential buildings are comprising mainly on rental apartments and flats. A maximum change is occurred by commercial buildings including malls, retailer, show rooms, and offices. Commercial area in 2008 was about 1.1 hectare, however, in 2020 it reached to the 5.6 ha with a total change of 386%. The reason of rapid revolution in the commercial is due to rapid change in the business over the area. The area is most renowned and famous for its business and trade. Variation in the urbanization over the area is also a significant factor of expanding commercial in the area. In 2008 mix-use buildings were comprised on the area of 7 ha ^{but} as rapid change in the commercial and urban growth these buildings increased and spread over the area of 19 ha and got change about 176%. These buildings have hotel rooms and flat along with offices and restaurants within the same building. The area is divided by the waterway in the center. This waterway was very less in 2008 by comprising area of 48 ha but increased near to 103 ha by expanding it towards the beach area made flyover roads over the diversion waterway. Along the waterways there are also Lakes those got change during the period from 2008 to 2020. Lakes were existed on an area of 5.6 ha in 2008, however they have reached 11.5 ha by 2020. The only natural feature that decreased over the time was the public green spaces. for further details, see table 3.

Table 3. Change in land use areas at Business Bay.

Land Use (ha)	2008	2020	Changes %
Residential	-	4.81	-
Commercials	1.159	5.6	386%
Commercial-Residential	7.02	19.43	176%
Green spaces	41.2	25.78	-37%
Lakes	5.67	11.58	104%
Waterways	48.77	103.29	111%
Roads (Km)	54.35	121.91	124%

Only few Green spaces were preserved to maintain the environment by the Dubai Municipalities. Due to construction of all the new buildings of every category, there were also construct new roads for transport availability for new buildings, and to maintain the carrying capacity in the urban growth. In 2008, there were only 54 km of roads and streets collectively in the area, however, in 2020 new roads were constructed and increased up to 121 to improve the connectivity among the urban areas one hand and between the urban areas and the metro stations on the other hand.

5. Conclusion

This research presents a comprehensive analysis of three stations of the metro system to demonstrate the effects of rail transit development in urban areas. The impacts of two scenarios before and after the opening of the metro are examined through an analysis of population development, land-use change. The introduction of a light rail transit system in Dubai or the expansion of an existing one had a more significant impact on the surrounding development.

In the case of the population, the metro is one of the fastest and easiest means of transport in cities to get to work or to travel for any other purpose from one part of the city to another. Whether underground or above ground, the metro is a revolution in transport and changes the landscape around it through urbanization, producing significant changes.

The research found that the population growth of the whole metro network increases after building the metro, and the population is concentrated around the metro areas. The more expansive development areas, such as the business bay, facilitated more intense and city residents' activities, resulting in a diverse range of land uses. Dubai metro correlated with changes in land use (mainly residential land), and improvements can be observed over time.

The findings of this study serve as a guide for designing and analyzing rail transit networks in densely populated cities and can optimize and organize the operation of new and existing transit lines. Due to the complexity of gathering data for an entire metro line, the analysis described in this research can be expanded by performing land value assessments for three stations. Further research is expected to be conducted to determine the economic impact and conduct buffer analyses across metro surrounding areas to assess how the metro line contributes to the overall network after a long service period

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Consumer Adoption of Renewable Energy

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Abstract: Renewable energy has been serving as an alternative source of energy for heating and electricity purposes over the last few decades. Its success in developed countries like USA, UK and in Europe is laudable. This sector of the energy industry is gradually growing in developing countries like China, India and even Nigeria. It has greatly contributed to the improvement of economic activities and standard of living in some of these countries. The aim of this research was to investigate the factors that influence consumers in Nigeria to adopt renewable energy. The research approach that was adopted for this study was quantitative. Data was collected from the consumers of renewable energy in Nigeria. The questionnaires served as the main data collection tool and was administered to the respondents via the internet. The main findings from the study show that environmental benefits that consumers receive when they adopt renewable energy have the most significant influence on their adoption of renewable energy. Technological knowledge also has an influence on consumer adoption of renewable energy. Cost has the least significant influence on consumer adoption of renewable energy. The findings also show that government policy does not have a significant influence on consumer adoption of renewable energy in Nigeria. This study has contributed to academic literature by adding to the available literature on renewable energy in developing countries. The study has also introduced a new model that can be used by future researchers who would like to undertake research in a related field.

Keywords: Renewable energy; Consumer adoption; Nigeria; Energy consumption

1. Introduction

Energy resources have existed probably as long as man has. Over the years, developmental studies have been carried out to ensure efficient use and utilization of energy. Renewable energy, which is one of these resources, has also developed tremendously over the last decade. Renewable energy is defined as energy sourced from natural resources that are can be replenished. These include wind, fossil fuels, sunshine, biomass and small rivers. (Martinot, Chaurey, Lew, Moreria, & Wamukonya, 2002, p. 101) state that “renewable energy compliments the energy sourced from non-renewable sources and contributes about 7%-11% of the global energy consumption”. Renewable energy has experienced development globally especially in developed countries like USA, Germany, and Netherlands. In recent times, some developing countries like China, India, Bangladesh and Nigeria have also shared in these developments. These developments have efficiently provided consumers with energy via solar energy (sunshine), wind energy, biomass energy and small hydropower. The existence of these sources in different geographical locations has also encouraged the rapid deployment and development of renewable energy and has enhanced energy security. The design of renewable energy allows it to suit remote areas where energy is crucial for development. Consumers of renewable energy have also contributed to its development especially with its acceptance in the developed countries. Examples include consumers availing their rooftops for installation of solar panels for solar energy and using of energy efficient appliances (smart appliances) (Paetz, Dutschke, & Fichtner, 2012).

Renewable energy sources in Nigeria include water from rainfall and rivers that have capacity to generate 734.2MW of hydropower located in river basins. Power Holding Company of Nigeria (PHCN), before its privatization, estimated exploitable hydro potential as 12,220MW. The current generation is about 14% of the nation’s hydropower potential (Abiodun, 2012). With solar resources existent in the country due to a mean annual temperature of 270C, it indicates a possibility of generating 1850 x 103 GWh of solar electricity per year for solar energy development in Nigeria (Sambo, 2009). The biomass energy yearly resource of 144 million tons dominates the Nigerian landscape. It is a leading source of energy for Nigeria especially in the rural areas for the urban poor. This accounts for 37% of the total energy demand and is usually an off-grid usage. Sambo (2009) also highlights the development of 3-stone stoves that have efficiency as low as 15% and reduce fuel wood consumption. Biomass generation and utilization is underway but there is no biomass fired power plant in the country presently. Developmental initiatives with regard to small hydropower have been encouraged via the collaboration of United Nations Industrial Development Organization (UNIDO) and relevant government agencies (Sambo, 2009). Though this source has not been fully exploited, a few consumer beneficiaries have felt its progress impact.

Solar energy especially photovoltaic has been developed mainly for the use of solar cooking and solar water heating for hospitals. Biomass energy development has also been aided by the sources from vegetation and led to the development of stoves used in the household to replace the fuel wood that has been prevalent in these settings. Wind energy available in the north is being used for water pumping by people living in communities in this area (Sambo, 2009). In Nigeria, the endowment of natural resources such as abundant sunshine, fossil fuels reserves, wind and hydro, e.g. rivers, streams and the challenge of decline in total electricity consumption by consumers due to incessant outages, suggest a need for renewable energy (Akinbami, 2001). Sambo (2009) and Abiodun (2012) analyze the electricity situation with the following perspective: 69% of urban areas have access to electricity as compared to 26% of rural areas. For those connected to the grid system, 60% of the time they experience power shortage, and less than 40% of the population is connected to the grid. This has generated a need for renewable energy sources to augment the present energy source in the country. The renewable master plan was expected to be 42% in 2005, and an expected rise to 60% by 2015, but this has not been achieved. Analysis shows that with investment in renewable energy, there is inconsistency in its projected development (Abiodun, 2012). Nigeria requires more energy to meet the needs of its populace, as its present source from the Power Holding Company of Nigeria (PHCN) is no longer efficient in meeting the consumers' needs. Therefore, the development of renewable energy would contribute to her energy needs as the energy sector struggles to provide its populace with sufficient energy[6] supply (Sambo, 2009). Figure 1 below shows the renewable energy potential of Nigeria and shows that hydro power provides the largest contribution to the energy mix.

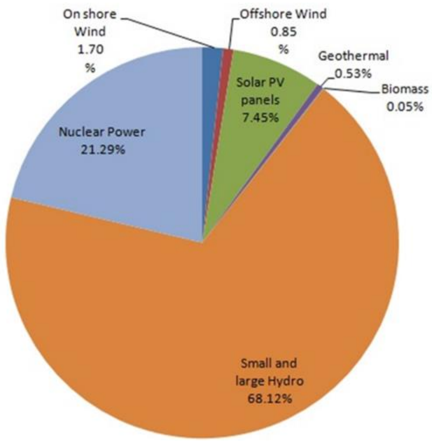

Figure 1 Olaoye et al, 2016

Several researchers have demonstrated the need for renewable energy development. (e.g. Akinbami, 2001; Martinot et al. 2002; Mondal, Kamp & Pachova, 2010 and Bada, 2011). They observed that suppliers still face challenges of importing their products and that policies to integrate energy

[6] Energy in this case refers to electricity.

sources still exist in developing countries. However, there is still a knowledge gap in relation to the factors that influence consumer adoption of renewable energy in developing countries (Caird & Roy, 2008). Therefore, this research aimed at exploring those factors that influence the Nigerian consumer in adopting renewable energy. Energy plays a key role in the economic growth and development of any country contributing to income via trade internationally. Nigeria is no exception to this as its economic growth is heavily dependent on the availability of energy. Energy is also an input to the nation's industry in health, agriculture, education and the political sectors (Sambo, 2009). Renewable energy, when harnessed, can be used with non-renewable energy in an energy mix to aid economic growth and development since it replenishes from its source when compared to non-renewable sources of energy. However, Nigeria still faces the challenge of reliable electricity and in general sustainable energy. This has led to a decline in total electricity consumption by consumers due to incessant outages and inability to meet consumer needs by the present national grid (Sambo, 2009).

According to Olugbenga et al. (2013), the energy situation still suffers some setbacks in meeting consumer demands of electricity. These include low available capacity, physical deterioration of transmission and distribution facilities, high technical losses and vandalism, inefficient usage capacity, inappropriate industries and market structure and limited access to infrastructure. Renewable energy is considered a possible alternative that can help to overcome the current electricity challenges faced by Nigerian consumers and enable the government to avail consumer's clean energy especially in this era of climate change impacts on the environment. This research was aimed at achieving the following two main objectives:

1. To explore the motivating factors affecting consumer adoption of renewable energy in Nigeria.
2. To identify the strategies that can be adopted by government and suppliers of renewable energy to meet consumer needs in a more efficient and effective manner

The major research questions is "What factors influence Nigerian Consumers to adopt renewable energy?" and the minor questions are:

- What perception do Nigerian consumers have about renewable energy?
- How does cost influence consumer adoption of renewable energy?
- How does technological knowledge influence consumer adoption of renewable energy?
- How does government policy influence consumer adoption of renewable energy?
- How do environmental benefits influence consumer adoption of renewable energy?

This research adopted a quantitative approach. This method was considered most appropriate because of the nature of the study, which is descriptive and explanatory. Such studies seek to discover the associations among variables and to further investigate the causes of this relationship (Saunders, Lewis, & Thornhill, 2009). There are only few studies that have focused on consumer adoption of renewable energy in Nigeria. Thus, a quantitative approach would enable the researcher to describe the factors that motivate Nigerian consumers to adopt renewable energy.

2. Background

Energy is an important necessity for human life and existence. It can be likened to food, shelter and clothing needed by humans for daily living. It is usually associated with power (electricity) and has been viewed as a major contributor to economic development. This has contributed to improvement in energy technologies over time. The business dictionary has defined energy as

> "*Measure of the ability of a body to do work or produce a change, expressed usually in joules or kilowatts hours (kWh)*" (BusisnessDictionary)

The free Merriam- Webster dictionary also defined it as

> *"Usable power (as heat or electricity); also the resources for producing such power"* (Merriam-Webster dictionary)

Akinbami (2001) Further defines renewable energy sources as

> *" The harnessing of natural energy flows (e.g. sunlight, wind, waves, falling water, ocean currents, and*

tides) or the tapping of natural stocks of energy whose rate of replenishment are comparable to or greater than the human use rates (such as ocean thermal gradients, biomass, and hydro-power reservoirs)" (Akinbami, 2001, p. 155)

There are two major energy sources: renewable and non-renewable sources. The usage of non-renewable sources is very popular worldwide. However, renewable sources of energy are encouraged and have been on the increase in the years 2011 and 2012. In 2011 they grew by 19% while 1470GW was the power capacity worldwide from renewable energy sources making the total percentage generated in 2012 26% and 21.7 % of the global electricity (REN21, 2013). It is important to note that renewable sources include hydropower, wind, solar PV, and biogas. These sources used in the cooling and heating sectors of the industry in countries like Spain, China, Germany, Denmark and the Netherlands to mention a few. With regard to the power sector, renewable energy sources have received much development in policies of feed in tariffs (FITs) and renewable portfolio standards (RPSs) which improved in 2012 and involved countries in Africa and the Middle East (REN21, 2013). This improvement in the policies and standards indicate that consumers are adopting renewable energy especially in Africa.

In Nigeria, the increasing need for energy has created a search for sources that have been earlier neglected, for example wind, sunshine and biomass (Akinbami, 2001). Renewable energy is harnessed natural energy from sources like water, wind, sun and biomass whose rate of replenishment is greater than its use by human consumption (Akinbami, 2001). Its benefits include improving the standards of living with its mitigating of CO2 emissions, reducing climate change challenges, creating options to meet energy needs, creating of new employment and availing energy supply where it exists or is harnessed. Further, Mondal, Kamp, & Pachova, (2010) in their study advocate the need for renewable energy in rural areas for economic growth, which is used as a measure of the physical quality of life of the people. There are different types of renewable energy sourced from different renewable sources. These are discussed in detail below.

2.1 Solar Energy

Solar energy is the conversion of sunrays to energy. It can be used for electricity or for heating purposes. The geographical location of places determines how much solar energy can be harnessed and used. This includes time of the day, its dryness and its landscape (U.S Energy Information Administration, 2013). For electricity purposes, solar energy is converted using Photovoltaic cells (solar panels), or through thermal plants for heating purposes. The Solar photovoltaic cells have been used in developed countries like the USA and in Europe, which is leading in its usage (REN21, 2013) while the market is growing in Africa, MENA region and Latin America. For thermal heating and cooling from solar, China and Europe were leading in its usage in 2012 though this was not without challenges arising from mergers of leading companies and consolidation in China (REN21, 2013). In their studies Sambo (2009) and Bada (2011) highlight the abundance of sunshine in Nigeria, which relates to its fair solar radiation of about 19.8MJm/day. With the use of solar modules, an energy capacity of 1850x103 GWh / year could be generated in the country. This would improve greatly the electricity available for consumption. Furthermore, if this electricity is generated, it could be used in every part of the country especially in rural areas where there is still a lack of electricity.

2.2 Wind Energy

Wind energy for electricity dates back to 120 years ago. In the last decade, wind energy has received concessionary policies that have made the wind turbine market expand from Europe (e.g. in Denmark and Spain) to China and Turkey. Though most of the wind energy comes from onshore, developments are geared towards the offshore wind, which is stronger and uniform since it originates from the sea (Leung & Yang, 2012). Wind, has been exploited as a source of renewable energy especially in developed countries like Denmark, Germany and the Netherlands. Developments have been improved to include off shore farms that supply electrical energy to consumers (Menanteau, Finon, & Lamy, 2003). In their research, Leung & Yang (2012) estimated that the production projection for 2015 is 425GW. In Nigeria, offshore areas in the south like Lagos, Cross-river, Rivers, and Bayelsa possess potentials for wind energy to be harvested and used. In the inlands, the hilly parts of the north possess these potentials, which if harnessed, and converted with the use of wind turbines, wind generators, and wind dynamos could be used to generate electricity. With this development, consumers can also enjoy the benefit of portable electricity as compared to the benefits of the windmills used in providing portable water in the north in the 1960s Bada, (2011) and Awogbemi & Ojo, (2009). In his study, Ajayi (2010) estimated the speed of wind to be 3m/s to 3.5m/s in the southern part of Nigeria depending on the state and 4.0m/s to 7.5m/s in the northern part of the country. This shows that wind energy could be used to generate standalone generating systems, which can provide electricity for rural areas. Though wind energy provides these benefits, it has noise and climatic impacts on the environment, which should be considered.

2.3 Biomass Energy

Biomass is defined as organic decomposing matter from plants or animals on a regular basis. It could be organic waste, herbaceous plants, wood as well as manure. Biomass energy is energy sourced from fuel wood and refuse from dead leaves and waste products. It accounted for 10% of the world primary energy in 2009 and it is projected that its demand will increase by 3-fold by 2050 (International Energy Agency, 2014). Sambo (2009) observes that about 95% of the total fuel wood consumption is used in households for cooking and for cottage industrial activities, such as for processing cassava and oil seeds. Under an integrated rural energy supply project, selected communities are assessed for renewable energy resources, energy requirement and available human resources. An integrated energy supply system is then designed that utilizes the available renewable energy resources to supply the energy requirement of the communities. To sustain the integrated rural energy project, local human resources are trained to maintain the system. Amidst these developments a three-stone stove has been designed for use in households to replace fuel wood usage. This stove has an efficiency of about 15% although developing it also has an impact on health and the environment, which require development of policies to minimise this impact (International Energy Agency, 2014).

2.4 Consumer Adoption.

Rogers (1983) as cited by Sahin (2006, p. 1) defines adoption as "a decision of full use of innovation as the best course of an action available". Similarly, Sathye (1999, p. 325) defines adoption as "the acceptance and continued use of a product, service or idea". She further observes that consumers go through several processes to adopt an innovation or technology and that this process begins only when consumers are aware of the product. Labay & Kinnear (1981) argue that the individual process of consumer adoption and diffusion can later be integrated as a part of a larger process of change. We can conclude from Rogers (1983) as cited by Sahin's (2006) and Sathye's (1999) studies that the adoption process involves persuasion i.e. awareness of the new process or idea, deciding and confirming acceptance of the new process or idea. In this study, renewable energy is viewed as an innovation that will require Nigerian consumers to go through the consumer adoption process.

2.4.1 Adopter Categories

Consumer adoption is a process that involves several adopters at different points in time. Rogers (1983) as cited by Sahin (2006) categoried adopters in a bell-shaped curve over time. This led to five adopter categories on their basis of innovativeness. According to Rogers (1983) innovativeness measures the degree to which individuals adopt new ideas when compared with other individuals. The five adopter categories are as follows: **Innovators** are individuals, who are willing to experience new things and ideas. They are usually willing to cope with the unsuccessful innovations with a certain level of uncertainty and this usually requires them to have complex technical knowledge. **Early adopters** are more limited within the boundary of the social system. They are likely to hold leadership roles in social systems and hence other adopter seek advice from them making their attitudes towards the innovation very important. They help in decreasing the level of uncertainty and put their stamp of approval on ideas by adopting them. **Early majority** also relate with the society but not with a strong leadership role. However, their interpersonal networks play an important role in the innovation diffusion process. They are deliberate in adopting innovations and are neither the last nor the first to adopt an innovation. **Late majority** are mainly members of the social system that wait until most of their peers have adopted the innovation. Although skeptical, the economic necessity and peer pressure contributes to their adopting of the innovation. The uncertainty of innovation is reduced when their peers persuade them to adopt the innovation. **Laggards** These have a traditional view and are more skeptical about innovations and change. Due to lack of awareness, they make sure that an innovation works before they adopt it

3. Methods

This study uses the deductive approach. The deductive approach explains the causal relationship between variables using quantitative data. Deductive theory offers a testable proposition about the relationship between two or more variables in a theory. The theory can be tested to examine the outcome, to either confirm the theory or modify the existing theory with respect to new findings. Deductive studies lead to a generalization, and this is possible when samples are used during studies to enable generalization of deductions (Saunders, Lewis, & Thornhill, 2009). The deductive approach was chosen because of its ability to describe and explain causal relationships between variables.

This research is quantitative in nature as it seeks to describe those factors that may have an influence on the adoption of renewable energy in Nigeria. Surveys were conducted using web-administered questionnaires, which comprised of several open ended and closed ended questions. The closed ended questions were used to find out from respondents those factors that have an influence on consumer adoption of renewable energy and their influence. The open-ended questions were used to find out from respondents' other possible factors that might influence consumer adoption of renewable energy, but which had not been considered in this study and to get respondents views, on the challenges they face while using renewable energy and how these could be overcome.

3.1 Research Setting

The setting for this research was Nigeria. Nigeria is located in the western part of Africa and has a population of 168.8 million. Renewable energy is relatively new in Nigeria, and its adoption by consumers is still a process that is in its exploratory stage. However, due to the challenges faced by the Nigerian population with regards to electricity supply, renewable energy is considered as a possible solution to this challenge. Nigeria has two seasons yearly, namely the rainy and dry seasons. Also, two major rivers, river Niger and river Benue have tributaries running into them making the source for renewable energy from hydro available. The maximum average temperature is about 440C with high sunshine, which can also be used as a source of solar energy. In Nigeria, the endowment of natural resources such as abundant sunshine, fossil fuels reserves, wind and hydro, e.g., rivers, streams (Akinbami, 2001) and the challenge of decline in total electricity consumption by consumers due to incessant outages, suggest that renewable energy could be used as a possible support to avail its population electricity.

3.2 Population and Sampling Size

The research population for this research was the Nigerian consumers of renewable energy. A non-probability sampling method was used in the research since the population was not easy to define Bloomberg et al. (2011). For this research there was a lack of existing records of the total consumers of renewable energy in Nigeria, hence the motivation to adopt this sampling method. There are several types of non-probability sampling. However purposive and snowball sampling were used in this research to access respondents. Purposive sampling was used to ensure that only those respondents who had adopted renewable energy in Nigeria filled in the questionnaires in order to get meaningful responses and thus be able to answer the posed research questions in chapter 2. Snowball sampling was used in this research by asking respondents to suggest other consumers known to them who also used renewable energy. This was done to ensure that as many responses as possible could be obtained during the short time that was available for the survey. A total number of 50 web administered questionnaires were sent out and 41 answered questionnaires were received back dully filled which gave a response rate of 82%(see table 1).

Table 1: Sample size of Respondents

Sample Selected	Number of Respondents	Response Rate
50	41	82%

Source: Edu (2014)

3.3 Data Sources

For this study, we used two main sources of data namely, primary and secondary sources. **Primary Data** Primary sources enable a researcher to collect primary data. According to Saunders et al. (2009), primary data include data that were collected specifically for the research purpose. Primary data for this study were collected from the consumers of renewable energy in Nigeria using a web administered questionnaire. The questionnaire was chosen for its versality, efficiency and economic attribute which has been highlighted by Bloomberg et al. (2011). The limited time frame for the research and the financial implications for physical administering of the questionnaire were also considered. Thus, an email survey using a web-based response was used for this study.

Secondary Data According to Bloomberg et al. (2011) , secondary data is information that has already been collected and recorded by someone else for other purposes. In this study, secondary data was collected from energy reports, web sourced information, conference proceedings and publications on renewable energy. These data were properly referenced, and they were chosen because they provided easy and accurate data and information on renewable energy especially from a global perspective.

3.4 Data Collection Method

The questionnaire administered was designed to answer the questions about the independent variables of cost, technological knowledge, government policy and environmental benefits and dependent variable which is consumer adoption. The questions were divided into four sections namely, demographic, influencing factors, consumer adoption and a section that gave respondents an opportunity to answer open ended questions. The questionnaire was designed using *esurveycreator.com*. The email had an introductory message with the link for the survey included asking respondents to partake in the survey by clicking on the link. A five point likert scale was used to answer questions on consumer adoption and the influencing factors of consumer adoption namely cost, technological knowledge, government policy and environmental benefits. Cost was measured using insights from Menanteau et al. (2003) and Arkesteijn & Oerlemans, (2005) ; technological knowledge was measured using insights from (Arkesteijn & Oerlemans, 2005) and Sathye, (1999) ; Government policy was measured using insights from Labay & Kinnear, (1981) and Mondal et al. (2010) ; and environmental benefits was measured using insights from Menanteau, Finon, & Lamy, (2003) and Caird & Roy, (2008). Consumer adoption was measured using insights from Irani et al. (2009), Sathye, (1999) and some insights from service quality were used also from Caruana, (2002).

Three open ended questions were used to find out other possible factors that might not have been mentioned in the questionnaire and to allow respondents to suggest ways of overcoming the challenge they face while using renewable energy. The questionnaire was self-administered via the internet due to time constraint of reaching respondents considering the large population of Nigeria as well as the high cost of transportation to different parts of the country.

Internet based tools of data collection have advantages which include low cost , time efficiency, and bias reduction because the questionnaire is sent to only those respondents who are approved by the administrator of the questionnaire. The internet-based tool also helps to see who responded and who completed the questionnaire thus giving the detailed report. However, one disadvantage of the internet-based tool when compared to the telephone or postal mail is that the rate of response is 11 % or less for email administered survey as compared to 30% for telephone and 50% or more for postal mail Saunders et al. (2009). Other disadvantages are that the questionnaires have to be simple and sometimes there are limits to the questions that can be asked. Also clarifications cannot be offered if respondents do not understand some questions. However, the advantages of internet-based tools (survey via emails) far outweigh the disadvantages. Thus, this encouraged the researchers to use of internet-based questionnaire. Prior to its administration, a pilot test was carried out to clarify some of the concepts in the questionnaire. The pilot questionnaire was administered to four volunteers who were also consumers of renewable energy in Nigeria. Results showed that some terms needed to be defined more clearly. Some sentences also needed to be made shorter for clarity sake. Revisions were made to the questionnaires. The final survey was rolled out on the 2nd of July 2014 and a week later, a remainder was sent. The survey ended on the 19th of July 2014, and it fulfilled the required period of two to six weeks for a survey as suggested by Saunders et al. (2009). Though more time could have given more respondents an opportunity to participate and thus increase the sample size, the short period for analysis and reporting made it impossible to implement.

3.5 Data Analysis

In designing the questionnaire, *esurveycreator.com*, an online survey instrument was used. Part of the reason why it was used was because it also provided an analysis of the results received like graphs, standard deviation and mean, which can be exported in pdf, excel and png formats. Demographic information was analysed by esurvercreator.com. Stata version 13.1, a statistical package was used for more detailed analysis of the findings. For example, multiple regression tests between both dependent and independent variables and correlations to find out if there is a relationship between the independent variables and dependent variables were also run.

Multiple regressions enabled us to identify the relationship between the dependent variable consumer adoption and the independent variables cost, technological knowledge, government policy and environmental benefits. Factor analysis test was used to condense each of the independent variables into a smaller set of factors. Stata was also used for descriptive statistics especially for mean and frequencies, which further confirmed the results from esurveycreator.com.

3.6 Reliability and Validity Issues

To ensure reliability, the data gathered from the survey were tested for internal consistency. Cronbach’s alpha was used to test for internal consistency of all the variables of interest namely cost, technological knowledge, government policy, environmental benefits and consumer adoption. The results are shown in table 2 below. To further ensure reliability, proper records of the survey responses were kept in case clarification was needed for further study.

Table 2: Cronbach's Alpha values for the study Variables

Variable	**Cronbach’s Alpha Value**
Cost	0.66
Technological Knowledge	0.86
Government Policy	0.77
Environmental benefits	0.98
Consumer Adoption	0.95

Source: Edu (2014)

To ensure validity, the questionnaire was pilot tested on a small sample of respondents to check for errors and adequateness of wording before distributing it to all respondents. This was done to ensure all credibility and minimise errors and biases as Yin (2003) suggested.

4. Results and Discussion

4.1 Usage of Renewable Energy

In the survey, questions 6 to 8 asked the respondents how long they had been using renewable energy, what source of electricity they used prior to renewable energy and what reason influenced their usage of other sources of electricity apart from renewable energy. 18 of the respondents (50%) had used renewable energy over 5 years, 14 (30%) had used renewable energy between 3-5 years and 8 respondents (20%) had only used it between 1-2 years. Details are shown in figure 2. The source of electricity that respondent used prior to renewable energy was popularly from the grid source and supplied by the Power Holding Company of Nigeria (PHCN). With regards to the reasons that influenced respondents' usage of other sources (see question 8 of the questionnaire), respondents were asked to choose from one or more options that were given namely, convenience, reliability, cheapness and to explain in case they had other reasons, why they used other sources of electricity. 22 of the respondents (39%) had other reasons for using other sources of electricity. The reasons included the availability of PHCN though it was not reliable. This was indicated with only 9 respondents (16%). 14 respondents (25%) indicated that it was more convenient and 11 of the respondents (20%) cited cheapness as their reason for using other sources. In view of the data collected, the minor and major research questions for this study are discussed in details below

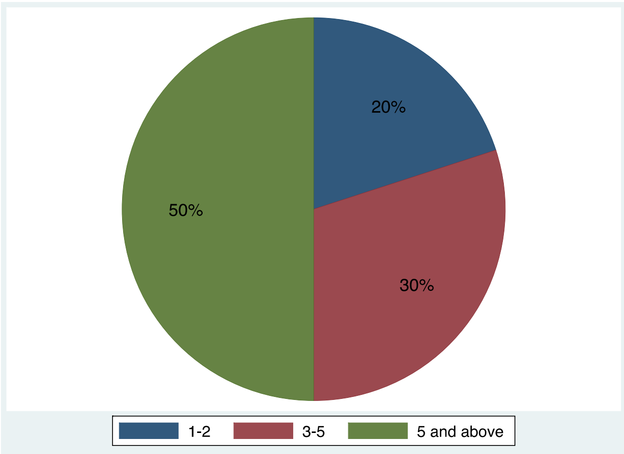

Figure 2 Source: Edu (2014)

4.2 Minor research questions:

1 *"What perception do Nigerian's consumers have about renewable energy?"*

To answer this question, descriptive statistics was done to find out the mean scores of each of the four influencing factors of consumer adoption namely cost, technological knowledge, government policy and environmental benefits. Table 4.1 below shows that environmental benefits had the highest mean value of 4.34, followed by technological knowledge which had a mean value of 4.00, then cost followed it had a mean of 3.22. Government policy had the lowest mean value of 2.62. These results indicate that respondents had the most positive perceptions about environmental benefits and the least positive perceptions about government policy. The attribute under environmental benefits that had the highest mean value was "By using renewable energy I contribute to a better environment". The attribute under government policy that had the lowest mean value was

"The subsidies given by the government on renewable energy have encouraged me to use it". From these findings, we can conclude that in general, consumers of renewable energy in Nigeria have very positive perceptions about environmental benefits followed by technological knowledge and cost. Consumer's perceptions are less positive with regards to government policy

2 *"How does cost influence consumer adoption of renewable energy?"*

To answer this question, first a factor analysis was run on the cost variable using stata 13.1 to identify the underlying factors under the cost variable (see table 4.2 above). Two factors for the cost variable were identified namely factor 1 and factor 2. The results showed that factor 1 had four factor loadings with each component's value higher than 0.4 while factor 2 had only one factor loading higher than 0.4. These results indicate that factor 1 is more dominant than factor 2 as supported by Acock, (2012). Therefore, factor 1 was selected and retained under the cost variable. Secondly, a correlation test was run as already discussed in section 4.4. The results of the correlation test in table 4.6 showed that cost had a weak negative correlation with consumer adoption (i.e., r = -0.02). The negative correlation means that if cost decreases, consumer adoption of renewable energy would increase and vice versa. Thirdly, a multiple regression test was performed the results show that cost has a significant influence on consumer adoption of renewable energy, and it was observed that the p-value for cost is less than 0.05 (i.e. P=0.04) at 95% confidence level.

3 *'How does technological knowledge influence consumer adoption of renewable energy?"*

To answer this question, first a factor analysis was run on the technological knowledge variable using stata 13.1 to identify the underlying factors under the technological knowledge variable (see table 4.3 above). Two factors for the technological knowledge variable were identified namely factor 1 and factor 2.

The results showed that factor 1 had six factor loadings with each component's value higher than 0.4 while factor 2 had only one factor loading higher than 0.4. These results indicate that factor 1 is more dominant than factor 2 as supported by (Acock, 2012). Factor 1 was selected and retained under the technological knowledge variable.

Second, a correlation test was run as already discussed in section 4.4. The results of the correlation test in table 4.6 showed that technological knowledge had a strong positive correlation with consumer adoption (i.e., r = 0.77). The positive correlation means that if technological knowledge increases, consumer adoption of renewable energy would also increase.

Third, a multiple regression test was performed, the results show that technological knowledge has a significant influence on consumer adoption of renewable energy.

These findings are similar to those of Arkesteijn & Oerlemans (2005) who in their study on green energy adoption (green energy is similar to renewable energy), found that adoption by consumers was influenced by how knowledgeable they were about green energy technology. Thus, our findings are supported by the work of Arkesteijn & Oerlemans (2005). In contrast, Caird & Roy, (2008) had contrasting results as they found that consumers were more influenced by the design of the technology for renewable energy and how efficient the technology would be in its usage.

In summary, we conclude that there is a relationship between technological knowledge and consumer adoption and that technological knowledge has a significant influence on the adoption of renewable energy in Nigeria. These findings provide an answer to minor research question 3 of this study.

4 *'How does government policy influence consumer adoption of renewable energy?"*

To answer this question, first a factor analysis was run on the government policy variable using stata 13.1 to identify the underlying factors under the government policy variable (see table 4.4 above). Two factors for the government policy variable were identified namely factor 1 and factor 2. The results showed that factor 1 had four factor loadings with each components' value higher than 0.4 while factor 2 had two factor loadings higher than 0.4. These results indicate that factor 1 is more dominant than factor 2 as supported by (Acock, 2012). Factor 1 was selected and retained under the government policy variable. Secondly, a correlation test was run as already discussed in section 4.4. The results of the correlation test in table 4.6 showed that government policy had a weak positive correlation with consumer adoption (i.e., r = 0.13). Though the positive correlation is weak, it indicates that if government policy increases, consumer adoption of renewable energy would also increase. Third, a multiple regression test was performed the results show that government policy has an influence on consumer adoption of renewable energy. From the table we observe that the p-value for government policy is greater than 0.05 (i.e. P=0.78) at 95% confidence level. This indicates that government policy does not have a significant influence on consumer adoption of renewable energy.

Menanteau et al. (2003) showed from their studies that government policies that supported price reductions and tariffs aided in the development of renewable energy. The findings of this research contrast Menanteau et al.'s (2003) work. The reason for this could be that government is not currently giving subsidies on renewable energy. However, we expect government policy if clearly formulated and implemented to influence consumer adoption of renewable energy in Nigeria. Infact, Martinot et al. (2002) argued that in developing countries, renewable energy markets would require (i) government policies that would support them and (ii) technical knowledge and capabilities for maintenance of the equipment. However, scholars like Paetz et al. (2012) found from their studies that the issue of government policy on the design of renewable equipment and appliances to support adoption has not been sufficiently addressed. They argued that though the policies supported the technologies and environmental issues, they did not put into consideration the perspective of the consumers. In summary, we conclude that there is a relationship between government policy and consumer adoption. However, government policy does not have a significant influence on the adoption of renewable energy in Nigeria. These findings provide an answer to minor research question 4 of this study.

5 *'How do environmental benefits influence consumer adoption of renewable energy?"*

To answer this question, first a factor analysis was run on the environmental benefits variable using stata 13.1 to identify the underlying factors under the environmental benefits variable (see table 4.5 above). One factor for the environmental benefits variable was identified and named factor 1. The results showed that factor 1 had f factor loadings for all components of environmental benefits with values higher than 0.4. The result indicates that factor 1 was dominant supported by (Acock, 2012). Factor 1 was selected and retained under the environmental benefits variable. Second, a correlation test was run as already discussed in section 4.4. The results of the correlation test in table 4.6 showed that environmental benefits had a strong positive correlation with consumer adoption (i.e., r = 0.93). With the strong positive correlation, it indicates that if environmental benefits increase, consumer adoption of renewable energy would also increase. Third, a multiple regression test was performed the results show that environmental benefits have an influence on consumer adoption of renewable energy. From the table we observe that the p-value for environmental benefits is less than 0.05 (i.e. P<0.001) at 95% confidence level. This indicates that environmental benefits have a significant influence on consumer adoption of renewable energy. It is evident from the results in table 4.7 that environmental benefits have a significant influence on consumer adoption of renewable energy in Nigeria. This can be explained by the awareness of consumers of the benefits they receive from a pollution free environment especially when they contribute to it with the use of renewable energy. Similarly, Arkesteijn & Oerlemans, (2005) and Paetz et al. (2012) in their studies also discussed the perceived responsibility consumers had towards the environment and how it influenced that adoption of renewable energy by consumers of renewable energy. Consumers were interested and willing to contribute to the carbon footprint via their use of renewable energy. This influenced their adoption of renewable energy. In summary, we conclude that there is a relationship between environmental benefits and consumer adoption and that environmental benefit has a significant influence on the adoption of renewable energy in Nigeria. These findings provide an answer to minor research question 5 of this study.

4.3 Major research question

Following the above answers to the 5 minor questions, the major research question was answered as below. The major research question for this study was ***"What factors influence Nigerian Consumers to adopt renewable energy?***

From the results of the multiple regression shown in table 4.7 and the stepwise multiple regression shown in table 4.8, we observe that three of the independent variables namely cost, technological knowledge and environmental benefits have a significant influence on consumer adoption in Nigeria. Of the three variables, environmental benefit has the most significant influence ($P<0.001$), followed by technological knowledge ($P= 0.02$) and lastly cost ($p=0.04$). Moreover, government policy did not have a significant influence ($P= 0.78$). From these findings, we conclude that there is a relationship between cost, technological knowledge, government policy, environmental benefits and consumer adoption. Moreover, we conclude that cost, technological knowledge and environmental benefits have a significant influence on consumer adoption of renewable energy. However, of the three factors environmental benefits has the most significant influence. These findings provide an answer to the major research question of this study

4.4 Other Findings

Some open-ended questions were also asked and sought respondents' views on the challenges faced in using renewable energy in Nigeria and suggestions on how these challenges could be overcome. Most respondents' mentioned lack of government policy and awareness on renewable energy as the main challenge. Other challenges were lack of access to spare parts for replacement especially with regards to solar panels. Respondents suggested that these challenges could be overcome by a government policy on subsidy for renewable energy, awareness programs of the benefits to encourage its usage and installing renewable energy in every local government area in Nigeria.

Other suggestions included setting up institutions of learning that would transfer the knowledge of renewable energy and research on its development, research on more efficient components that would enable consumer energy needs to be met, government encouragement to import renewable energy equipment by lowering the import tax and encouraging local development of some renewable energy components to further reduce its cost of acquisition.

5. Conclusions and recommendations

The fundamental purpose of this research was to explore the motivating factors that influence the Nigerian consumer in adopting renewable energy and identify strategies that the government and suppliers can use to improve the consumers' adoption of renewable energy in Nigeria.
The major findings from this research are presented below:

1. The perception of the consumers is most positive towards the environmental benefits followed by technological knowledge and cost. Consumers' perception is least positive towards government policy.
2. Cost has a significant influence on consumer adoption of renewable energy in Nigeria. This influence could be related to acquisition cost of renewable energy equipment and it's maintenance.
3. Technological knowledge has a significant influence on consumer adoption of renewable energy in Nigeria. From the responses of the consumers, the interest of consumers in technology was contributory to their adoption of renewable energy.
4. Government policy did not have a significant influence on consumer adoption of renewable energy. This could be either due to lack of awareness of the existing government policies or the policies are not supportive to consumers.
5. Environmental benefits had the most significant influence on consumer adoption of renewable energy in Nigeria. This indicates that consumers are aware of the benefits they

contribute to the environment and also gain from the environment thru the use of renewable energy. This has greatly influenced their use of renewable energy.

Among the four factors that influence consumer adoption of renewable energy, environmental benefits had the most significant influence on consumer adoption of renewable energy. This was followed by technological knowledge and then cost.

Government policy did not have a significant influence on consumer adoption. This could be due to the non-existence of subsidy on renewable energy in Nigeria, which could help in reducing acquisition cost of renewable energy. Overall, there are indications that the Nigerian consumer of renewable energy will continue to use renewable energy irrespective of the challenges faced by using it. The following implications are recommended for practice:

1 The renewable energy market is relatively new in Nigeria. It is faced with challenges especially with importation and cost. This research recommends that government policies that avail subsidies on renewable energy, support importation of spare parts and research in the development of renewable energy equipment locally in Nigeria should be used as a possible means of improving the market for renewable energy.

2 Design and manufacture of equipment and spare parts locally would aid the development of the renewable energy sector and in the long run, could be a solution to the electricity challenge existence presently in Nigeria.

3 Suppliers of renewable energy should design products that are cost effective and meet the requirement needs of the Nigerian consumers. This will contribute to an improvement and possibly growth in the renewable energy market in Nigeria.

4 Suppliers and government agencies should ensure that renewable energy is affordable and efficiently delivered to consumers in Nigeria.

5 The Federal Government of Nigeria should focus on awareness of Nigerians on the policy of renewable energy. It should also consider the introduction of subsidies on renewable energy. Research institutes should be set up to carry out research on renewable energy, especially with focus on the design, fabrication, and possible manufacturing of renewable energy equipment. This could further reduce its acquisition cost and further increase its usage. This in the long run, could be a possible solution to the energy challenge in Nigeria

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Improving the Thermal Performance of Double Skin Façade Using Phase Change Material Louvers

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Abstract: The double-skin facade is a building system consisting of two layers, or facades, including the intermediate cavity, used to meet changing requirements for comfort, function, and energy efficiency. The purpose of this study is to maximize using the double skin façade to improve thermal comfort in summer and winter and decrease the problem of overheating in summer time by adding PCM louvers with different spacing and thickness. The risk of overheating within DSF's envelope is high, therefore, accurate designing to the DSF with louver must be followed in order to reduce overheating and get more benefit out of DSF layering. Several steps followed in this study, first of all the data collected on the analysis , openings, materials and thermal behavior of the single and double skin façade building , and then a simulation using Design Builder software to make adjustments on the building to maximize the use of DSF for cooling and heating by adding aluminum louvers and phase change material PCM louvers with different spacing and thickness, to achieve thermal comfort and reduce the problem of overheating during summer time. The current research found that a double skin façade with PCM louver system will maximize efficiencies that improve the thermal performance, and decrease the overheating during summer time by increasing the thickness of louvers.

Keywords: Double skin façade, Phase Change Material (PCM), Overheating, Thermal performance.

1. Introduction:

According to Dixit, Fernández-Solís [1], the construction sector is liable for around 50% of energy usage, greenhouse gas (GHG) emissions, in addition to the depletion of natural resources worldwide. This usage of energy required the buildings to be more energy efficient than they currently are by reducing its energy demand while also 'greening' its energy supplies through maximizing the use of renewable energy. Otherwise, carbon dioxide (CO2) emissions will continue growing and will double by 2050 [2]. Double Skin Façades (DSFs) can reduce the energy required for the operation of buildings. Also, DSF technology has been selected as one of the best choices as a solution in the interaction between the internal and the external spaces [3].

Double skin façades (DSFs) is a hybrid system and a promising type of building façades, aimed to improve thermal performance in highly glazed envelopes. DSFs made of three various layers; the actual building facade, and the external glazed skin separated by an air cavity which has fixed or controllable inlets and outlets and may or may not integrate with fixed or movable shading devices. The cavity may work as a thermal buffer zone, as a ventilation channel or, predominantly, as a mixed of the two. It may be naturally or mechanically ventilated, and vary in width and height. The physical behavior of the DSFs depends on three variables; the typology, as well as the ventilation mode and finally the material components. All of these design variables can be combined in several ways for a wide variety of design possibilities. Also these variables define the dimensions of the DSF [3, 4].

Different studies were carried out to investigate the thermal and energy performance of the DSFs in temperate and cold climate as evident in a previously published literature reviews especially by [5-16]

The performance of the DSFs in term of the reduction in the heating load is the most widely used supporting arguments especially in temperate climates. The solar radiation passing through the external layer of the DSFs reaching the internal cavity and transformed to heat. The restricted heat inside the cavity starts to warm up the air which causes it to create conventional airflow patterns. This working mechanism helps to reduce the heat losses through the internal skin of the building. Moreover, where the quality of air is satisfactory, the warmer air in the cavity can also be supplied to indoor spaces [3].

A study by Baldinelli [5] showed a reduction in the heating load with a saving about 65% in the case of DSF compared to fully glazed single skin facade. The same results have also been achieved in similar contexts. In a study by Kolokotroni, Robinson-Gayle [7] in the UK, the results showed a reduction in the heating load about 70% compared to advanced single skins. Also, a reduction in the heating load about 50% and 40% have been found by [8] and [9] respectively, because of the greenhouse phenomena when DSFs are compared to single skin facade. Similarly, results in this range have been obtained by [10] in Korea, [11] in Iran, [12] in Belgium, [13] in Germany and Austria, and [14] in a lab-based experiment.

For the cooling load, the performance of the DSFs work as a supplier of the fresh air with or without mechanical means or extraction of the hot air from the occupied space by the stack effect. Also, even when the internal spaces does not have a ventilation to the cavity the DSFs can work as a natural fan which cools off the inner skin. Stec and Van Paassen [15] in their study investigated the ventilation strategies and their effect on energy consumption. The study showed a reduction in the cooling loads about 70%. But when comparing the performance of DSFs with a fully glazed facade a higher result of up to 93% were found. In like manner, the reduction in the cooling loads still impressively high up to 86% especially when comparing the results with a traditional facade with a WWR 50%.

From real measurement, Kragh [17] and Kragh [18] in two cases one in the UK and other in Belgium report a numerical reduction of about 30%-40%. Also, similar results found in Jordan, Iran and central Korea about 37.8%, 30% and 38% respectively [19, 20]. A study by Faggembauu, Costa [16], evaluated the effect of different parameters like the shading devices and low-e glazing. The study achieved a maximum reduction of about 27% of indoor gains and cooling loads.

1.1 Overheating in the double skin façade

After all of the mentioned above, there are several disadvantages related to DSFs. For example, the high investment cost compared with the traditional façade [21] and the external glazed layer reduce the daylight illumination level in the internal spaces. Lastly, from thermal point of view, there is a risk of overheating especially during the sunny days which may cause an increase in the energy consumption for cooling load [12].

For this end a lot of researchers have been studying the possible solutions for minimizing the overheating problems. For example, a study by Jager [22] concluded that the overheating problem can be avoided by minimizing the distance between the internal and external layer of the DSFs which help to enhance the stack effect. Wigginton [23] mentioned that the ventilation opening size is a very important parameter affecting the temperature inside the cavity. Especially, these openings define the efficiency of the air exchange between the DSF and the external environment.

Other flexible methods such as shading, thermal mass integration, application of energy storage materials such as phase change materials, and thermal control strategies have been studied to assess their effectiveness in removing excess thermal gains in DSFs [24].

Maybe the above mentioned methods can be used as a solution for the overheating problem in DSF but there are several obstacles to be beat. studies by Bentz and Turpin [25] and Jiru, Tao [26] conducted on the venetian blinds and concluded that variables like the position of the blind, the slat tilt angle and the color and size of the blind can affect the performance of the DSF. For venetian blinds, the big problem is the high surface temperature occurred as a result of the solar radiation absorption on the blinds [27]. In this case, the blinds work as a source of heat and contribute to overheating in the internal spaces.

1.2 The contribution of PCM in reducing overheating risks

The main feature of PCM devices is to store heat energy in a latent form, increasing heat storage capacity per unit size than that of traditional building materials. When the ambient temperature rises, the chemical bonds of the material break down so that the material changes from liquid to liquid. This phase change is a heat-absorbing process and as a result it will absorb heat. With lower ambient temperature again, PCM will return to solid state and give absorbed heat. This cycle stabilizes internal temperature, reduces off- peak cooling loads and reduces heating loads, not by affecting the thermal resistance of the building envelope but by influencing surface temperatures. For construction applications, the PCM used in the transition phase must be close to the human resting temperature (22-26 ° C). In general, the melting temperature must be obtained within the application temperature range [28].

2. Methodology

The use of whole-building energy simulation is an essential step to evaluate and analyze the performance of PCM-enhanced buildings. These tools can numerically analyze the dynamic thermal behavior of the building passively enhanced with PCMs. Different simulation programs can be used to investigate the dynamic energy simulation for different applications [29], but a few of these programs can be used to analyze the energy performance and indoor comfort of the building enhanced using PCM materials. According to literature review, EnergyPlus, have been widely used by researchers to investigate the behavior of PCM in buildings, and several studies validated these simulation tools [30]. Due to its popularity, the thermal modeling using EnergyPlus has been validated under various applications, as described in the Best Test Report [31].

In this paper, DesignBuilder used EnergyPlus, which is a widely used simulation engine developed by the Department of Energy (DOE) in the USA, has been adopted to investigate the performance of the building through various simulation scenarios. The DesignBuilder version of V4.2 was used in this research and EnergyPlus 8.1 was adopted as the engine for the thermal dynamic simulations. Using EnergyPlus, PCM can be modeled as a separate layer of material and then attached to any construction components within the building. Similar to that in EnergyPlus, Design-Builder allows users to enter manufacturers phase change properties in the form of a temperature - enthalpy curve on the Phase change tab of the Materials dialog. Also, some default PCMs are provided with the materials database that comes with Design Builder [32].

Amman-Jordan, with latitude 31.9539° N, and longitude 35.9106° E, was selected as the location for the simulation. The study investigated the effect of double skin during summer and winter and solved the problem of overheating during summer time, louvers were used to reduce the problem of overheating, aluminum and PCM louvers added in the cavity with different spacing between louvers and different thickness. All the proposed cases were tested and compared with the base case which is a single story double skin façade office building with a room facing the south. The interior dimension of the room is (8 x 6 x 2.7 m) for length, width, and height respectively and a cavity width about 0.6m as shown in Figure 1 below.

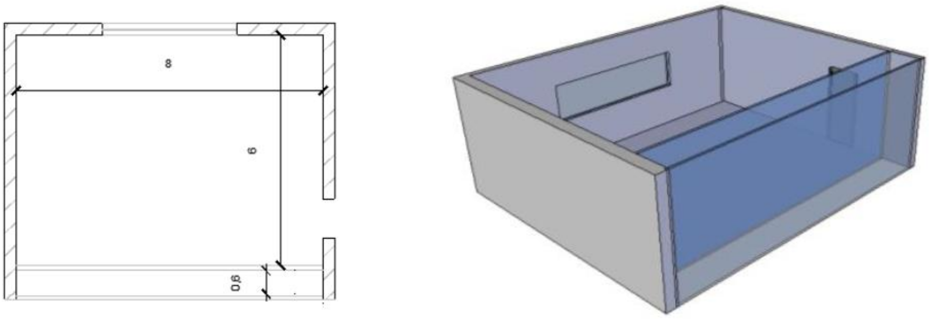


Figure 1. Simple Double skin façade single story office building.

Figure 2 showed the simulation flowchart and thereafter, a simulation for air temperature was conducted. The air temperature was used as the main factor to evaluate the performance of the double skin façade. The variables that affected the air temperature were the louvers in the cavity, the material of the blades, PCM and aluminum; and the spacing between louvers; these effect on the heat gain of the cavity and therefore effect on the air temperature on the DSF.

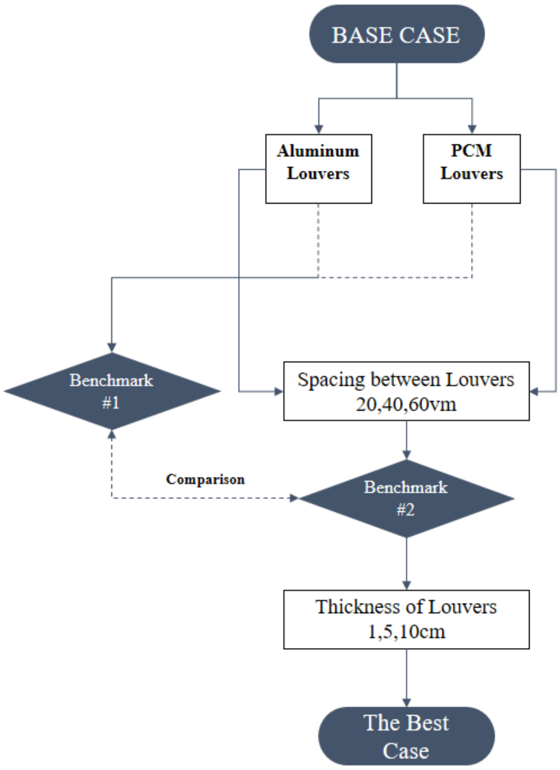


Figure 2. The simulation flowchart.

Firstly, a comparison between the aluminum louvers or phase change material was conducted to achieve the maximum efficiency of using louvers and improve thermal performance by reducing the air temperature inside the cavity as described in Table 1 and Figure 3.

Table 1. Louvers characteristics.

Materials	Value and Description
Aluminum louvers	1 cm Aluminum Density *kg/m3* : 2719 Latent heat **C** : 660 Thermal conductivity k (W/m·K):202.4
PCM louvers	3mm Aluminum 7 mm PCM Density of PCM *kg/m3* : 650 Latent heat **C** : 25 Thermal conductivity k (W/m·K): 0.1

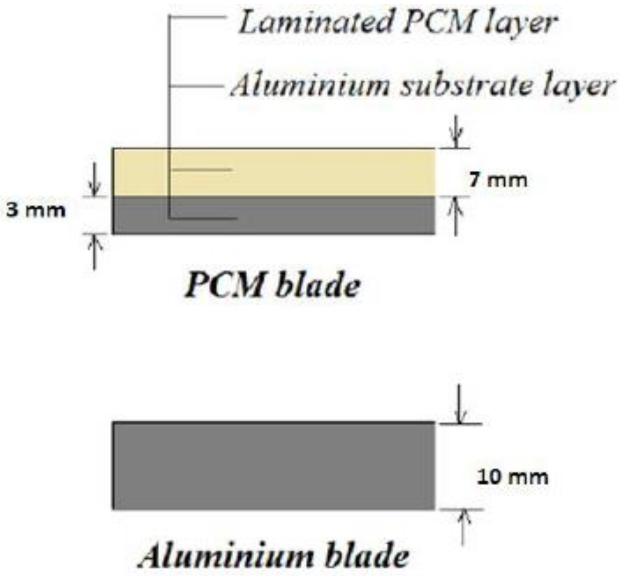
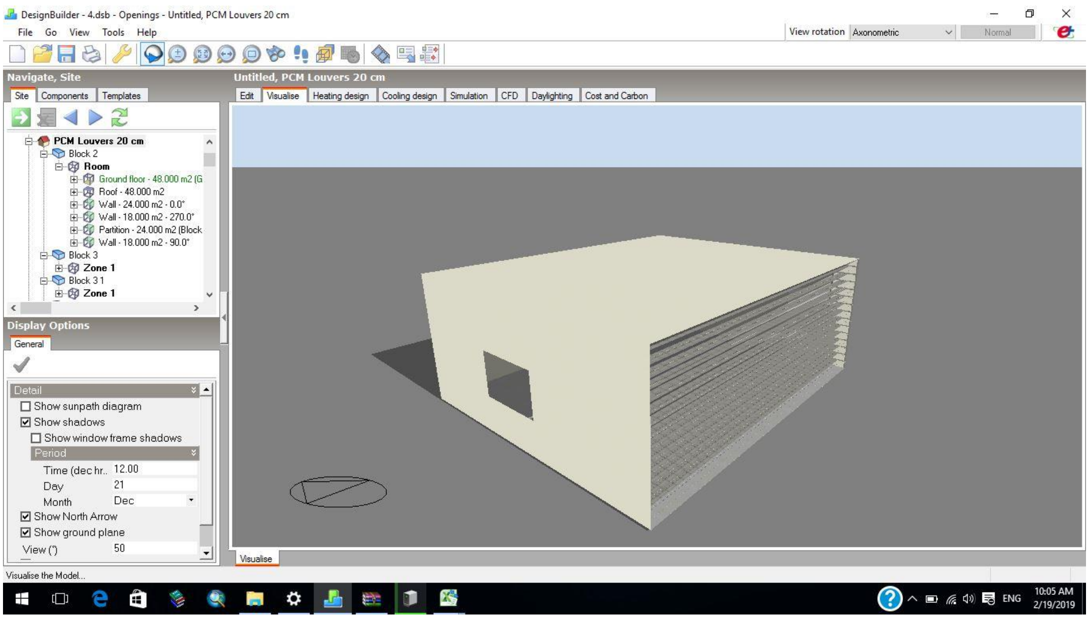
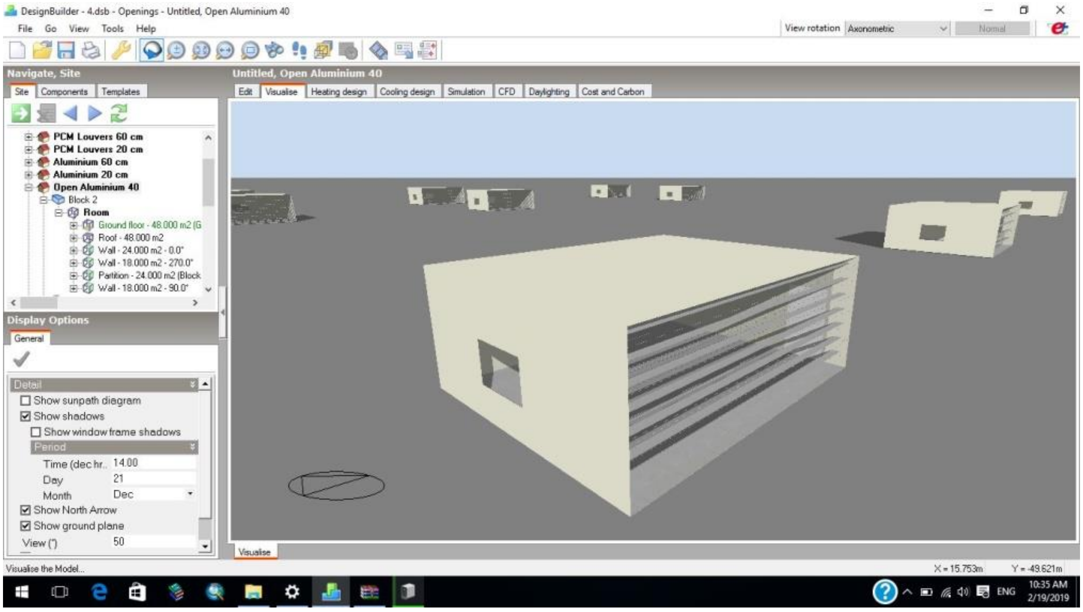


Figure 3. Aluminum and PCM Louvers.

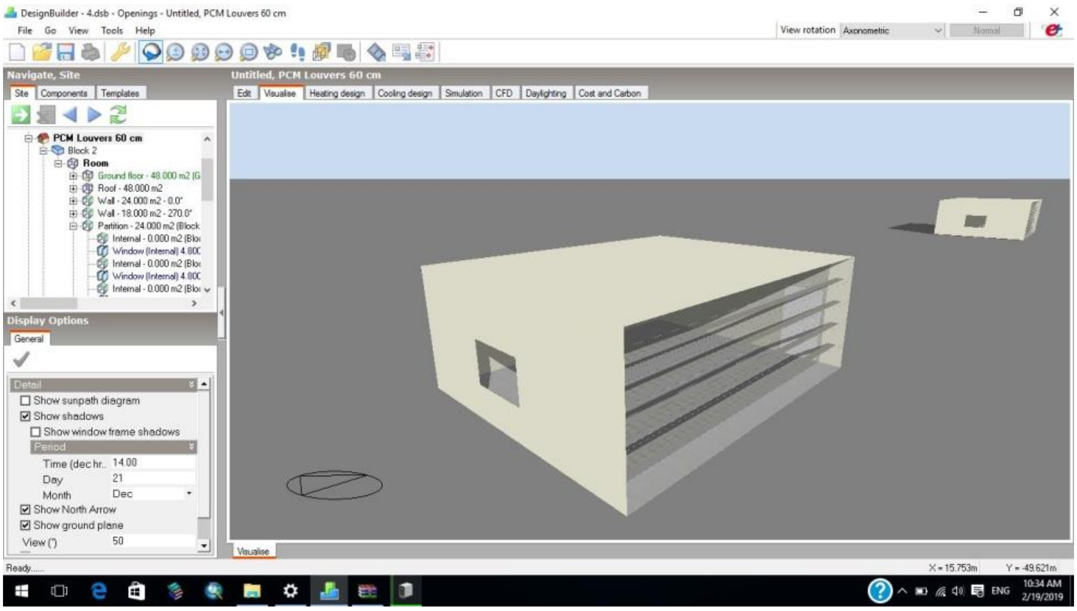
According to Figure 4, a spacing between the louvers (aluminum and PCM), 20, 40, and 60cm, were conducted in order to find the best dimension between louvers. A horizontal louvers with a 1 cm thickness and 30 cm width along the façade were conducted. Lastly, a simulation for the louvers thickness 1, 5, and 10 cm were conducted in order to specify the best thickness to decrease the indoor temperature, especially during summer as shown in Figure 5.



(a)



(b)



(c)

Figure 4a-c. Spacing between the louvers.

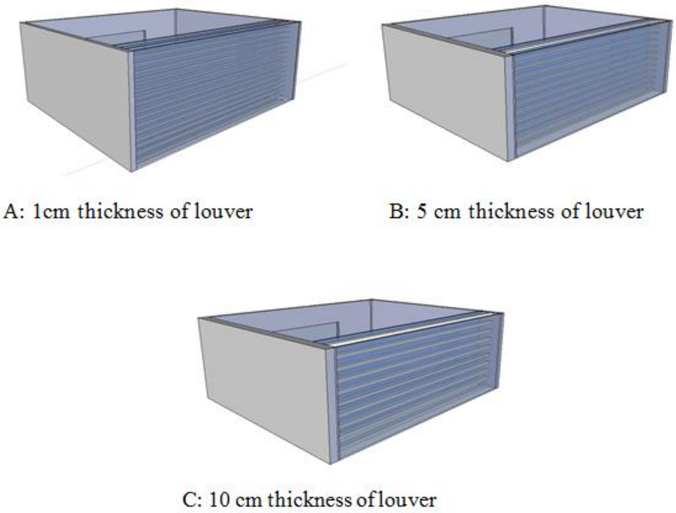


Figure 5. Thickness of louvers.

3. Results and discussion

3.1 Summer:

Table 2. PCM louvers with spacing 20 cm between louvers in21June.

PCM louvers 20 cm – 21 June				
	Base case	**Louvers PCM**	**Difference**	**Ratio**
01:00	27.95115	27.15055	-0.8006	-2.9%
02:00	27.66434	26.93101	-0.73333	-2.7%
03:00	27.3687	26.68678	-0.68192	-2.6%
04:00	27.06043	26.44512	-0.61531	-2.3%
05:00	26.74578	26.19707	-0.54871	-2.1%
06:00	26.47658	25.97714	-0.49944	-1.9%
07:00	26.30488	25.78612	-0.51876	-2.0%
08:00	26.61662	25.98426	-0.63236	-2.4%
09:00	26.99635	26.20034	-0.79601	-3.0%
10:00	27.34974	26.40279	-0.94695	-3.6%
11:00	27.76771	26.6326	-1.13511	-4.3%
12:00	28.20369	26.8551	-1.34859	-5.0%
13:00	28.63279	27.13178	-1.50101	-5.5%
14:00	29.05003	27.44427	-1.60576	-5.9%
15:00	29.37413	27.70749	-1.66664	-6.0%
16:00	29.66799	27.98538	-1.68261	-6.0%
17:00	29.8701	28.18891	-1.68119	-6. 0%
18:00	29.96353	28.33998	-1.62355	-5.7%
19:00	29.93732	28.38239	-1.55493	-5.5%
20:00	29.47018	28.08519	-1.38499	-4.9%
21:00	29.15201	27.94777	-1.20424	-4.3%
22:00	28.84883	27.79947	-1.04936	-3.8%
23:00	28.5175	27.57961	-0.93789	-3.4%
24:00	28.25533	27.39738	-0.85795	-3.1%

Average	28.21857125	27.1349375	-1.08363375	-3.84%

Table 3.PCM louvers with spacing 40 cm between louvers in21June.

PCM louvers 40 cm – 21 June				
	Base case	**Louvers PCM**	**Difference**	**Ratio**
01:00	27.95115	27.25393	-0.69722	-2.6%
02:00	27.66434	26.99752	-0.66682	-2.5%
03:00	27.3687	26.74077	-0.62793	-2.3%
04:00	27.06043	26.48167	-0.57876	-2.2%
05:00	26.74578	26.21885	-0.52693	-2.0%
06:00	26.47658	25.98845	-0.48813	-1.9%
07:00	26.30488	25.79148	-0.5134	-2.0%
08:00	26.61662	25.99203	-0.62459	-2.4%
09:00	26.99635	26.21664	-0.77971	-3.0%
10:00	27.34974	26.43158	-0.91816	-3.5%
11:00	27.76771	26.70354	-1.06417	-4.0%
12:00	28.20369	26.98578	-1.21791	-4.5%
13:00	28.63279	27.31924	-1.31355	-4.8%
14:00	29.05003	27.68754	-1.36249	-4.9%
15:00	29.37413	28.00295	-1.37118	-4.9%
16:00	29.66799	28.30035	-1.36764	-4.8%
17:00	29.8701	28.51043	-1.35967	-4.8%
18:00	29.96353	28.66191	-1.30162	-4.5%
19:00	29.93732	28.72987	-1.20745	-4.2%
20:00	29.47018	28.40995	-1.06023	-3.7%
21:00	29.15201	28.20888	-0.94313	-3.3%
22:00	28.84883	28.01376	-0.83507	-3.0%
23:00	28.5175	27.75043	-0.76707	-2.8%
24:00	28.25533	27.52548	-0.72985	-2.7%
Average	**28.21857125**	**27.28845958**	**-0.930111667**	**-3.30%**

Table 4.PCM louvers with spacing 60 cm between louvers in 21June.

PCM louvers 60 cm – 21 June				
	Base case	**Louvers PCM**	**Difference**	**Ratio**
01:00	27.95115	27.40075	-0.5504	-2.0%
02:00	27.66434	27.13595	-0.52839	-1.9%
03:00	27.3687	26.86862	-0.50008	-1.9%
04:00	27.06043	26.59606	-0.46437	-1.7%
05:00	26.74578	26.32059	-0.42519	-1.6%
06:00	26.47658	26.07851	-0.39807	-1.5%
07:00	26.30488	25.87471	-0.43017	-1.7%
08:00	26.61662	26.08577	-0.53085	-2.0%
09:00	26.99635	26.32994	-0.66641	-2.5%
10:00	27.34974	26.56605	-0.78369	-2.9%
11:00	27.76771	26.87051	-0.8972	-3.3%
12:00	28.20369	27.20172	-1.00197	-3.7%
13:00	28.63279	27.57991	-1.05288	-3.8%

14:00	29.05003	27.98236	-1.06767	-3.8%
15:00	29.37413	28.31357	-1.06056	-3.7%
16:00	29.66799	28.61003	-1.05796	-3.7%
17:00	29.8701	28.81792	-1.05218	-3.7%
18:00	29.96353	28.95535	-1.00818	-3.5%
19:00	29.93732	29.03837	-0.89895	-3.1%
20:00	29.47018	28.69389	-0.77629	-2.7%
21:00	29.15201	28.45518	-0.69683	-2.4%
22:00	28.84883	28.23188	-0.61695	-2.2%
23:00	28.5175	27.94337	-0.57413	-2.1%
24:00	28.25533	27.69545	-0.55988	-2.0%
Average	**28.21857125**	**27.48526917**	**-0.733302083**	**-2.60%**

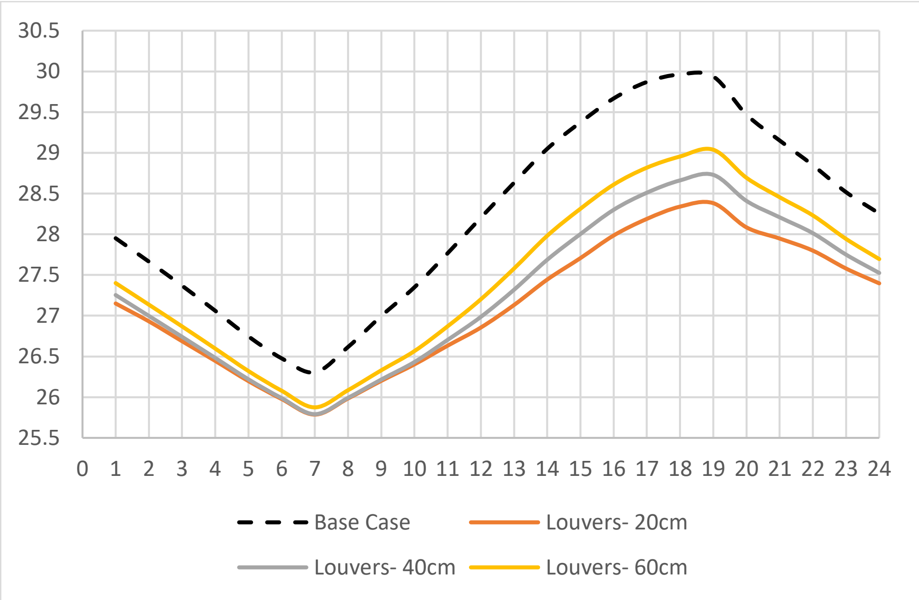


Figure 6. The difference in air temperature with different spacing between louvers during 21 of June.

During the summer, as the spacing between louvers increases, the reduction in air temperature decreases. Louvers with spacing 20cm showed the maximum reduction in air temperature about 3.84% (1.08°C) compared to the base case. Also, the spacing 60 cm showed the minimum reduction in air temperature about 2.60% (0.733°C) compared to the base case.

3.2 Winter:

Table 5.PCM louvers with spacing 20 cm between louvers in 21 December.

PCM louvers 20 cm – 21 December				
	Base case	**Louvers PCM**	**Difference**	**Ratio**
01:00	23.2756	17.9733	-5.3023	-29.5%
02:00	22.82556	17.71226	-5.1133	-28.9%
03:00	22.43804	17.48418	-4.95386	-28.3%
04:00	22.0676	17.26724	-4.80036	-27.8%
05:00	21.68844	17.04456	-4.64388	-27.2%
06:00	21.29439	16.81487	-4.47952	-26.6%

07:00	20.89981	16.58185	-4.31796	-26.0%
08:00	20.58807	16.38656	-4.20151	-25.6%
09:00	21.16018	16.64281	-4.51737	-27.1%
10:00	22.84908	17.45988	-5.3892	-30.9%
11:00	24.73442	18.26147	-6.47295	-35.4%
12:00	26.28112	18.84075	-7.44037	-39.5%
13:00	27.56097	19.25395	-8.30702	-43.1%
14:00	28.26107	19.5117	-8.74937	-44.8%
15:00	28.73994	19.81514	-8.9248	-45.0%
16:00	28.66759	19.86971	-8.79788	-44.3%
17:00	28.04247	19.92214	-8.12033	-40.8%
18:00	26.52631	19.16918	-7.35713	-38.4%
19:00	25.83896	19.02666	-6.8123	-35.8%
20:00	25.36221	18.92641	-6.4358	-34.0%
21:00	24.94333	18.81589	-6.12744	-32.6%
22:00	24.57285	18.70495	-5.8679	-31.4%
23:00	24.1982	18.52102	-5.67718	-30.7%
24:00	23.73359	18.18391	-5.54968	-30.5%
Average	**24.439575**	**18.25793292**	**-6.181642**	**-25.29%**

Table 6.PCM louvers with spacing 40 cm between louvers in 21 December.

PCM louvers 40 cm – 21 December				
	Base case	**Louvers PCM**	**Difference**	**Ratio**
01:00	23.2756	18.31013	-4.96547	-27.1%
02:00	22.82556	18.02462	-4.80094	-26.6%
03:00	22.43804	17.76727	-4.67077	-26.3%
04:00	22.0676	17.51909	-4.54851	-26.0%
05:00	21.68844	17.26064	-4.4278	-25.7%
06:00	21.29439	16.99265	-4.30174	-25.3%
07:00	20.89981	16.72156	-4.17825	-25.0%
08:00	20.58807	16.50381	-4.08426	-24.7%
09:00	21.16018	16.79659	-4.36359	-26.0%
10:00	22.84908	17.65655	-5.19253	-29.4%
11:00	24.73442	18.54473	-6.18969	-33.4%
12:00	26.28112	19.24965	-7.03147	-36.5%
13:00	27.56097	19.85544	-7.70553	-38.8%
14:00	28.26107	20.3112	-7.94987	-39.1%
15:00	28.73994	20.86057	-7.87937	-37.8%
16:00	28.66759	21.19463	-7.47296	-35.3%
17:00	28.04247	21.16919	-6.87328	-32.5%
18:00	26.52631	20.26261	-6.2637	-30.9%
19:00	25.83896	19.86616	-5.9728	-30.1%
20:00	25.36221	19.58136	-5.78085	-29.5%
21:00	24.94333	19.34452	-5.59881	-28.9%
22:00	24.57285	19.15481	-5.41804	-28.3%
23:00	24.1982	18.90441	-5.29379	-28.0%
24:00	23.73359	18.53071	-5.20288	-28.1%
Average	**24.439575**	**18.76595417**	**-5.6736208**	**-23.21%**

Table 7.PCM louvers with spacing 60 cm between louvers in21December.

PCM louvers 60 cm – 21 December				
	Base case	**Louvers PCM**	**Difference**	**Ratio**
01:00	23.2756	19.66658	-3.60902	-18.4%
02:00	22.82556	19.34087	-3.48469	-18.0%
03:00	22.43804	19.04659	-3.39145	-17.8%
04:00	22.0676	18.76224	-3.30536	-17.6%
05:00	21.68844	18.47239	-3.21605	-17.4%
06:00	21.29439	18.17049	-3.1239	-17.2%
07:00	20.89981	17.86568	-3.03413	-17.0%
08:00	20.58807	17.61679	-2.97128	-16.9%
09:00	21.16018	17.93901	-3.22117	-18.0%
10:00	22.84908	18.97622	-3.87286	-20.4%
11:00	24.73442	20.26214	-4.47228	-22.1%
12:00	26.28112	21.351	-4.93012	-23.1%
13:00	27.56097	22.23869	-5.32228	-23.9%
14:00	28.26107	22.84359	-5.41748	-23.7%
15:00	28.73994	23.38323	-5.35671	-22.9%
16:00	28.66759	23.58482	-5.08277	-21.6%
17:00	28.04247	23.33369	-4.70878	-20.2%
18:00	26.52631	22.18683	-4.33948	-19.6%
19:00	25.83896	21.59019	-4.24877	-19.7%
20:00	25.36221	21.1844	-4.17781	-19.7%
21:00	24.94333	20.86705	-4.07628	-19.5%
22:00	24.57285	20.61583	-3.95702	-19.2%
23:00	24.1982	20.33563	-3.86257	-19.0%
24:00	23.73359	19.94861	-3.78498	-19.0%
Average	**24.439575**	**20.39927333**	**-4.04030167**	**-16.53%**

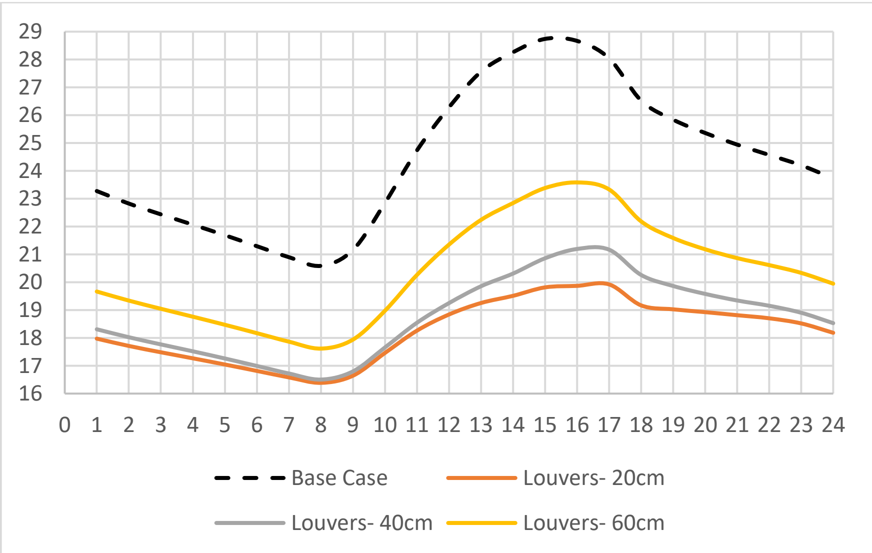


Figure 7. The difference in air temperature with different spacing between louvers during 21 of December.

In winter, louvers with spacing 60 cm showed the minimum reduction in air temperature about -16.53% (4.04°C) comparing to the base case, and louvers with spacing 20 cm showed the maximum reduction in air temperature about -25.29% (6.18°C) comparing to the base case.

Table 8. PCM louvers with different thickness in 21 June.

	PCM louvers Thickness– 21 June			
	Base Case	**1 cm PCM louvers**	**5 cm PCM louvers**	**10 cm PCM louvers**
01:00	27.95115	27.15055	26.58827	26.25264
02:00	27.66434	26.93101	26.39924	26.05927
03:00	27.3687	26.68678	26.19644	25.852
04:00	27.06043	26.44512	25.9798	25.63525
05:00	26.74578	26.19707	25.76432	25.41962
06:00	26.47658	25.97714	25.68222	25.33301
07:00	26.30488	25.78612	25.61051	25.28625
08:00	26.61662	25.98426	25.81201	25.49994
09:00	26.99635	26.20034	26.02049	25.70513
10:00	27.34974	26.40279	26.17737	25.85703
11:00	27.76771	26.6326	26.35055	26.0262
12:00	28.20369	26.8551	26.53313	26.21031
13:00	28.63279	27.13178	26.74199	26.41128
14:00	29.05003	27.44427	27.01886	26.679
15:00	29.37413	27.70749	27.26895	26.92877
16:00	29.66799	27.98538	27.54505	27.22221
17:00	29.8701	28.18891	27.7145	27.41521
18:00	29.96353	28.33998	27.75901	27.46242
19:00	29.93732	28.38239	27.68999	27.37072
20:00	29.47018	28.08519	27.55997	27.22205
21:00	29.15201	27.94777	27.46223	27.11576
22:00	28.84883	27.79947	27.31998	26.96273
23:00	28.5175	27.57961	27.07707	26.71063
24:00	28.25533	27.39738	26.87261	26.50264
Average	**28.21857125**	**27.1349375**	**26.71435667**	**26.38083625**

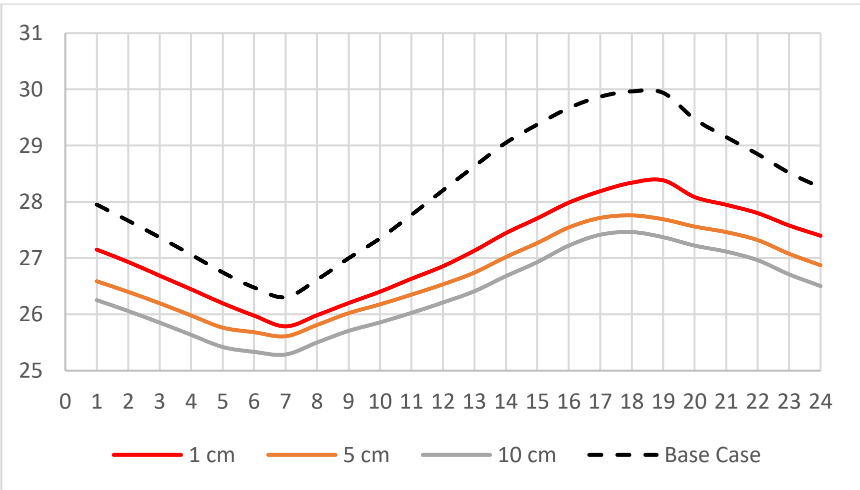


Figure 8. The difference in air temperature with difference louvers thickness in 21 June.

The average air temperature of double skin without louver is **28.21857125** and the average with 1 cm PCM louvers will decrease about 1 C and when increase the thickness to 5cm the indoor air temperature will decrease 1.5 C and when increase the thickness to 10 cm the indoor air temperature will decrease 2 C as shown in the **Figure 8** above.

4. Discussion

The simulation results indicate that integrating the PCMs has a significant potential to reduce the overhearing problem comparing to aluminum louvers. As shown in the table below, the average reduction in the overheating problem during the summer using PCM louvers was 3.20% comparing to 2.40% using aluminum louvers. On the other hand, the best case was with 20 cm spacing between louvers. The percentage of the air temperature reduction inside the room using aluminum louvers with 20cm spacing is 2.75% comparing to 3.84% using the PCM louvers.

Table 9. Summarize of using aluminum and PCM louvers with different spacing during summer.

Spacing	Aluminum louvers	PCM louvers
20	2.75%	3.84%
40	2.50%	3.30%
60	1.95%	2.60%
Average	**2.40%**	**3.20%**

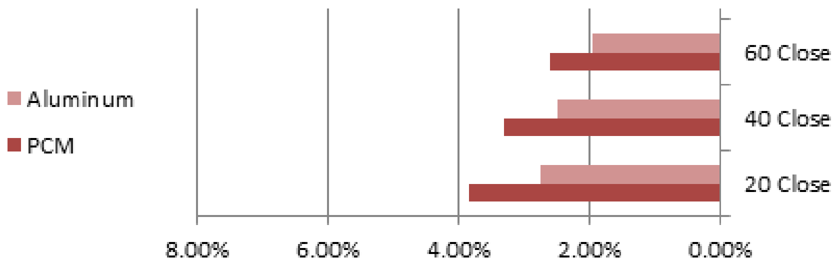


Figure 9. Summarize of using aluminum and PCM louvers with different spacing during summer.

Based on the results, it can be conclude that the thickness of louvers plays an important role in the heat reduction using PCM louvers. Table00 below summarize the average reduction in the air temperature using different thickness of PCM louvers. The average air temperature reduction increase about 3.99%, 5.63% and 6.96% for 1cm, 5cm, and 10cm thickness respectively. The results showed that, as the thickness increase the efficiency of using PCM louvers and its contribution to the overheating problem during the summer increase.

Table 10. Summarize of the thickness of PCM louvers and average of temperature reduction.

Thickness of louver	Average of temperature reduction
1 cm	3.99 %
5 cm	5.63 %
10 cm	6.96 %
Average	**5. 52%**

5. Conclusion

The objective of this study is to improve the double skin facade performance during the summer and winter by controlling the solar radiation and avoidance the overheating problem especially during the summer. To reduce this problem the louvers, aluminum or PCM louvers, were added in the cavity of the DSFs with different spacing between louvers and with different thickness.

The simulation results showed that using the PCMs louvers integrated with the double skin façade has significant potential to reduce the overheating and reduce the air temperature inside the room especially during the summer time. The results showed that the best performance of the DSFs was with 20 cm spacing between the louvers. Also, the research showed a major effect of the louvers thickness comparing to other variables. Increasing the louvers thickness from 1 cm to 5 cm showed a reduction in the air temperature from 1.0 to 1.50 degree and about 2.0 degree when the thickness reach to 10cm.

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Assessing the Non-Motorized Modes as a Sustainable Transportation Option in the Industrial Area of Al Ain City, UAE

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Abstract: It is vital to consider the main actor of the urban scene, which is the pedestrian citizen, and therefore to plan a city around the pedestrian needs. Non-Motorized Transportation (NMT) includes all forms of travel that do not rely on an engine or motor for movement, which includes walking, bicycle and using small-wheeled transport such as skates, skateboards, push scooters and handcarts. While designing the sustainable modes of non-motorized transportation system, it is important to consider all pedestrians, whose interests vary according to their age, physical and sensorial abilities, psychological and cultural personal approaches to make them able to use public spaces and to have safe, easy, and pleasant pathways. The industrial area, which is located on the eastern side of AL Ain city, at United Arab Emirates is considered as one of the most crowded parts of the city due to the concentration of the main industrial services imposing huge burdens on the existing infrastructure. This study evaluates the existing condition of the non-motorized mode as a sustainable transportation system in one of the most crowded areas of Al Ain City, taking into consideration the new vision of Al Ain Master plan 2030. The study recommends possible improvements to non- motorized transport system, which would accelerate the development of the industrial area on one hand and improve the safety on the other hand. To fulfil the aim, the study attempts to identify the main problems facing the pedestrian movements within the industrial area of Al Ain City. The investigations carry out qualitative analysis to provide clear descriptions and illustrations by observing the occupants' interactions with the surrounding environment to record the pattern of the movement in a specific condensed zone in the industrial area. A literature review to disclose the lessons, which may be drawn from experiences in similar areas with similar problems. Based on the assessment of the existing pattern of the non-motorized movement, the study also recommends possible standards and guidelines to improve the non-motorized transport modes and user safety within the industrial area of Al Ain.

Keywords: Sustainable transport, Non-motorized mods, Industrial area, Safety, Al Ain

1. Introduction

The subject of accessibility is a complicated one that falls within a larger issue, an issue that also relates to the usability of the geographical territory and the mobility of the users, the latter includes urban parameters connected to the organization and management of urban spaces and road traffic. This theme has since many years taken on a strategic importance at international level to consider the main actor of the urban scene, which are the pedestrian citizen, and therefore to plan a city around the pedestrian needs. To be able to use public spaces and to have safe, easy, and pleasant pedestrian routes, is important for all pedestrians, whose interests vary according to their age, physical and sensorial abilities, psychological and cultural personal approach. It is therefore important to realize public spaces that can guarantee usability and autonomous mobility to the highest possible number of people. With autonomous mobility it means the possibility to move within the environment without escort and without having to make a psycho-physical effort for adaptation that is too much not only in terms of human thresholds, but in terms of human abilities that can highly differ. Therefore, the possibility to walk becomes the common denominator for different users and urban quality should be evaluated according to how accessibility is achieved in certain area [4].

The growth of cities is shaped or guided by human interaction and by physical infrastructure. However, inefficient use of space and natural resources is caused by the urban expansion around and the uncontrolled urban sprawl. And to achieve efficient functionality of any city accessibility is considered essential to carry the goods and for services from one place to another, help people to integrate and for adapting civic environments to all citizens. Various modes of transport including walkability, bike ability are sustainable modes of transportation and cities are being encouraged to shift towards these kinds of man powered transportation systems to achieve environmental, social, and economic sustainability.

Non-Motorized Transportation (NMT) includes all forms of travel that do not rely on an engine or motor for movement which includes walking, bicycle and using small-wheeled transport. It involves walking and riding, as well as forms such as small-wheeled transportation (skates, skateboards, push scooters and carts) and wheelchair transportation. These modes include both leisure (they are an end in themselves) and commuting (they make products and activities accessible). While designing the non-motorized transportation system it is important to consider all pedestrians. These modes of transport can provide both recreation and transportation. For example, some people will choose to walk or bicycle rather than drive because they enjoy the activity.

Around the world, many people rely on walking and cycling for transport. Many more begin and end each trip on foot. Such affordable, people-friendly transport offers huge social, economic, and environmental benefits for urban and rural areas. But many of these people risk their lives every time they travel. Every thirty seconds one person dies in a road accident. In 2016 1.3 million people died in road accidents. By 2030 that will add up to almost 30 million deaths in road accidents. More than a quarter of the people killed in road accidents are pedestrians; a number increasing steadily due to a tragic lack of investment.

1.1. Aim and objectives:

The long-term plan helped AL Ain municipality to study the repetitive problems over the 14 years. The research investigated the current problems related to NMT and user safety that have been immerging due to the high industry demand during the last 19 years. The preliminary observation during the site visit showed that there is main issue with the existing street network in the existing industrial zone, people are not capable to transport easily from one point to another because the main street infrastructure it is not serving the actual need and capacity of the area and causing serious safety issues to users while they are traveling through.

Another matter is that the Al Ain vision 2030 is proposing the transitioning of industrial land uses which are currently in the industrial zone to a totally new areas located at the southern part of the city with a bigger area provided from the government.

The aim is to investigate the NMT as a sustainable transportation in the industrial area. The study recommends list of short-term solution for the area and guidelines to improve the walkability, other non-motorized modes, and safety within the industrial area of Al Ain to realize public spaces that can guarantee usability and autonomous mobility to the highest possible number of people. More significantly, the research proposed long-term design guideline for ALAIN 2030 vision. Further independent study is under process to find out the possibility to implement the proposed short- and long-term solutions.

1.2. Problem definition:

The preliminary observation during the site visit showed that there is main issue with the existing street network in the existing industrial zone, people are not capable to transport easily from one point to another because the main street infrastructure it is not serving the actual need and capacity of the area and causing serious safety issues to users while they are traveling through.

Another matter is that the AL Ain vision 2030 is proposing the transitioning of industrial land uses which are currently in the industrial zone to a totally new areas located at the southern part of the city with a bigger area provided from the government. The research looked weather AL Ain 2030 plan have considered the existing problems in the current condition of the industrial area which are related to Non-motorized Transportation and people's safety.

2. Industrial Area in Al Ain city

2.1. Location

Al Ain is in the Eastern Region of the Emirate of Abu Dhabi, on the United Arab Emirates' border with Oman, neighboring the town of Al-Buraimi. It's known as the "Garden City" because of its greenery areas. Recently Al Ain city is going under many urban planning projects and developments to achieve the 2030 vision of the government toward more sustainable city. The industrial area, which is located at the eastern side, is considered the most crowded part of the city due to the concentration of the main services imposing huge burdens on the existing infrastructure, especially transportation systems (Figure 1, 2). It sits in a natural amphitheater between two rocky escarpments to the east and west. To the south is Hafeet Mountain – Al Ain famous mountain – and to the north is the town Centre [6].

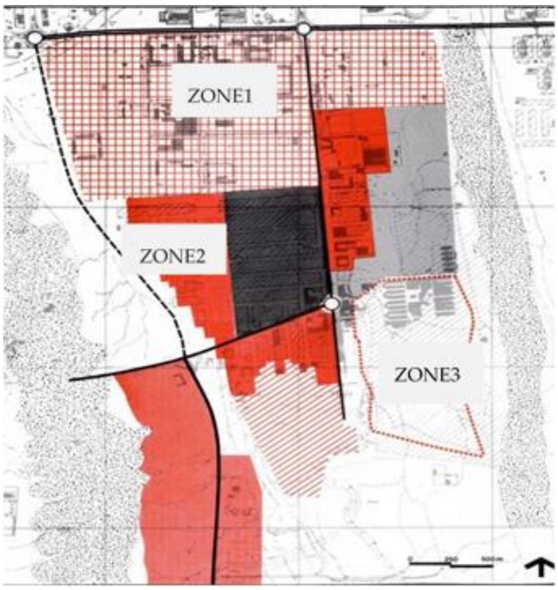

Figure 1. The location of the industrial area in Al Ain city **Figure 2.** The industrial area zones at the early stages of planning and land distribution

2.2. Activity descriptions

The industrial area is composed of identical attached two-story buildings and warehouses arranged on a regular street pattern. The multi-story building is mixed use building having the stores such as restaurants, grocery stores, hairdressers, tailors, lighting centers and car maintenances workshops at the ground floor and the accommodation units of the labors at the upper floor.

The industrial area is one of the densest populated districts in Al Ain because it's passing on the main road leading the south part of Al Ain to the mid-town and because of the availability of numerous types of services. It is mainly dominated by inhabitants consisting of large number of single men hailing from Bangladesh, the Philippines and India. This area is considered as a passageway to the central part of Al Ain and at the same time it provides wide types of all the citizens in Al Ain, which means at most of the daytime the area is busy and having high traffics.

2.3. History of the industrial are and the Current land use

At the beginning of early 1986 Al Ain municipality proposed to design the area in long term plan divided to three stages from 1986 to 2000, and at each stage they accomplished to build 5 different zones which now represent the current and final situation. Currently the industrial area has total number of 880 shops concentrated at the northern part which includes garages, car spare part shops, building material shops, mixed use shops such as cafeterias and supermarkets. The other types of land use are exhibitions, government offices, carwashes, and mosques.

2.4. Al Ain city 2030 plan for the industrial area

Al Ain is a modern society shaped by an ancient culture. The strategic policies in this Urban Structure Framework Plan, "Plan Al Ain 2030", are inspired by this history to provide a way of reversing sometimes inappropriate development trends and of satisfying the needs of a growing population. These policies are grounded by the three basic elements of sustainability: the natural environment, economic development, and cultural heritage.

As shown in the Figure 3, the current industrial zones take places on the Northwest side (red color). The industrial sector will grow with the development of the new High Tech Business Park at the airport, focusing on clean light manufacturing sectors such as computer software and hardware development, and the heavier industrial zone along the truck route, focusing on heavier industries like cement manufacturing. There are many goals in Al Ain vision 2030. One of the most important structural moves in the plan is to transition heavier industrial uses away from the current industrial area. Industries rely on sound logistics and so the best place to locate them is near the infrastructures that supply them. In the case of Al Ain, two major industrial areas are allocated: a High-Tech Business Park at the airport, and a heavy Industrial district along the truck route. This minimizes the amount of overland travel required for materials and products and keeps necessary processes of heavy industry away from the centers of population density. Figure 3 shows the three new industrial areas which are 10 and 17 time bigger than the current one, which means that the design of these areas must be done in a way to provide the needs at the same time make sure to cover the problems and lesson learnt from the current industrial area design.

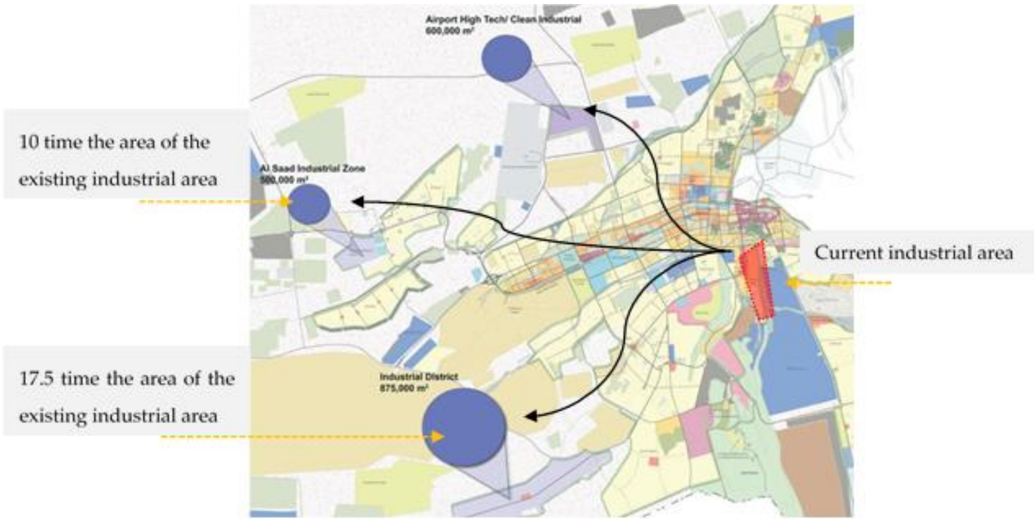

Figure 3. Three new industrial areas based on AL Ain 2030 vision.

2.5. Proposed questions:

There are several questions evolved just by doing the literature review and as mentioned above, the list of the questions below is going to be investigating further to build more reasonable study and analysis of the case taken:

1. To which extent the existing streets and roads networking of the industrial area in Al Ain is supporting with the actual needs and safety requirements for the users? to get with the

accurate results for this question we will be assessing the accessibility using the following indicators:

- What is the quality of the existing street and road networks: Connection between services using each of the following: (walking, cycling, and privet cars)?
- To what extent the safety is related to the street networking?
- Availability of safe and convenient pedestrian realm.

2. What is the proposed solution to enhance the existing NMT accessibility and street networking of the industrial area Alain city to provide more safety for the users?
3. What is the proposed solution for the parking area, so pedestrians and drivers can move easily in the area?
4. What are the possible design guidelines that has to be stated to be respected in future planning?

2. Materials and Methods

To investigate for the accessibility of NMT in the industrial area we conducted qualitative method to provide rich descriptions and illustrations which strongly added high potential to improve the analysis and findings and strengthen the accuracy. The following points describes the methodologies which was used to reach the findings and answer the questions:

1 Walk Through and Observation: it's a method used with the intention of observing occupants' interactions with the surrounding environment while they are unaware that they are being monitored which allows to make

2 An objective analysis. It is used to record the pattern of the movement in a specific condensed zone at the industrial area such as the traffic intersections or the pedestrian walkways.

3 Photography: method which offers several visual images of how activities are distributed over time. The concentration is on the main streets and the inner pathways to try to have an overlook through the accessibility modes in the industrial area.

3. Observations:

Through the site observation the following photos has been taken to report the Status of most of crowded streets in the industrial area:

Figure 4. Location of the **observed block**

Figure 5. Google map screen shoot of the points where the photos were taken during the observation

Figure 4 illustrates the location of the block, which was observed to do the analysis, and this block was chosen because it is in the most crowded area having several conjunction routs which made the study more effective and made the observation more real and reliable. Figure 5 Shows Google map screen shoot of the points where the photos were taken during the observation, which reflects the daily street life behavior of the labors. Photos in Figure 7 were taken in normal working days between (10:00 am – 12:00 pm). It is important to highlight that most of the problem was noticed to be accruing while crossing and problems related to parking.

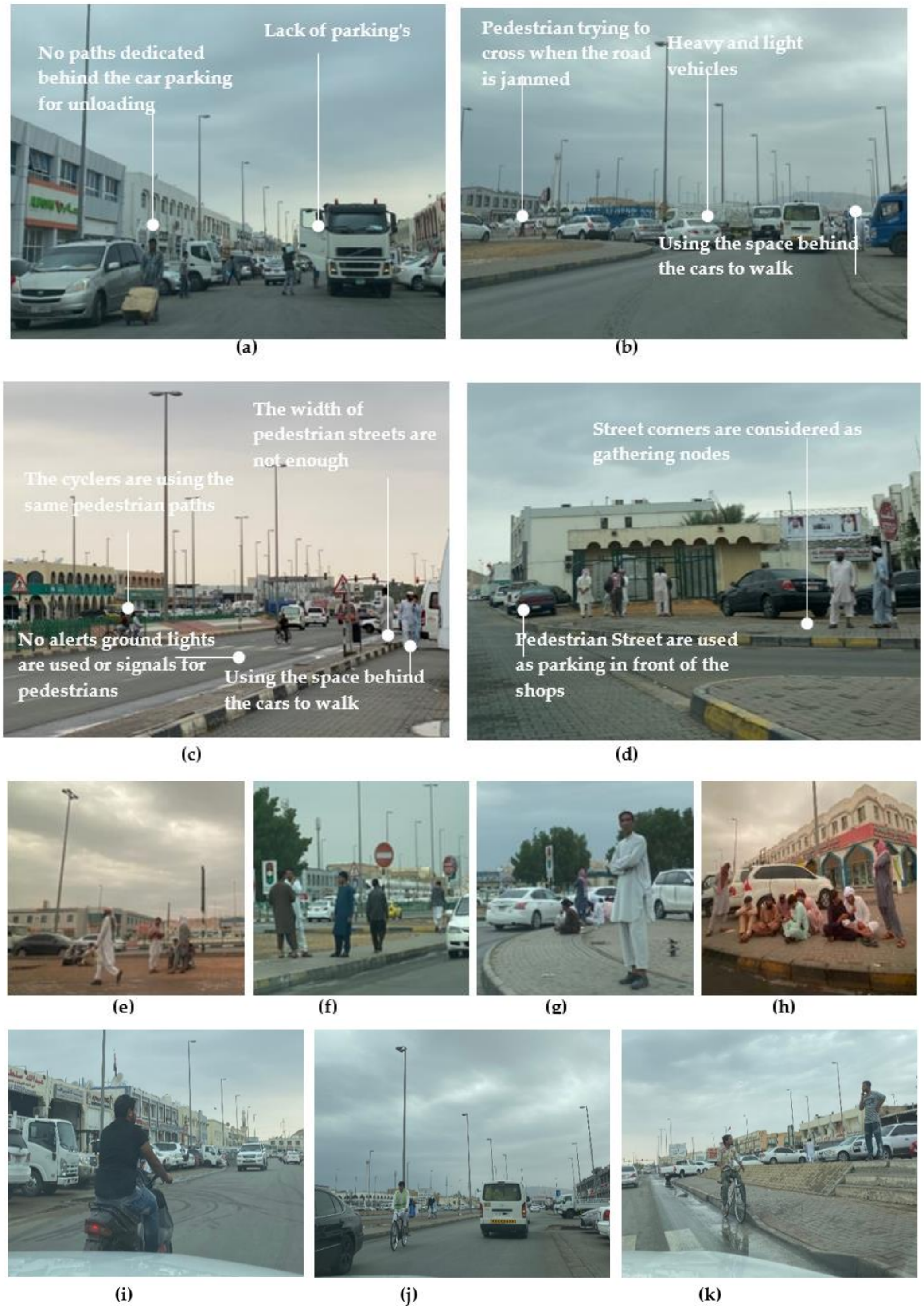

Figure 6. (a); (b); (c); (d): general observation which reflects the daily street life behavior of the labors (e); (f); (g); (h): Gathering around the walkways and streets corners put the labors under high risks (i); (j); (k): Cycler was having no specific routs and roaming together with the pedestrians and cars.

4. Results and Findings

The preceding data provide an overall, qualitative view of street life. They are useful in offering descriptive verification for the high level of street use. Yet the particularly complex manners in which such interactions take place needs shall be evaluated and understood as well [3]. Thus, as discussed in the methodology section walk through and observation methodology is used to observe occupant's interactions with the surrounding environment to make an objective analysis. Several patterns of the movement in a specific condensed zone at the industrial area such as the traffic intersections or the pedestrian walkways was captured and analyzed. Table 1 summarize the observations of the site and the overall Findings:

Table 1. Site observations and Findings

Level	Observations of the site	Findings
Main Road networks	The road was all the day busy with heavy vehicles which carries goods and privet cars (Figure 7d). Intermediate pedestrian cross lines: to cross from one road to another labors had to wait until the main signals gets red(Figure 7a) The road is considered to be one of the spine road that connects the southern part of ALAin city to the central district, and due to that we noticed the cars passing through was over speeding considering that the industrial area is very pedestrian congested zone .	Highly motorized roads. Poor quality of road calmers are provided (no signal lights, no ground lights indications). Speed limits are not enough 80km/Hr.
Pedestrian streets	Some of streets and pathways were used mainly as a gathering nodes and other were used as car parking's (Figure 7b). No enough spaces behind the car parking's for loading and offloading and for pedestrian crossing to the other street (Figure 7c) (Figure 7d). Some of the streets are very tight and carry only one pedestrian (Figure 7a).	Overcrowded and congested streets and misusing the existing network. There are limited corridors in between the building which lead to limit the accessibility (walking and cycling), and they are not in good shape.
Cycling lanes	cycler was having no specific routs and roaming all together with the pedestrians and cars (Figure 7 l,n,m)	There is no dedicated lanes for cycling
Parking's	Most of the cars was parking behind the parked cars or at the pedestrian walkways due to lack of parking available (Figure 7c) (Figure 7b).	Undisciplined Traffic and Parking. Lack of parking availability
Gathering areas	Gathering is happening around the walkways, streets corners which may put the users under high risks (Figure 7 b,e,f,g,k).	Lack of seating or resting places. Lack of proper social gathering spaces

4.1. Road safety audit:

Based on the issues identified from the observations, road safety audit is done and this section gives a summary of the findings. Furthermore, the audit was executed to determine if the four E's of road safety, namely; Engineering, Enforcement, Education and Evaluation, were taken into account during the implementation of the studied routes.

This section includes not just an assessment of the pedestrian and road safety problems but also recommendations of how to improve the road safety in the study area [5].

The objectives of a road safety assessment are to:

1 Provide an independent assessment of the design from a road safety perspective; Look beyond the limits and consider the effects in transition areas
2 Identify potential safety problems for the particular design or section of road project
3 Ensure list of measures to eliminate or reduce the problems for consideration.
4 An additional category is used to denote actions which may not improve safety, but which are needed to correct

Table 2. Likely frequency of the problem to lead to a crash

Likelihood	
Frequent	Once or more per week
Probable	Once or more per year (but less than once a week)
Occasional	Once every five to ten years
Improbable	Less often

Table 3. Likely severity of the resulting crash

Severity of resulting crash	
Catastrophic	Likely multiple deaths such as: High-speed, multi-vehicle crash on a freeway Car runs into crowded bus stop Bus and petrol tanker collide
Serious	Likely death or serious injury such as: High or medium-speed vehicle/vehicle collision High or medium-speed collision with a fixed roadside object Pedestrian or cyclist struck by a car
Minor	Likely minor injury such as: Some low-speed vehicle collisions Cyclist falls from bicycle at low speed
Limited	Likely trivial injury to property damage only such as: Some low-speed vehicle collisions Pedestrian walks into object (no head injury) Car reverses into another parked car or pedestrian.

Table 4. Resulting level of risk to draws the base line that helped us to assess the level of the risks, which have been observed at the site.

Resulting level of risk		Likelihood of crash			
		Frequent	Probable	Occasional	Improbable
Likely severity	Catastrophic	Tolerable	Intolerable	Intolerable	High
	Serious	Intolerable	Intolerable	High	Medium
	Minor	Intolerable	High	Medium	Low
	Limited	High	Medium	Low	Low

4.2. Likelihood, severity and risk rating:

From the assessment findings, all the locations that were assessed presented similar pedestrian and road safety issues. Seven detrimental road and pedestrian safety key elements were derived from the locations and further assessed in terms of the likelihood, severity and risk taking, see Table 5.

Table 5. Likelihood, severity and risk rating

Key aspects	Description	Likelihood	Severity	Risk rating
Pedestrian crossing	Pedestrians were observed walking on road or running while crossing the road. Perceived to be an uncomfortable and unsafe environment for pedestrians, especially if there are vehicles on road passing at speed. Running also increases the chances of them falling are higher especially carrying a heavy backpack.	Frequent	Serious	Intolerable
Poor visibility at late afternoon of pedestrians	Glare late afternoon and reduced visibility of pedestrians At night contributes to higher pedestrian accident and fatality rate at night	Frequent	Serious	Intolerable
Speed management	Drivers were perceived to be driving over the speed limit and observed to take unnecessary risks overtaking slower vehicles. This was compounded with heavy vehicles overtaking each other.	Occasional	Serious	High
Cars parking behind the loading area	First there is no loading area dedicated and the users usually not aware if any specific car is going to unload, usually lots of car park and block the passage which may lead to high risk in case any thing falls on the pedestrian and if the car reversed without paying attention.	Occasional	Serious	High
Gathering areas	There were random gathering points on the streets (no safety cautions)	Occasional	Serious	High
Vehicles conjunctions and high traffics	The area is designed mainly for cars only, but in the current situation the pedestrians have to be given the main priority at the crossing lines since they are in big numbers. Some drivers noticed to be driving in high speeds which may lead to crashes especially when sudden break is hold strong enough to make a crash.	Probable	Serious	Intolerable
Corridors	There are limited corridors in between the building which lead to limit the accessibility (walking and cycling), and they are not in good shape. Some areas they are not clear and these points are considered highly danger in case of any thefts and crime cases.	Occasional	Minor	Medium

5. Discussion

In discussing the meaning of these findings and observations it should be pointed out that one of the main issues emerging from this study is that the existing network of the industrial area are overburdened and misused while the cars are parked in the dedicated place of pedestrians, the pedestrians are using the car lanes to move. Furthermore, the gathering nodes around the streets and near by the car passages, all of these issues puts the pedestrian under high risks. Some of the labors spend most of their day time there and most of them lives in the same area and the overall perception that it's their right of the users to have a safe and pleasant area to live in.

It seems that the main considerations in planning the district's streets was to facilitate a medium traffic and neglecting the fact that area has residential units which may need high requirements to be managed such as pedestrian walkways and cycling lanes. Thus, the street corners became an ideal place for gathering. Policies and planning decisions should aim to assure efficiency of network designing in these kind of zones. Labor camps, worker cities, etc. are the preferred solution.

SHORT TERM SOLUTIONS

Several temporary solutions are proposed to ensure that the area works with more discipline, make it more accessible for NMT mode users and enhance safety. Table 9 includes the list of the proposed solutions provided with illustrative photos:

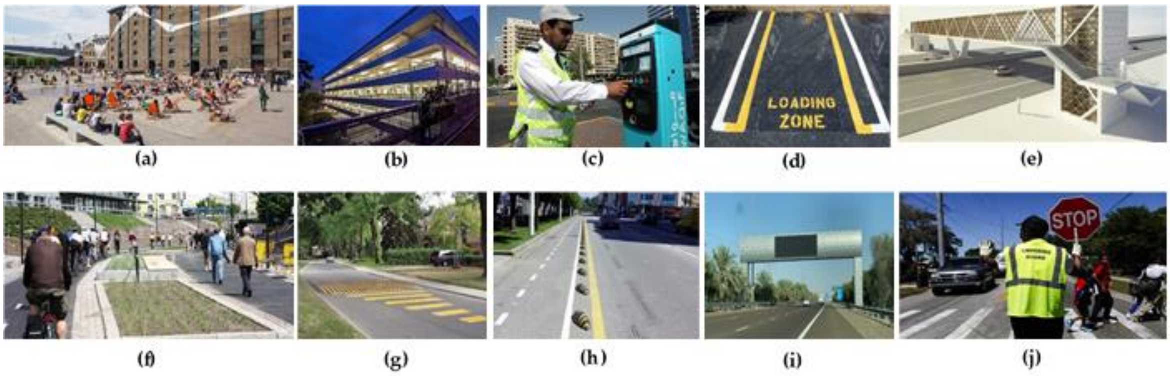

Figure 7. Short-term solutions illustrative pictures

a) Enhance the quality of the public and the pedestrian environment by creating a sense of identity/community by animating the edges of the routes and creating decent public spaces (Street furniture e.g., benches).
b) Evacuate one block which is dedicated for industrial use at the most accessible point in the area and construct a multi-story parking buildings in order to gain public space on the road and gradually reducing parking space on the streets in order to promote cycle and walking and make sure it provide an easy, safe connections to the area.
c) If any illegals parking pattern showed after providing the adequate number of parking's, fine shall apply.
d) Dedicate several parking's for loading and unloading at the frontage of the shops.
e) For the main road and because there is high flow of pedestrian its more easier and safer to provide pedestrian bridges
f) Enhance the permeability of the pedestrians by renovating the existing corridors).
g) Enhance pedestrian accessibility at the inner roads through the roads by adding road calmers such as humps or finishing them with different materials
h) At the inner roads, provide soft barrier between motorists and NMT road users such as using adaptive and native trees, shading devices.
i) Safety education, law enforcement and encouragement programs, for example provide big screens with writings that shows what user have to do and not to do, maps and other information on how to walk and cycle to a particular destination.

j) Monitoring of the public parking space with a special control task force. And applying fines for illegal crossing behaviors.

LONG TERM PLAN

We have communicated with UPC team regarding 2030 vision for the industrial areas in Al Ain city and they have confirmed that the concept design of the road infrastructure has not begun yet, we have listed several design guidelines to insure the problems that are faced by NMT users at the current industrial area to be covered and solved at the new industrial areas in Al Ain city, the design guidelines shall be set after conducting several meeting and researches between the following:

1. The Higher Building Code Committee (Abu Dhabi Urban Planning Council (UPC), Civil Defense and Abu Dhabi and Al Ain City Municipalities.
2. Key Stakeholders and Contributors.
3. Users and other significant participants.

The following design guidelines shall consider all the points mentioned in table 9 and also insure providing complete, well connected and safe pedestrian and cycling lanes at the main and inner roads, where the dimensions and locations shall follow Abu Dhabi building code standards. The following figure 13 shows design proposal based on the current area to understand the NMT requirements.

Figure 8. Proposed design for the new industrial area as per Al Ain vision 2030

5. Conclusion:

To achieve sustainable NMT for better life quality, cities must address the accessibility to the different urban zones by enhancing and developing network planning and infrastructure and by providing proper policy framework. However, accessibility-based planning techniques still needs to be developed to apply them to specific decisions while designing a very different land use such in our case

The most compelling argument, for walking and cycling, is that only via an integrated range of environmental features including infrastructure and facility improvements, or education programs will substantively change result [2].

We can't neglect the fact the industrial zone is considered as condensed retail/services area but the design of street networks should be based on the function of the area, in other words the street networking of any neighborhood shall be totally different that street networking of the industrial area .but what has been noticed is that the existing networks in not complying with the actual needs of the occupants/users and putting the pedestrian into high risk which lead to many random behaviors.

This study showed that existing issues in the industrial area, where the planning entities shall consider them to put new design standards and guidelines to encourage the sustainable transport in terms of non-motor transportation mode for the new industrial areas in Al Ain city which promises a better world for future generations.

To validate the possibility to implement the proposed short- and long-term solutions, further independent study is under process.

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Conflicts of Interest: The authors declare no conflict of interest.

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Hybrid Energy Storage System Sizing in Electric Vehicles Using Butterfly Optimization Algorithm

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Abstract: Carbon dioxide emission from transportation systems surpassed emission from any other energy sector. Thus, electric vehicles (EV) have gained extensive awareness among society as this can scale down the greenhouse gas emissions. Present internal combustion engine vehicles have considerable performance and none of the alternative source can individually replace them. Hence, hybridization of multiple sources is indispensable. In this paper, a multi-objective optimization problem is developed to optimally size a battery unit (BU)-ultracapacitor (UC) hybrid energy supply system (HESS) of an EV. The performance indices considered for optimization are the investment cost of the source system, combined weight of multi-sources and dynamic source degradation. Initially, the dynamic variation of source parameters is contemplated in the modelling. Then the power demand by the electric vehicle power train is shared amongst the BU and UC using the wavelet transformation approach. The property of multi resolution analysis makes the wavelet technique very attractive in analysis and synthesis. Thus, the power splitting can be realized between BU and UC effectively. In this work the butterfly optimization algorithm is implemented to optimize BU-UC HESS sizing for a given drive cycle. The problem is solved for the combination of urban dynamometer driving schedule and Artemis rural drive cycle. The simulation results show that the proposed method can provide least possible cost and weight with less BU and UC degradation for HESS in EV.

Keywords: Hybrid energy storage system, Wavelet transformation, Power splitting, Hybrid electric vehicle, Optimal sizing.

1. Introduction

As a consequence of excess use of internal combustion engine (ICE) vehicles, greenhouse gas (GHG) emissions have increased and account for about 28 percent of total GHG emissions. The transition from ICE vehicle to EV can considerably reduce greenhouse gas emission over the course of vehicle's lifetime. With present technology, none of the available energy sources can individually replace the performance of present ICE vehicles. Thus, hybridization of multiple sources is obligatory, and the major obstacle is to size the multiple sources economically and energy efficiently [1]. In this paper BU-UC hybrid source is contemplated with BU as the primary and UC as the secondary energy source.

BU is the most prominent energy source that is highly efficient, pollution free and can retrieve braking energy. The detrimental factors associated with BU are higher charging time, impact on power system because of excessive charging and social recognition concern because of increased capital cost, range anxiety and inadequate charging infrastructure [2]. UCs with its long-life attribute are capable of providing high power density and the recovering of braking energy can be achieved more efficiently than BU. By incorporating UCs in conjunction with BUs, dimension of BU can be compressed [3]. Despite all these advantages, high cost and low energy density are the main challenges UC technology is facing [4].

In the absence of an ideal source, hybridization of different energy sources is proposed in the literature with distinct power splitting approach. The diverse procedures adopted for power splitting among multi-sources are rule-based approach [5], adaptation of optimal power ratio decided by an optimizer [6], filter-based power splitting [7] and wavelet transformation (WT) technique [8]. Among this WT technique is most recently used and effective method as the power signal can be split into any number of sub-signals. In this paper the sizing of multiple energy sources is realized by considering the initial investment, weight, and source degradation (both BU and UC) along with optimal power allocation from individual sources. WT technique is applied for power splitting since diverse combinations of waveform are available for the optimizer to select a group of signals to be endowed by multiform energy sources.

2. Modelling and problem framework

In this section the hybrid electric vehicle (HEV) modelling and problem framework is elucidated.

2.1. HEV modelling

To define the problem, analysis of the power demand from vehicle and the source modelling are significant. Various system models and requirements are interpreted in the following sub-sections.

2.1.1 Vehicle power demand

The tractive force (F_{tr}) propels the vehicle at desired speed and is the summation of aerodynamic drag force (F_{ad}) due to viscous resistance, rolling resistance force (F_{rr}), gravitational force (F_{gr}) and acceleration force (F_{acc}) [9].

$$F_{tr}(t) = F_{ad}(t) + F_{rr}(t) + F_{gr}(t) + F_{acc}(t) \quad (1)$$

The product of the tractive force and the velocity (V) at the same instant is the traction power demand (P_{tr}).

$$P_{tr}(t) = F_{tr}(t)V(t) \quad (2)$$

2.1.2 Source modelling

In this paper, BU and UC are the hybrid sources used and the detailed electrical model is investigated in the following subsections.

2.1.2.1. Battery modelling

Second order Thevenin model with two RC pair is endorsed from [10] for modelling BU. As seen in Figure 1, $R_{1b}C_{1b}$ pair represents short term transient effects and $R_{2b}C_{2b}$ pair corresponds to long term transient effects. R_{intb} represents the effective series resistance and V_{ocb} is the open-circuit voltage of the BU.

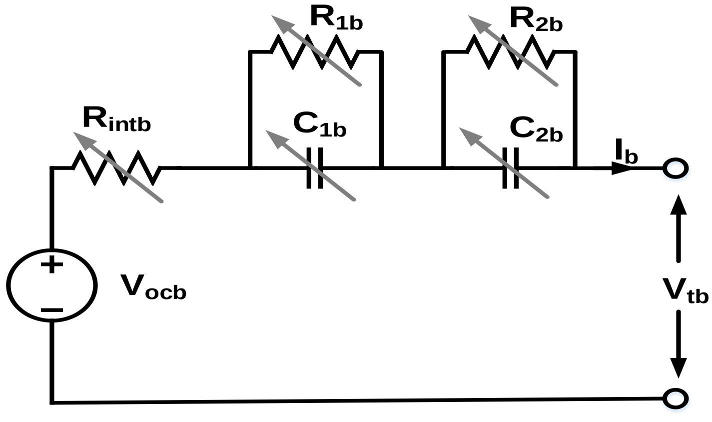


Figure 1. Second order Thevenin battery model.

The terminal output voltage (V_{tb}) of the battery cell can be indicated as:

$$V_{tb}(t) = V_{ocb} - I_b\left[R_{intb} + R_{2b}\left(1 - e^{-t/(R_{2b}C_{2b})}\right) + R_{1b}\left(1 - e^{-t/(R_{1b}C_{1b})}\right)\right] \quad (3)$$

The output power of BU can be expressed as:

$$P_b(t) = V_{tb}(t)I_b(t) \quad (4)$$

Here the dynamic variation of source components is inspected and since these parameters vary with state of charge (SoC) of BU, SoC of battery cell can be estimated as:

$$SoC_b(t) = SoC_b(t - \Delta t) - \frac{\Delta t I_b(t)}{3600C_b} \quad (5)$$

Here, C_b defines the rated capacity of battery cell in ampere hour, and Δt is the time difference between the samples.

Battery degradation model is contemplated in this work to safeguard the operation of EV for a distinct driving range. The capacity loss at any distinct time can be expressed as [11]:

$$\frac{dQ_b(t)}{dt} = \Delta A_h z B^{\frac{1}{z}} e^{\left(\frac{-E_a(C_r)}{zRT}\right)} Q_b(t - \Delta t)^{\frac{z-1}{z}} \quad (6)$$

Where, T is the absolute temperature, R is the universal gas constant, A_h is the ampere-hour throughput and is interpreted as the quantity of charge delivered by BU during cycling. z is the power law factor, $E_a(c)$ is the activation energy and is a function of coulomb rate (C_r)and is modelled using empirical fitting:

$$E_a(C_r) = 31700 - 370.3C_r \quad (7)$$

ΔA_h is the ampere-hour throughput from time t to t+Δt and is characterized using:

$$\Delta A_h = \frac{1}{3600}\int_t^{t+\Delta t} |I_b| dt \quad (8)$$

2.1.2.2. UC modelling

Identical to BU, second order dynamic model of UC is inspected for sizing the HEV as in Figure 2. Due to charge distribution dynamic transients occur, and two RC pairs demonstrate dynamics of different time constants. The internal resistance (R_{intuc}) is the sum of ionic resistance of electrolyte and the contact resistance between electrodes and metallic current collectors [12].

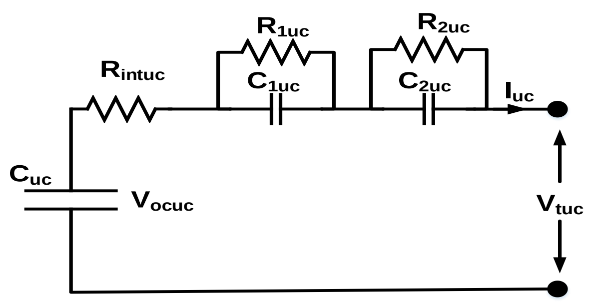


Figure 2. Second order UC model.

The terminal output voltage (V_{tuc}) of the UC unit can be indicated as:

$$V_{tuc}(t) = V_{ocuc} - I_{uc}\left(R_{intuc} + R_{1uc}(1 - e^{-t/(R_{1uc}C_{1uc}}\right) + R_{2uc}\left(1 - e^{-t/(R_{2uc}C_{2uc}}\right) \quad (9)$$

Like BU, the output power (P_{uc}) from UC can be calculated using:

$$P_{uc}(t) = V_{tuc}(t)I_{uc}(t) \quad (10)$$

As well the SoC of UC can be estimated using coulomb counting as given by,

$$SoC_{uc}(t) = SoC_{uc}(t - \Delta t) - \frac{I_{uc}(t)\Delta t}{C_{uc}V_{maxuc}} \quad (11)$$

where C_{uc} is the nominal capacitance (in farad) and V_{maxuc} is the maximum voltage across the unit at full charge.

The state of aging (SoA) is not well explored in the literature. In this paper this is scrutinized and the expression for SoA of UC can be expressed as [13]:

$$\frac{dSoA_{uc}(t)}{dt} = \frac{1}{\tau_0} * exp\left(\frac{V_{tuc}(t)}{V_0} + \frac{\theta_{uc}(t)}{\theta_0} + \frac{I_{uc}^{rms}(t)}{I_{uc}^{rms0}}\right) \quad (12)$$

Here, SoA_{uc} is the state of aging defined as aging over time, $\theta_{uc}(t)$ is the dynamic temperature across the UC in °C and $I_{uc}^{rms}(t)$ is the root-mean-square current output from the UC. In Eq. (12), τ_0, V_0, θ_0, and I_{uc}^{rms0} are the constants and can be derived from numerical applications.

2.2 Problem framework

With BU-UC configuration, the main advantage is that BU life can be sustained by decreasing the ripple power output from battery. Thus, the problem formulation aims to utilize both sources efficiently to satisfy the power demand without capacity degeneration. Thus, the objective function constitutes the investment cost, initial weight, and source decay factor (for both BU and UC) [14]. The fitness function can be formulated as:

$$O = \psi_1[(n_{pb}n_{sb}c_b) + (n_{puc}n_{suc}c_{uc})] + \psi_2[(n_{pb}n_{sb}w_b) + (n_{puc}n_{suc}w_{uc})] + \psi_3\left(\frac{dQ_b(t)}{dt}\right) + \psi_4\left(\frac{dSoA_{uc}(t)}{dt}\right) \quad (13)$$

where n_{pb}, n_{sb}, n_{puc} and n_{suc} are the number of battery cells in parallel, number of battery cells in series, number of UC units in parallel and number of UC units in series respectively, c_b and w_b are the cost and weight of single battery cell, c_{uc} and w_{uc} are the cost and weight of UC unit. ψ_1, ψ_2, ψ_3 and ψ_4 are the multi-objective function weight factors.

In-order to establish satisfactory operation of distinct sources, operational constraints are applied to power output, current drawn, SoC and degradation of BU. The constraint on battery decay is to ensure a specific driving range before the end of battery life. In addition, the constraints related power (P_{uc}), current (I_{uc}), and terminal voltage output (V_{tuc}) and SoC (SoC_{uc}) for a UC unit are also applicable depending on the UC selected.

3. Methodology

In this section the energy management strategy and the optimization algorithm used in this paper is explained in detail. Discrete wavelet transform (DWT) is applied here to split the power demand among BU and UC. Butterfly optimization algorithm (BOA) is applied to optimize the fitness function and to determine the decision variables.

3.1. Discrete wavelet transform analysis

Considering the aspect of battery and UC sources, UC is well-known to have a high dynamic operation. Thus, the power demand at the transmission side can be split by the technique of WT. Mathematically, transformations are practiced on signals to collect additional information that are not promptly accessible in the raw signal. Most unprocessed signals available are in time domain and can obtain time-amplitude representation of the signal. However, in most cases, remarkable information is concealed in the frequency spectrum and WT is the conclusive solution that provides the time- frequency portrayal. In WT, the analysis of the signal is performed by an approach called multi-resolution analysis (MRA) which investigate the signal at different frequencies at different resolutions [8].

A wavelet is a function ψ defined by,

$$\int_{-\infty}^{\infty} \psi(t)dt = 0 \quad (14)$$

The set of time frequency components is attained by scaling ψ by s and translating it by u. The wavelet transform of a function f can be defined by the expression:

$$W f(u,s) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{s}} \psi^* \left(\frac{t-u}{s}\right) dt \quad (15)$$

The discrete wavelet transform (DWT) is very easy to implement and in this time scale representation is obtained using digital filtering techniques. A series of high pass filters are used to interpret the high frequencies and a series of low pass filters to inspect the low frequencies. The resolution of signal is commutated by filtering operations and the scale is varied by up-sampling and down-sampling operations. The authentic signal x[n] is initially send through a half band high pass filter g[n] and through a low pass filter h[n]. This is the stage one decomposition and can mathematically expressed as:

$$y_{high}[k] = \sum_n x[n].g[2k-n] \quad (16)$$

$$y_{low}[k] = \sum_n x[n].h[2k-n] \quad (17)$$

After down-sampling by 2 $y_{high}[k]$ and $y_{low}[k]$ are the outputs of high pass and low pass filters. This process can be repeated for further decompositions. At every stage filtering and sub-sampling result in half the number of samples (half time resolution) and half the frequency band (double the frequency resolution). Figure 3 illustrates the procedure.

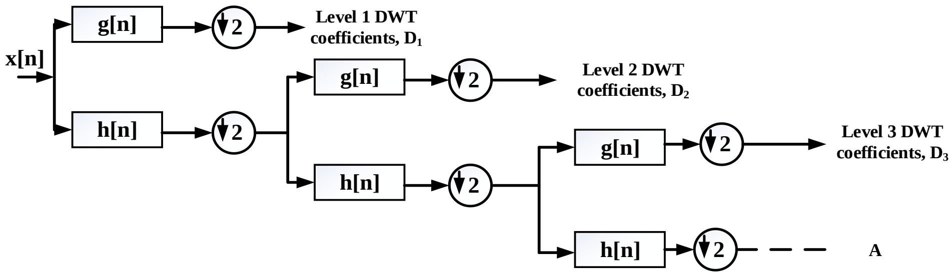


Figure 3. The sub-band coding of DWT for 3 levels of decomposition.

3.2. *Butterfly optimization algorithm*

Recently, S. Arora et al. [15] developed the BOA, influenced by the food exploration nature of butterflies. Butterflies use sense of smell to locate source of food and mating partner. Every butterfly generates a fragrance (f) and this fragrance can be sensed by other butterflies. Here in the optimization, best position butterfly generates more fragrance as the fragrance depends on the fitness value (I) and is expressed as:

$$f = cI^a \quad (18)$$

Here, c is the sensory modality, I is the stimulus intensity and a is the power exponent value. Parameter a is an important parameter that takes values in the range zero to one. The c value is also critical, and these two parameters have demanding effect on the algorithm's convergence speed. The stimulus intensity value is estimated from the objective function to optimize by inputting the particle's location. A group of butterflies from the population detect the best fragrance and move towards it and this process is known as exploitation phase. The updated position can be expressed as:

$$x_i^{t+1} = x_i^t + (r^2 g^* - x_i^t)cI^a \quad (19)$$

Where g* is the global best among all solutions in the current iteration, and r is a random number in the range of zero to one. Other butterflies in the population move randomly and this process is exploration phase. This movement can be expressed as:

$$x_i^{t+1} = x_i^t + (r^2 x_j^t - x_k^t)cI^a \quad (20)$$

where x_j^t and x_k^t represent the positions of any two butterflies belonging to the same swarm, and r is a random number in the range of zero to one. The decision to select between exploration and exploitation phase is performed randomly based on probability switch (p) value [16].

4. Result and discussion

This section first illustrates the test system with detailed dynamic modelling equations of BU and UC. The next sub-section presents and discusses the optimization results.

4.1. Test system

Two well-known driving cycles Urban dynamometer driving schedule (UDDS) and Artemis rural drive cycles were combined for 200km of driving range for HEV sizing evaluation. The next important task is to decide the main specification of the vehicle for HEV design. The specification of the test vehicle is depicted in Table 1.

Panasonic 18650 battery cell with specification demonstrated in Table 1 were used as BUs. The open circuit voltage (V_{ocb}), R_{intb}, R_{1b}, R_{2b}, C_{1b}, C_{2b} can be dynamically defined as the function of SoC using Eqs (21) to (26)[17].

Table 1. Specification of test vehicle and Panasonic 18650 battery cell

Specification of test vehicle		
Parameter	**Unit**	**Value**
vehicle mass	kg	1500
Frontal area	m^2	2.35
Drag coefficient	-	0.3
Rolling fiction coefficient	-	0.011
Wheel radius	m	0.3
Accessory electrical load	W	1200

Specification of Panasonic 18650 battery		
Parameter	**Unit**	**Value**
Weight	gram/unit	46
Cost	$/kWh	200
Capacity	Ah	2.25
Nominal voltage	V	3.6
Maximum charging voltage	V	4.2
Maximum discharge current	A	11 (5C)

$$V_{ocb}(SoC_b) = [3.685 + 0.2156SoC_b - 0.1178{SoC_b}^2 + 0.3201{SoC_b}^3 - 1.031\mathrm{e}^{-35SoC_b}]\mathrm{n_{sb}} \quad (21)$$

$$R_{intb}(SoC_b) = [0.07446 + 0.1562e^{-24.37SoC_b}]TRB(T_b)\frac{n_{sb}}{n_{pb}} \quad (22)$$

$$R_{1b}(SoC_b) = [0.04984 + 6.603e^{-155.2SoC_b}]TRB(T_b)\frac{n_{sb}}{n_{pb}} \quad (23)$$

$$C_{1b}(SoC_b) = [4475 - 6056e^{-27.12SoC_b}]TCB(T_b)\frac{n_{pb}}{n_{sb}} \quad (24)$$

$$R_{2b}(SoC_b) = [0.04669 + 0.3208e^{-21.14SoC_b}]TRB(T_b)\frac{n_{sb}}{n_{pb}} \quad (25)$$

$$C_{2b}(SoC_b) = [703.6 - 752.9e^{-13.51SoC_b}]TCB(T_b)\frac{n_{pb}}{n_{sb}} \quad (26)$$

Here, Tb is the temperature of battery in degree Celsius. TRB and TCB are the temperature variation factor on resistance and capacitance respectively.

$$TRB(T_b) = 2.183 - 0.078T_b + 0.0009{T_b}^2 \quad (27)$$

$$TCB(T_b) = 0.967 + 0.015T_b \quad (28)$$

A cylindrical Maxwell BCAP3000 unit was contemplated with open circuit voltage as a function of SOC given by Eq (29) [12]. The details required for modelling are described in Table 2.

Table 2 Dynamic model parameters of Maxwell BCAP 3000.

Parameter	Unit	Value	Parameter	Unit	Value
Weight	**g/unit**	**510**	R_{1uc}	Ω	3.146 × 10−4
Rated voltage	V	2.7	R_{2uc}	Ω	3.883 × 10−4
Rated capacitance	F	3000	C_{2uc}	F	1843
Maximum leakage current	mA	5.2	τ_0	s	1.4 × 1013
Absolute maximum current	A	1900	V_0	V	0.2/ln (2)
Cost	$/kWh	5000	θ_0	0C	10/ln (2)
C_{uc}	F	2712	I_{rms0}	A	30/ln (2)
C_{1uc}	F	627	R_{intuc}	Ω	8.216 × 10−4

$$V_{ocuc}(SoC_{uc}) = [-0.18(SoC_{uc})^4 + 0.59(SoC_{uc})^3 - 1.2(SoC_{uc})^2 + 3.5(SoC_{uc}) - 1.910^{-4}]n_{Suc} \quad (29)$$

4.2. *Optimization results*

In BU-UC HESS with DWT approach, the decision variables to optimize the objective function are $n_{pb}, n_{sb}, n_{puc}, n_{suc}$ and the k, the number representing waveform combination equipped to BU and UC. Using DWT, four levels of decomposition are considered. Thus,

$$x[n] = A + D_1 + D_2 + D_3 + D_4 \quad (30)$$

Therefore 32 levels of waveform combinations are possible. For a comparative study the sizing is compared with BU composition only and BU-UC hybrid system. The power demand curve combining one cycle of UDDS, and one cycle of Artemis drive cycle is plotted in Figure 4(a). This cycle is repeated for more than 200km for source sizing optimization problem.

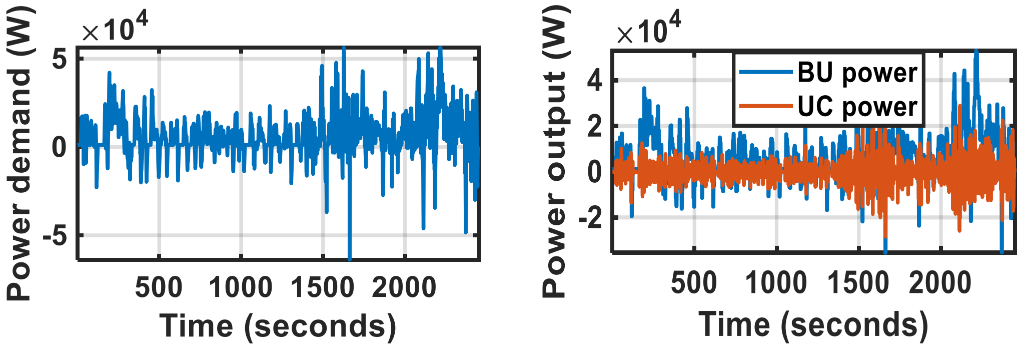
The results of optimization are tabulated in Table 3. In BU only HEV system - investment cost, source weight and battery degradation were combined to form the fitness function. The number of series and parallel BUs, series and parallel UC units, battery rating, UC rating, fitness function value, investment cost and source weight are characterized in detail in Table 3. Despite the high cost (cost/kWh) and weight of UC units, there is an enhancement in the fitness function value for BU-UC hybrid system over BU only source. Correspondingly, BU-UC HEV provides a source system with low investment cost and weight. With addition of 36 UC units, the BU rating is downsized by 14.86% for a driving range of more than 200km.

Table 3. Comparison of optimized EV-source sizing results with BU only and BU-UC HESS.

Parameter	BU only	BU-UC HEV
n_{pb}	123	102
n_{sb}	75	77
n_{puc}	-	1
n_{suc}	-	36
Fitness value	15379.85	14206.81
kWh rating of BU	74.72	63.61
Wh rating of UC	-	218.7
Initial cost ($)	14944.5	13816.98
Source weight (kg)	424.35	379.28

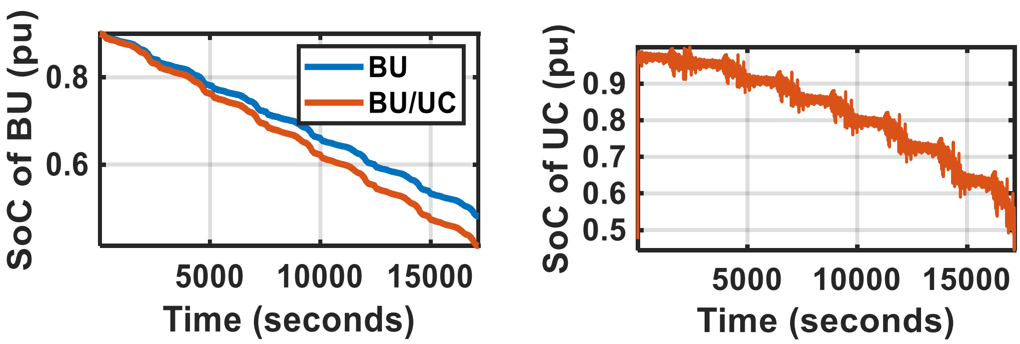
k	-	6; $P_b=A+D_4+D_3$; $P_{uc}=D_2+D_1$

The power demand from the HESS of the EV for one cycle is shown in Figure 4(a). For that demanded power, Figure 4(b) depicts the power split among BU and UC by applying DWT. The variation of SoC of BU for two distinct configuration (BU and BU-UC) is shown in Figure 5(a). The variation of SoC of battery is within the acceptable range of 80% depth of discharge (DoD) for lithium-ion batteries. To ensure the battery life for a particular number of charge-discharge cycles, the DOD is maintained above the boundary limits, that is, battery will not drain out completely for the selected driving range. Figure 5(b) displays the SoC of UC for BU-UC hybrid source configuration. BOA outputs the value of decision variable k as 6. That means, $P_b=A+D_3+D_4$ and $P_{uc}=D_1+D_2$.



(a) (b)

Figure 4 Power demand (a) from the energy source of HEV. (b) from BU and UC applying DWT.



(a) (b)

Figure 5. Variation of (a) SoC of the BU for two distinct configuration (b) SoC of the UC for BU-UC configuration.

5. Conclusion

In this paper, a methodology to optimally size the energy sources for a BU/UC HEV is presented. A multi-objective function comprising the investment cost, source weight, and source degradation was developed using the dynamic models of the BU and UC. The dynamic modeling of the BU and UC comprehend the temperature variation and parameter alteration with variations in SoC and temperature. DWT is applied here to split power among multiple sources and BOA is used to optimize the objective function. The result indicates the size reduction of BU by 15% for 200km driving range. The overall system investment cost and weight is reduced by incorporating UC along with BU.

Author contributions: conceptualization, A. Prasanthi and H. Shareef; methodology, A. Prasanthi and H. Shareef; software, A. Prasanthi and H. Shareef; validation, A. Prasanthi; formal analysis, A. Prasanthi; resources, A. Prasanthi and M. Asna; writing—original draft preparation, A. Prasanthi; writing—review and editing, H. Shareef and M. Asna; supervision, H. Shareef; funding, H. Shareef.

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A Metric for Sustainable Roadway Lighting Design Configuration

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Abstract: Road lighting standards are developed to improve night-time visibility and to assist drivers in their visual tasks. Most countries use the ANSI/IESNA recommended practice RP-8-14 or CIE Publication 115. These standards aim at illuminating road pavements by specifying targets of horizontal illuminance or luminance values at the pavement level. However, a sustainable road lighting standard should encompass all of what could be important for drivers to see. This includes the pavement and any obstacles on the road or in close proximity to the road. The objective of this manuscript is to investigate how to improve the configurations of the design variables in the current road lighting standards aiming at providing a sustainable visual environment for drivers during nighttime. The study used several techniques such as data collection, data analysis, and computer simulation. The tested metric was the contrast. The location and distribution of targets depended on the possible location of obstacles. We developed a new metric that we named "mean contrast". The analysis discussed in this paper includes four possible target heights, three pole spacings, five lateral target locations, and sixteen longitudinal locations of measuring points. Results showed that targets at low height (0.05 m and 0.5 m) exhibited negative contrast, while those at 1.0 m and above showed positive contrast. The negative mean contrast did get affected by pole spacing, while the positive mean contrast at 1.5 m became lower as the spacing increased. The positive and negative uniformity also dropped with larger pole spacings. We conclude that the mean contrast metric has merit and could be used to provide a better visual environment for drivers during night-time

Keywords: roadway lighting; visibility; contrast; roadway lighting standards; street lighting.

1. Introduction

The objectives of roadway lighting are: (1) to reduce night accidents and economic loss, (2) to increase sense of personal security, (3) to facilitate the traffic flow, and (4) to promote the use of public facilities during the night hours [1]. Roadway lighting standards are prepared to assist designers attain these goals. Most countries use the American National Standard Institute/IESNA recommended practice RP-8-14 [2] or the CIE Publication 115 [3] as reference for their own guidelines. These standards provide quantitative recommendations for the horizontal illuminance or luminance values at the pavement level for each road type. This means that they aim at illuminating the pavement with no consideration to other elements such as other obstacles or pedestrians. A sustainable roadway lighting standard should consider all what could be important for drivers to see. This includes obstacles on the pavement or close to it with an intention to cross the road. The current standards were critiqued by several researchers who called for some major revisions [4-10].

During dark hours, visual tasks for drivers become harder. Whereas the luminance and Illuminance approach in roadway lighting standards incorporate some factors that affect human visibility, other important factors such as the objects' contrast, size, shape, colour, and the background complexity are not examined in these standards. A recent study by Fotios and Gibbons [4] criticized the quantitative recommended design targets and suggested to change the parameters that are being measured to metrics that measure visibility during night-time. The Small Target

Visibility (STV) is another approach that has been introduced to improve visibility of objects on the pavement. Unfortunately, the measure in this approach is done for very low target only without considering the various possible targets' heights in the roadway lighting environment.

Visibility indices found in the literature rely primarily on target contrast. Several studies suggested shifting to contrast-based metric for roadway lighting standards [5,7,11-13]. Abouelhamd and Saraiji [5] developed a new calculation method for roadway lighting design. In this method, vector analysis was used to locate the immediate background for each target as seen by a driver. Contrast was then calculated by knowing the luminance of each target and its immediate background.

In addition to improving the visual environment for drivers, a sustainable roadway lighting standard should develop representative roadway configurations that considers possible locations and distribution of obstacles, vehicles' speed, and the position of the driver with relation to obstacles. Whereas the current road lighting standards [2,3] aims at illuminating road surfaces, a proper road lighting standard should consider all what a driver needs to see such as pedestrians. Pedestrians could have different heights and be in different locations, and they could be on the road or in a close proximity to the road with an intention to cross it. Saraiji and Oommen [12] found that the vertical illuminance changes from the top to the bottom of the pedestrian. Therefore, road lighting standards should account for different possible target height and locations in the road lighting environment. Vehicles' speed should also be considered to account for the needed total stopping distance to get to a full stop. In sum, the current roadway lighting standard faces these two main problems:

- The current standards use luminance and illuminance measures as design criteria, while human visibility is mainly based on the contrast between an object and its background.
- The roadway configurations are poorly developed, and more consideration should be given for the location and distribution of the measuring points.

This manuscript highlights some limitations in the current roadway lighting standards and propose new contrast-based metric named mean contrast (C_{ave}) for roadway lighting standards.

2. Methodology

At the outset, the ANSI/IESNA recommended practice RP-8-14 and CIE Publication 115 were studied carefully to collect and analyze information related to the design configurations in each standard. In this stage, information such as the size of calculation field, the distribution and heights of the measuring grid points, and the height and location of the targets in the longitudinal and transverse directions of the road were gathered. After that, a comparison between the design information in each practice were conducted to analyze the data and to understand the rationale behind them. Table 1 presents the main difference in the design configurations between both practices. This analysis highlights the limitations in the design configuration of each practice (see Table 1).

Table 1. Comparison between the design configurations in the ANSI/IESNA recommended practice RP-8-14 [2] and CIE Publication 115 [3].

Design element	CIE 115	IESNA RP-8-14	Limitations
Calculation field	Longitudinal arrangement: Covers luminaire spacing Transverse arrangement: Covers the whole carriageway width on roads without median, and the width of one carriageway with median.	Longitudinal arrangement: Covers luminaire spacing Transverse arrangement: Bounded by the edge of the travelled way.	In the transverse direction of the IESNA standard, there is no consideration for road configuration [whether it has median or not].
Grid points configurations	Longitudinal arrangement: The spacing between the points equals pole spacing divided by the number of points needed. Transverse arrangement: Three points per lane. The spacing between points equals lane width divided by 3. Level of measurement: At pavement level	Longitudinal arrangement: The points should be at least 10, and the spacing between them not more than 5m in center. Transverse arrangement: Two grid points per lane. Each grid is quarter the distance from the edge of each lane. Level of measurement: At pavement level	In the transverse direction, the calculation points are better distributed relative to the whole road, not relative to each lane. One point on each lane is enough to study luminance on that lane. Road lighting should not only illuminate the road pavement, but also all possible obstacles in the road environment
Observer configurations	Longitudinal arrangement: Is fixed at distance equals 60 m from the first luminaire. It does not change relative to each grid point. Transverse arrangement: One observer at the center of the lane Height: At 1.5 m above road level	Longitudinal arrangement: Is fixed at distance equals 83.07 m from each grid point. The observer moves with the grid points to keep constant observer-to-target relation. Transverse arrangement: Two observers per lane Height: At 1.45 m above road level	The distance between the observer and the calculation points should not be fixed and should rather be based on the AASHTO requirements of total stopping distance.

The current research is investigated in a two-lane road in rural area. We propose the following configuration for the measuring points and the driver to cover the limitations in the design configurations used in the current practices. The proposed configuration for the two-lane road includes five obstacles that are placed on the lateral direction of the road to cover its width. Three obstacles on the road pavement and two obstacles on the sidewalk beside the pavement. This represents obstacles on the road and obstacles with intention to cross it. These obstacles are labelled according to their lateral position as seen from an oncoming car as follows: Left (L), Left-canter (LC), center (C), right-center (RC), and right (R). Each obstacle is divided into four sub-obstacles of specific heights relative to the ground (0.05 m, 0.5 m, 1.0 m, 1.5 m) (see Figure 1). These heights were selected to represent obstacles of various heights in the road environment such as a rock, an animal, a child, and an adult pedestrian. This set of five obstacles is repeated at equal interval along the longitudinal direction of the road to cover the area between two poles with sixteen grids as illustrated in Figure 2. The driver is positioned at a distance equals the total stopping distance as proposed by [14].

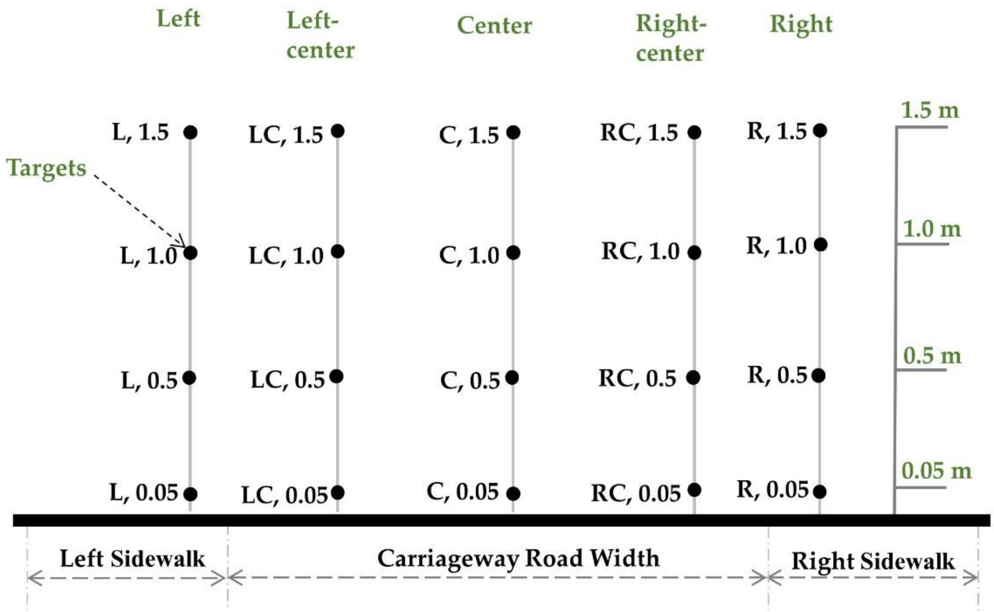

Figure 1. Distribution of targets along the lateral direction of the road, where L is left position, LC is left-center position, C is center position, RC is right-center position, and R is right position relative to the driver's vision.

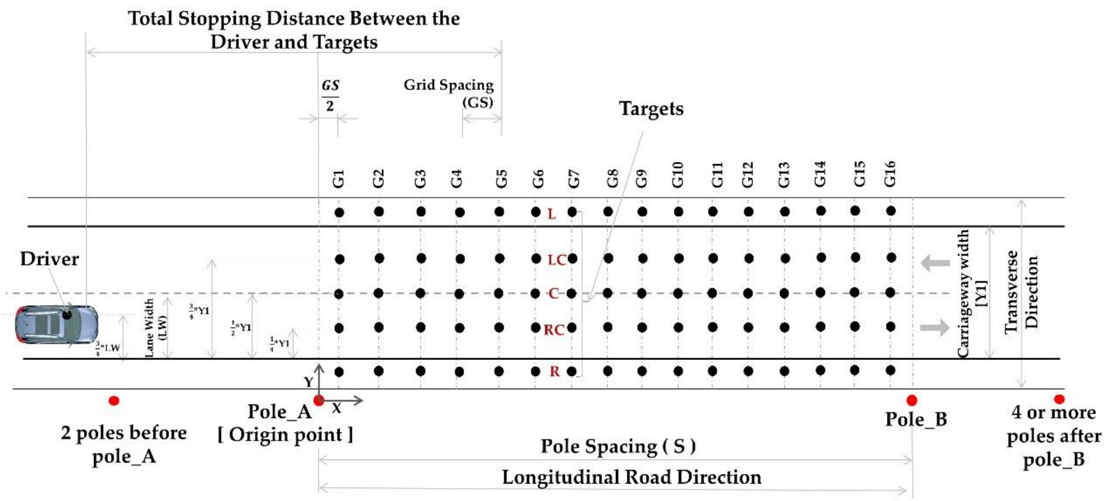

Figure 2. Plan view of the new arrangement of design element in the roadway lighting environment.

The tool used for computer simulation is DIALux software, which is customized for indoor and road lighting simulations. Several researchers have established the accuracy of DIALux in lighting simulations [15-18]. The software gives the user the option to choose different national standard lighting and the photometric databases can be imported directly from manufacturers. The two-lane road proposed in this study was developed using DIALux, and the design parameters for the base-road are as follows:

- Number of lanes: two
- Lane width: 3.6 m
- Pole arrangement: single sided
- Pole height: 10 m

- Pole spacing: 40 m
- Type of luminaire: light emitting diode (LED)
- Luminaire optic type: optic distribution type II, with 95 watts
- Obstacle's reflectance: 20%
- Background reflectance for sand area: 40%
- Total stopping distance: 65 m
- Drivers' eyes height: 1.45 m
- Road reflectance type: R3

The contrast calculation procedure applied to find contrast of targets at various heights in this research is based on a prior work done by the authors [5]. In this work, the contrast value of targets as seen by a driver is calculated via the following equation:

$$c = \frac{L_t - L_b}{L_b} \quad (1)$$

Where C is contrast, L_t is target luminance, and L_b is background luminance. The reader is referred to reference [5] for more details about the calculation procedure.

Contrast is the base of visibility for the human visual system. It is used as the main metric to evaluate the visual performance in roadway lighting environment. The contrast-based metric we propose in this paper is named mean contrast (C_{ave}). This metric calculates the average contrast of all targets at each height in the roadway environment. It has six values that are: (1) the positive mean contrast, (2) the negative mean contrast, (3) the positive contrast uniformity, (4) the negative contrast uniformity, (5) the percentage of road with positive contrast, and (6) the percentage of road with negative contrast. We differentiated between the positive and negative contrast values as not to skew the mean value. The uniformity measure in this paper is defined as the standard deviation over the mean. Equations 2, and 3 illustrate how the negative mean contrast and the negative uniformity are calculated.

$$Negative\ C_{ave} = \frac{\sum negative\ C}{n_{negative\ c}} \quad (2)$$

$$Negative\ uniformity = \frac{negative\ STDV_T}{negative\ C_{ave}} \quad (3)$$

Where:
Negative C_{ave} is the mean value of all negative contrasts.
Negative C is the negative target contrast values.
$n_{negative\ c}$ is the number of targets with negative contrast.
Negative $STDV_T$ is the standard deviation of the negative contrast values.

3. Results and discussion

This section is divided into two subsections that discuss the outcomes related to the contrast values found in the road, and the mean contrast metric that we propose in this paper.

3.1. Contrast results

Contrast is calculated for each target in a two-lane road at four heights. We assumed a rural road surrounded by sand. Figure 3 illustrates the contrast values as false-color maps for single sided poles at a two-lane road for three different pole spacing (30 m, 40 m, and 50 m) and at four targets' heights (0.05 m, 0.5 m, 1.0 m, and 1.5 m). A negative contrast value indicates that the background is brighter that the target, while the positive contrast values means the targets are brighter than their background. Figure 3 shows that the location of targets (in the longitudinal and lateral directions), their heights, and pole spacing all have significant impacts on the contrast results. The figure also shows that the contrast values of targets shifts from negative to positive as the target's height increases (from 0.05 m to 1.5 m), and as the pole spacing increases (from 30 m to 50 m). Contrast for targets at 1.5 m resulted in very high positive contrast compared to other targets at lower heights.

Figure 3 illustrates false-color maps of the positive and negative contrast values for taregts at the studies road. The exact percentage of road area with positive and negative contrast are presented in Figure 4 (a and b). These two figures show that the percentage of road area that have negative contrast at height 0.05 m is 100% for spacing 30 m, and 40 m, while it is 98% for spacing 50 m. On the other hand, the percentage of road area that have positive contrast at the same height is zero for spacing 30 m, and 40 m, while it is 2% when 50 m spacing is used. This indicates that the majority of targets at very low height (0.05 m) have the background brighter than the targets themselves (negative contrast). The same figures illustrate that the percentage of negative contrast at height 0.5 m is 100% for spacing 30 m, and 50 m, while it is 96% for spacing 40 m. The very small percentage of positive contrast at 0.5 m height when the three spacing are used indicates that short targets at this height appears darker than their background. Figure 3 and 4 also show that the percentage of road area that have negative contrast at height 1.0 m is 49% for spacing 30 m, 44% for spacing 40 m, and 46% for spacing 50 m. On the other hand, the percentage of road area that have positive contrast at height 1.0 m is 51% for spacing 30 m, 56% for spacing 40 m, and 54% for spacing 50 m. This output indicates that almost half the targets have positive contrast, while the other half have negative contrast at height 1.0 m above the ground. The false-color maps presented in Figure 3 help identify the locations of positive and negative contrast targets. Figure 3 shows that 100% of road area has positive contrast at height 1.5 m regardless of the spacing. The 100% of positive contrast at 1.5 m height indicates that targets at this height are brighter compared to their background. This is because the background for targets at this height is usually the sky with very low luminance value.

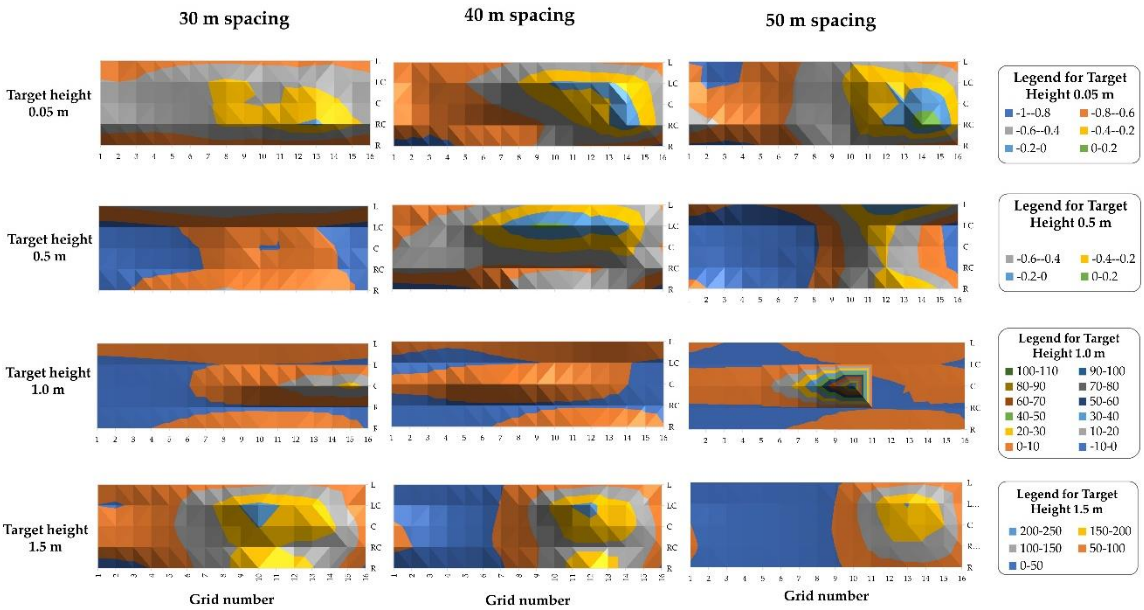

Figure 3. Contrast false-color maps for two-lane road with various pole spacing (30 m, 40 m, 50 m) and various targtes' height relative to the ground (0.05 m, 0.5 m, 1.0 m, 1.5 m).

3.2. Mean Contrast Metric Results

To fully understand the mean contrast metric, it is crucial to find the percentage of road area with positive and negative contrast, the negative and positive mean contrast, and the positive and negative uniformity. These measures are calculated for three different pole spacings (30 m, 40 m, and 50 m) and at four targets' heights (0.05 m, 0.5 m, 1.0 m, and 1.5 m). Figure 4 (a and b) shows that targets at low heights (less than 1.0 m) always exhibited negative contrast with 100% of road area. On the other hand, 100% of road area is positive contrast for targets at 1.5 m. Targets at 1.0 m has both positive and negative contrast. The percentage of the road with positive contrast and that with negative contrast were discussed in more depth earlier.

Figure 4 (c and d) presents the negative and positive mean contrast results. It shows that the negative mean contrast for low targets (less than 1.0 m) did not get affected by the increase in pole spacing from 30 m to 50 m. On the other hand, negative mean contrast for targets at 1.0 m fluctuated when the spacing increased. Similarly, the positive mean contrast at 1.0 m did not get affected by the increase in pole spacing from 30 m to 50 m. However, that at 1.5 m dropped gradually as the pole spacing increased from 30 m to 50 m.

Figure 4 (e and f) also presents the contrast uniformity for both positive and negative contrast values on the road. Given the definition of uniformity as the standard deviation over the average, the lower the value of uniformity, the better it is. This figure shows that the increase in pole spacing reduces both the positive and negative uniformity. Targets at height 0.5 m showed the best negative contrast uniformity compared to other heights at 0.05 m and 1.0 m. Additionally, the negative contract uniformity at 0.5 m was the best at the smallest pole spacing at 30 m. The positive contrast uniformity also became worst with larger pole spacings. Targets at 1.5 m showed the best positive contrast uniformity compared to the positive uniformity for targets at 1.0 m. Another important observation is that the positive uniformity at 1.5 m reduced gradually as pole spacing increased from 30 m to 50 m.

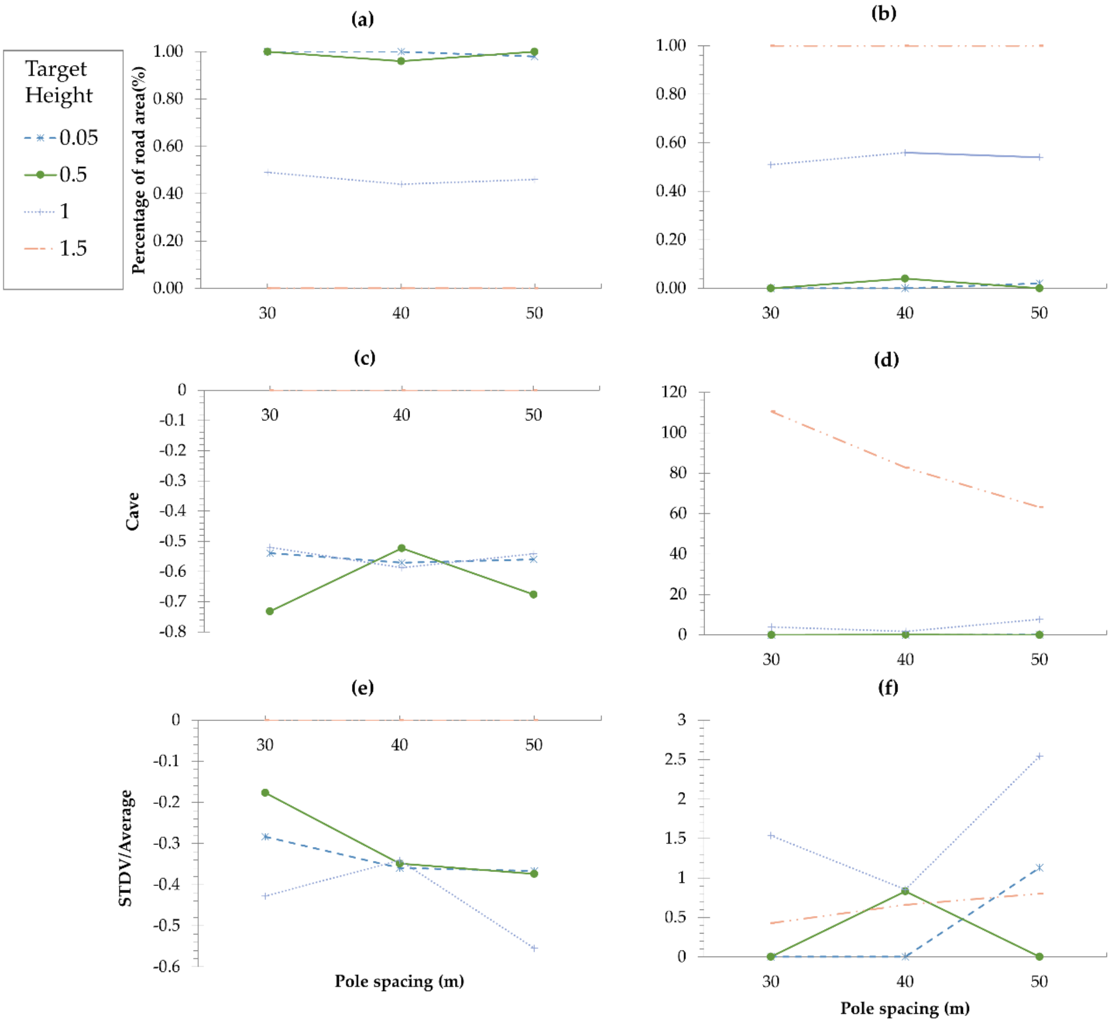

Figure 4. (a) Percentage of road area with negative contrast; (b) Percentage of road area with positive contrast; (c) Negative mean contrast; (d) Positive mean contrast; (e) Negative contrast uniformity; (f) Positive contrast uniformity.

5. Conclusions

The mean contrast metric (C_{ave}) is an attempt to incorporate contrast, which is the basis of human visibility, into roadway lighting design. The metric is the average contrast of targets along a roadway segement. We also measured the percentage of the road with positive and negative contrast values to give designers an overall idea about the contrast levels in the roadway lighting environment. The false-color maps can provide a visual view of the distribution of contrast along the road. In addition to knowing the percentage of the road with positive and negative contrast, this metric also calculates the mean contrast results and the contrast uniformity along the road. This helps roadway lighting designers understand the range of contrast values calculated for a specific road. Together with the percentage of the road with positive and negative contrast, a designer can fully understand the visual environment for a specific roadway. It is important to note that the target design values need more work before incorporating the proposed metric into a standard. Our main findings are:

- The contrast is affected by the location of targets along the longitudinal and lateral direction of the road, as well as their heights relative to the ground. Target's height has a large impact on contrast. Low targets (less than 1.0 m) usually exhibit negative contrast with almost 100% of road area. On the other hand, target at 1.5 m exhibit positive contrast with 100% of road area. Targets at 1.0 m exhibit both positive and negative contrast. The contrast shifts from negative to positive as target's height increases and as the spacing increases.
- The negative mean contrast did not get affected by the increase in pole spacing. On the other hand, increasing pole spacing reduced the mean positive contrast, especially for targets at 1.5 m. The positive and negative contrast uniformities dropped as pole spacing increased.
- The results suggest that the mean contrast metric has a merit and could be incorporated to roadway lighting standards. It helps understand the visibility of targets along any road segment. Nevertheless, more investigation is needed to find the design target values related to the proposed metric.

Author Contributions: conceptualization, A.A. and R.S.; methodology, A.A.; software, A.A.; validation, A.A., and R.S.; formal analysis, A.A.; investigation, R.S.; resources, R.S.; data curation, A.A.; writing—original draft preparation, A.A.; writing—review and editing, R.S.; visualization, A.A.; supervision, R.S.; project administration, R.S.; funding acquisition, R.S.".

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Conflicts of Interest: The authors declare no conflict of interest.

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The Proliferation of Electromagnetic Radiation Pollution in Smart Buildings: Role of Building Materials

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Abstract: Smart buildings using 5G and Internet of Things (IoT) acknowledge themselves as one of the most innovative byproducts occasioned by the Fourth Industrial Revolution, and are seen as the forward solution to the built environment issues once if fully implemented. Among these effects, radiation stem as the invisible one, but with a direct impact as dwellers inside a smart building will be continuously exposed to radiation. Several studies have already shown that a myriad of health issues can emerge from radiation, causing biological damages such as DNA alteration and hormone imbalance which could escalate to depression, anxiety disorders to various other illnesses including cancer and tumor. When smart buildings are actualized, building materials can influence the plethora of Electromagnetic radiation as these materials also exhibit Electromagnetic properties. The paper aims, through a pragmatic approach, to evaluate and quantify the influence of common building materials inside a simulated smart building using Computer Simulation Technology (CST). The study found that Electromagnetic Radiation (EMR) produced by 10 GHz is much higher than 2.45 GHz for all building materials and natural, sustainable materials such as wood and earth produced 2-3 V/m less EMR and overall scattering man-made building materials. The dissipation of EMR became more pronounced with higher frequency with concrete showing less dissipation in EMR compared to glass although the latter produced more. Steel showed significant difference in EMR when compared to other materials and a high level of scattering with stagnant radiation inside the space.

Keywords: Smart Buildings, Electromagnetic Radiation, Scattering, Building Materials, Wood, Concrete, Steel, Glass, Earth, 5G, CST

1. Introduction

Every industry of the 21st Century, such as construction, medical or automobile, has embraced smart technology for its continuous improvement and in providing better and efficient services to society. For the construction industry, buildings and even cities are slowly evolving to be connected using Artificial Intelligence, sensors and smart IoT devices [1] [2]. This prospective transformation is also believed to be the sustainable solution that can be utilized to rectify built environment problems which range from high electricity consumption [3], over-exploitation of renewable sources [4] to health and well-being[5]. Often the risks associated with these transformative paradigms are understudied. Some of these risks include cyber-security threats from smart buildings [6][7], CO2 emission from data centres [8], and electrosmog or electromagnetic radiation (EMR) [9][10]. Among the risks, EMR is the invisible problem that dwellers of the smart building can be exposed continuously; hence the focus of this research.

EMR sources in a building usually are generated from powerline distribution to which common household appliances are connected [3] and from high frequency tools such as smart devices, cordless phones, baby monitors [4][5][6]. When a typical household appliance uses 50/60 Hz, the magnitude of EMR is very high. However,, on the contrary, value of EMR is low for mobile phone or smart devices, but it used very high frequency [7]. Though earlier research began in the late 1960s with scientists noting the harmful effects from radiowaves, micro and millimeter waves, EMR pollution received maximum attention in the last decade. Numerous biological and mental effects have been recorded since 1960s [11][20]. It is only in 2011 that the World Health Organization (WHO)classified radiation from radiofrequency as possibly carcinogenic. However, the impacts received more attention than in the past decades, primarily because of multidisciplinary research studies and findings since 5G is opinionated to be implemented soon [20]. Based on these research findings, several countries such as the Netherlands, Switzerland, Australia have banned 5G [21].

Electromagnetic properties of a material can be defined as those influencing the rate at which the materials absorb and emit electromagnetic radiation [22]. While for construction stability, flexural strength, modulus of elasticity is analyzed; the electromagnetic radiation produced by building materials is expressed in parameters such as dielectric, relative permittivity, and conductivity [23]. However, these parameters for a material are not constant, but change with frequency, temperature, moisture content, orientation of the incident electromagnetic field on the material. Most of the residential building materials are made of either concrete, glass, wood and industrial warehouses are made of aluminum, steel or metal alloys [24] Electromagnetic properties of building materials have been studied by few authors [25][26] and mostly the studies were conducted in the range of 2.45 GHz, which is the most commonly used WLAN frequency [27][28].

Most studies that have been previously conducted related to 'buildings and electrosmog' concentrated around signal path loss and attenuation caused by building envelope or walls [23] with the goal of ensuring proper signal transmission. Only a few papers have addressed the relationship between buildings and electromagnetic radiation (EMR) pollution [23]. Further, these research papers have quantified EMR in terms of only electric field, but man-made magnetic fields are also linked to various health problems. For example, the insulation provided by buildings is found to produce a deficiency in the earth's natural magnetic field [11][29]. Vizi & Vandenbosch (2015) presented the influence of building shape and materials and their role in providing shielding effectiveness. The study was analyzed in CST and the building with different shapes and materials was irradiated with 1 GHz. They also concluded that reinforced steel mesh with grid size 5 cm × 5 cm can effectively attenuate EMR produced internally [23]. However, the study neither considered any field sources from real antenna, nor their different frequencies.

From a construction or building design perspective, architects and designers need quantification of this EMR, especially with wireless IoT devices that can help them design safer buildings. It is imperative to note that though sustainability rating systems such as Leadership in Energy and Environmental Design (LEED) [30],Building Research Establishment Environmental Assessment Method (BREEAM) and wellness rating systems such as WELL[31] and Fitwel [32] take into account pollution and health impacts from the air, water and toxic materials used in buildings, but EMR is excluded. Hence, quantification and shielding effectiveness of building materials are vital to provide the initial steps to understand this invisible pollution that take place in a building. This study aims to quantify how dominant building materials can influence the proliferation of EMR while changing the frequency from 4G to 5G. This study uses two different frequencies to carry out comparisons for different building materials, 2.45GHz (the commonly used frequency for Wi-Fi devices in the 4G spectrum) and 10 GHz (one of the frequencies that 5G will operate on).

2. Methodology

The simulation method was selected to conduct this research study as a suitable software can be employed to create a what-if scenario of the situation under study and estimation of the interested parameters with better accuracy than experimental studies. The advantage of using a simulation package compared to experimental testing lies in the fact that with the simulation, any frequency range from 2.45 GHz to even 300 GHz can be tested with reasonable accuracy. CST simulation software was chosen as the study's simulation package as the accuracy of results was confirmed by both academia and industry alike [23]. This research methodology involved designing the needed CST scenario and quantifying the EMR proliferated in a dwelling space with four commonly used building materials. Hence, the design consists of two factors, building material and frequency.

2.1 Simulation design

To accurately depict three-dimensional space and understand the influence and confluence of building materials on EMR, a simple small-sized home office space is modeled. This office space is used by the occupant who utilizes a laptop as the smart device. The geometrical building shape, number of occupants, the smart device is fixed and limited to unity so that the building materials can be easily understood without employing a lot of computational resources and time. The size of the model is 2 meters in length and width, and 3 meters in height shown in figure 1. The size of the room is also kept small to reduce the mesh cells as more complex the building geometry, more meshcells are needed to get accurate results which drastically increases the overall simulation time. Moreover, the only objective of this research was to study the influence of building materials on the EMR produced, hence the simulated space depicts a building space similar to that of a small office cubicle.

Figure 1. Model in Sweethome 3D

The exterior model is designed in CST while the interior model is designed using an open-source software named 'sweethome 3D', which allows the model to be imported in CST as an object file format. This imported file was used in conjunction with the model designed in CST using the 'Transform' function. Different materials were then assigned to each and every component of the 3D model. The interior material was kept the same for all models with the furniture being assigned the material 'wood' and other electronic devices as PEC. The human model was assigned as bio-tissue. All materials frequencies, including the human material, were updated to match the operating frequency.

2.1.1 Antenna for smart device and Field source excitation

The antenna selected for the IoT device was a rectangular patch antenna as this is one of the antennas that will be used for 5 G IoTs [33] as shown in figure 2. Antenna Magus software, available with CST, was employed to perform the antenna design and its simulation. This software is designed in such a way that it allows even non-antenna engineers to easily design the antenna. Though Antenna Magus gives Tentative performance results, the final antenna was exported to the CST EM studio suite to perform accurate computations using the time domain solver. This model's field source was saved and then used as import field excitation for the main 3d model. Figure 3 shows the complete model in CST, including the field source.

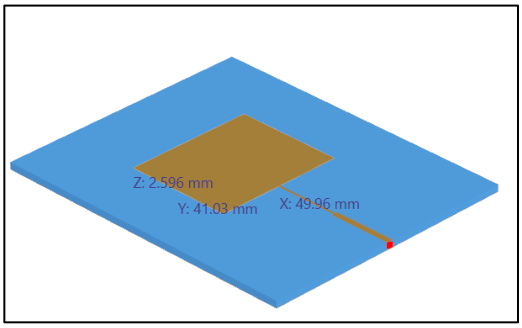

Figure 2. Rectangular edge-fed patch antenna at 2.45 GHz

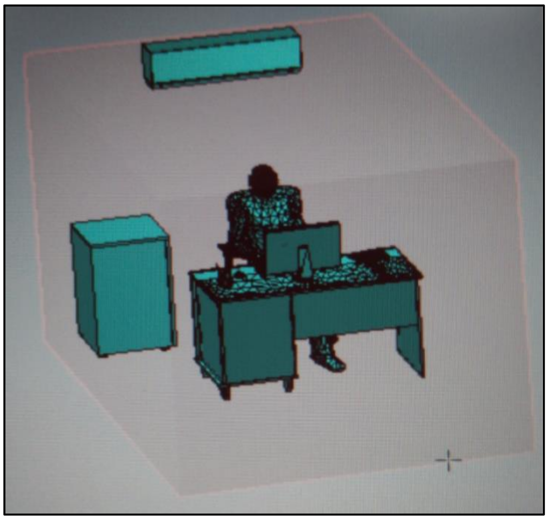

Figure 3. Model design in CST

2.2 Validation

In order to validate the result of the simulation, EMF measurement was determined from a real-room made of concrete where a laptop operated wirelessly at 2.45 GHz. EMF was measured using the wintact professional EMF measuring device. At 15 cm away from the device, average values of electric field and magnetic field was found to be 25 V/m and 0.058 A/m, respectively. Similar room space was then simulated in CST, and the electric and magnetic field values were found to be 27.247 V/m and 0.074 A/m respectively. Hence it was found out that the results using CST was reliable for carrying out further computations.

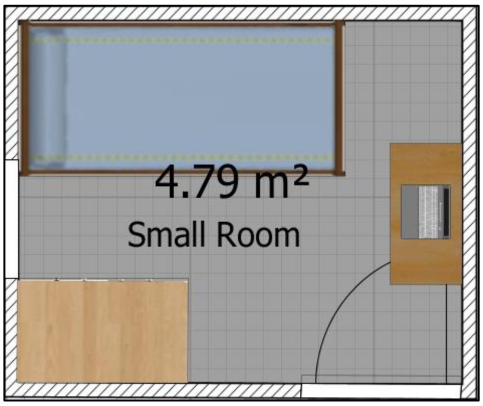

Figure 4. Real Room for validation

3. Results and Discussions

Results of all simulation runs are tabulated in table 1 for the two main factors, building material and frequency. Figure 5 displays the electric field produced in the simulation model for 2.45 GHz, concrete.

Table 1. Simulation Results for EMR for different building materials and frequencies

Building Material	Frequency (GHz)	Max E-field (V/m)	E-field @ 15 cm from smart device	Max Magnetic field (A/m)	Magnetic @ 15 cm from smart device
Wood	2.45	125.712	25.564	0.337	0.068
Concrete	2.45	127.428	27.835	0.339	0.073
Earth	2.45	126.116	25.956	0.339	0.068
Glass	2.45	128.648	27.726	0.339	0.069
Steel	2.45	159.432	100.407	0.4038	0.269
Wood	10	437.754	29.784	1.2878	0.066
Concrete	10	483.377	32.597	1.318	0.075
Earth	10	441.021	29.537	1.28	0.067
Glass	10	498.234	30.246	1.318	0.076
Steel	10	534.628	103.975	1.417	0.269

Figure 5. Electric field distribution for concrete at 2.45 GHz

For frequency 2.45 GHz (4G), all building materials exhibited similar EMR distribution except for steel inside the building space and the average maximum electric field, and magnetic field values were 126.976 V/m and 0.338 A/m, respectively. Contrary to this, at a higher frequency of 10 GHz (5G), the maximum electric and magnetic field distribution were 3.5 times higher and varied considerably among the building materials. For example, comparing the performance of concrete and glass at two frequency revealed that at 2.45 GHz, the difference in EMR was negligibly small, but at 10 GHz, EMR produced by concrete was around 2 V/m higher than produced by glass. This is true for all materials and it can, therefore, be inferred that materials do play a vital role in dissipation of EMR inside a building space and also becomes prominently significant at higher values. The reason for this can be linked to the change in electromagnetic properties of materials at different frequencies emphasizing that at higher frequencies, it would be better to choose wood or earth, i.e. naturally sustainable material than man-made ones. However, these values, when taken at a measuring distance of 15cm, assuming the laptop is very close to the person who is exposed, the lowest value was for wood, followed by earth, glass and concrete.

It is also imperative to note that though glass has higher maximum electric field when compared to concrete, electric and magnetic field measurement at 15cm disclosed that concrete has higher value than glass, which is more evident at 10 GHz. This signifies that the overall dissipation of EMR is slower in concrete when compared to glass as depicted in figure 6. Steel has the highest overall values in both electric and magnetic fields and also at the measuring distance, it gave the maximum value of 100. 407 V/m for 2.45 GHz and 103.975 at 10 GHz (figure 7 and 8). This can be explained by the fact that steel, whose relative permittivity and conductivity are very high, reflects the electric and magnetic fields it receives from the device and reemits them multiple times, causing an overall high value of EMR.

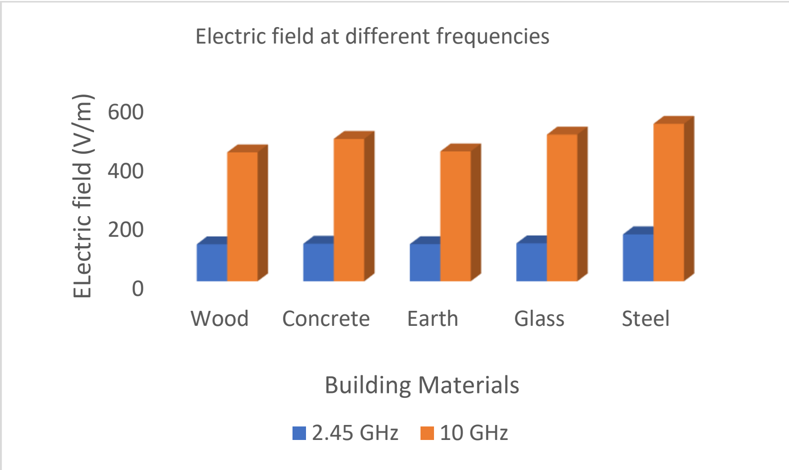

Figure 6. Maximum electric field at different frequencies

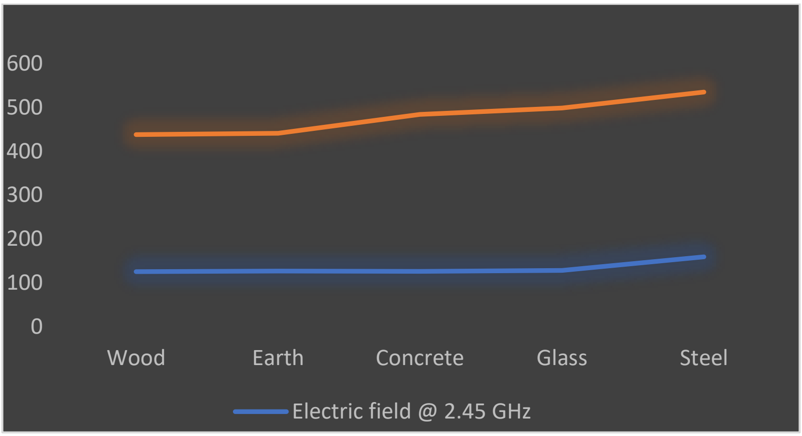

Figure 7. Trend graph of maximum Electric field (V/m) at different frequencies

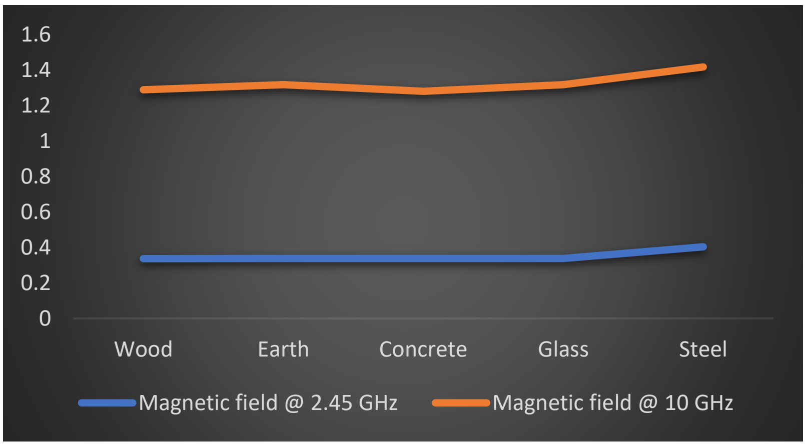

Figure 8. Trend graph of maximum Magnetic field (A/m) at different frequencies

Far-field pattern provides a visual representation of the radiation pattern. The radiation pattern was plotted to depict how actual radiation is formed inside a building space and which confirms the simulation value. Figure 9 depicts the radiation pattern for glass and wood at 10 GHz, and it can be seen that glass provides more scattering of EMR than wood.

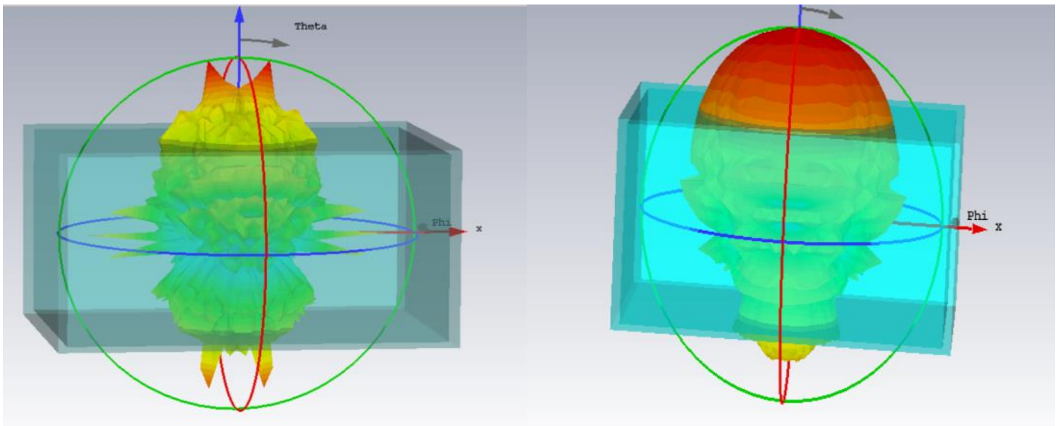

Figure 9. Radiation patterns of glass and wood at 10 GHz

Besides evaluating the EMR dissipation due to materials, shielding effectiveness may also be calculated for design purposes. Shielding effectiveness informs about the capability of the building material to block away from the incoming radiation. However, blocking away all radiation must be carefully ascertained as this may increase the EMR load on neighbouring buildings. For example, since simulation showed that steel had very high EMR even with increasing distance from the wireless source, it may be ideal to keep it as exterior building envelope and wood or low EMR based material inside the interior space.

4. Conclusions and Further Research Directions

The study investigated and analyzed the proliferation of EMR by most common building materials inside a building space. CST simulation software was used to design and perform the simulations to quantify both electric and magnetic fields. The smart device, a laptop was used to quantify EMR by different building materials. Upon assessing the results, it was revealed that building materials also play an essential role in increasing or decreasing EMR in buildings along with the frequency of the operating device. From this study, it was concluded that wood and earth gave a lower EMR and exhibited a much better dissipation throughout the interior when compared to concrete and glass. Further, steel gave the maximum EMR with a very lower attenuation of value, which implies the person in a steel building, is exposed far more than in other types of building material. The study overall recommends that there is a need to adequately select building materials in order to reduce EMR in buildings.

This was a nascent approach to determine and quantify several parameters such as electric, magnetic field and radiation pattern of a building. Therefore, several studies can be done further to understand how different building factors affect EMR produced in a building. Similarly, building geometrics and composite building materials can also be analyzed. Another such study can involve a plethora of EMR from multiple smart and IoT devices and their impact on humans.

One of the main limitations of this study was that although a CST simulation gives reasonable accuracy to quantify EMR in building models and can be even used for hypothetical cities, it would require heavy computational resources which is expensive to procure and is available with advanced research centre. The main reason for this problem can be attributed to the fact that as mesh cells for transient solver exclusively depend on the frequency used, billions of mesh cells will be generated that need to be used to get accurate results.

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Conflicts of Interest: The authors declare no conflict of interest.

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Session 10:

Building and Architecture

Towards Achieving SDGs in Social Housing in the UAE: From Conventional to BIPV Houses

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Abstract: The United Arab Emirates (UAE) has tailored its own local agenda for realizing Sustainable Development Goals (SDGs) by 2030. This Agenda includes providing clean sustainable energy and achieving sustainable communities. In accordance with these efforts, this research aims at, first, exploring an appropriate method of integrating photovoltaic panels in existing and future social single-family housing in the UAE without compromising the architectural style and the identity of the original designs. Second, it aims at assessing the sufficiency of the generated electricity through this proposed Building Integrated Photovoltaic (BIPV) system. A frequently developed single-family house model in social housing projects in the UAE was selected to undertake the research investigations and the most suitable architectural elements of its envelope were defined for accommodating the integrated PV panels. Afterwards, a complete set of to-scale BIPV panel designs tailored to fit with the defined architectural elements of the selected house was prepared. The dimensions and areas of the BIPV panels were defined in these designs based on their selected type. After considering the efficiency of the selected type of the BIPV Panels and figuring out the expected system losses, the PVWatts Calculator was used for simulating the expected electricity output in kilowatt hours (kWh) for the four main orientations of the house as well as the overall average electricity output. The results of the yearly electricity output were very close regardless of the orientation of the house with the total average output exceeds the estimated yearly average electricity consumption of this house model. This is obviously indicating the potential efficiency of the proposed BIPV system, especially with the continuous decrease in the capital cost of the PV panels and their increasing efficiency. The proposed BIPV system might be also considered as an efficient alternative to the currently applied rooftop PV solutions in the UAE.

Keywords: Sustainable housing; Social housing; SDGs; Solar Energy; BIPV; UAE.

1. Introduction

The United Arab Emirates (UAE) is experiencing a rapidly increasing demographic and economic growth with a parallel increase in the demand of water and electricity. The conventional source of energy generation in the country is based essentially on fossil fuel, which has serious environmental impacts [1]. The UAE is considered among the highest energy consumer countries per capita as in 2013 the demand of electricity usage reached 105 billion kilowatt hours (kWh) with about 9% expected annual increase in energy demand as the economy continues growing [2]. Buildings in the UAE are consuming about 80% of the country's energy. As a result, the federal authorities have set some initiatives and regulations that aim at achieving more efficient energy consumption in buildings [3]. For example, one of the main pillars of the National Vision 2021 in the UAE is to increase the contribution of clean energy and implement green growth plans [4]. Moreover, three main sustainability programs have been launched in the last decade in Abu Dhabi, Dubai, and Ras Al Khaimah. Launched in 2009, *Estidama* (which means 'Sustainability' in Arabic) was the pioneering sustainable building initiative in Abu Dhabi Emirate. Estidama implements a rating system in the new buildings to ensure realizing sustainability measures. In Dubai, another building rating system called AL *Sa'fat* (meaning 'Palm tree benches' in Arabic) is recently implemented. It firstly targeted governmental building in 2011 then it became a mandatory for all new buildings in 2014. The measures of the initiative ensure that the building is constructed and operated in a sustainable manner [5]. Ras Al Khaimah Emirate followed the same steps and devised its *Barajeel* (traditional wind towers in the region) rating system for sustainable buildings.

On the same sustainability track, the UAE is taking local actions regarding realizing the Sustainable Development Goals (SDGs) that were launched by the United Nations in its 2030 Global Agenda. This Agenda aims at enhancing the living condition through 17 different sectors including affordable and clean energy, sustainable cities and communities, and climate change actions [6]. The UAE has developed its own local 2030 Plan to meet the SDGs [7]. In this local Plan, considerable efforts have been directed towards providing clean sustainable energy where mega scale projects have been either fully developed or are under construction to produce clean energy for buildings. For example, Shams (Sun in Arabic) 1 project in Abu Dhabi has the capacity to feed the national grid with 100 Mega Watt (MW) that is enough to operate about 20,000 homes. Also, the Concentrated Solar Power (CSP) project in Dubai, which has a capacity power generation of 150 MW, is expected to operate its first phase this year (2021). A third mega project is Mohammed Bin Rashid Al Maktoum Solar Park in Dubai that will be completed by 2030, and it is planned to increase its generated power from 1,000 MW in 2020 to 5,000 MW by 2030. More other projects are being constructed to implement the country's vision for the provision of sustainable energy resources [8].

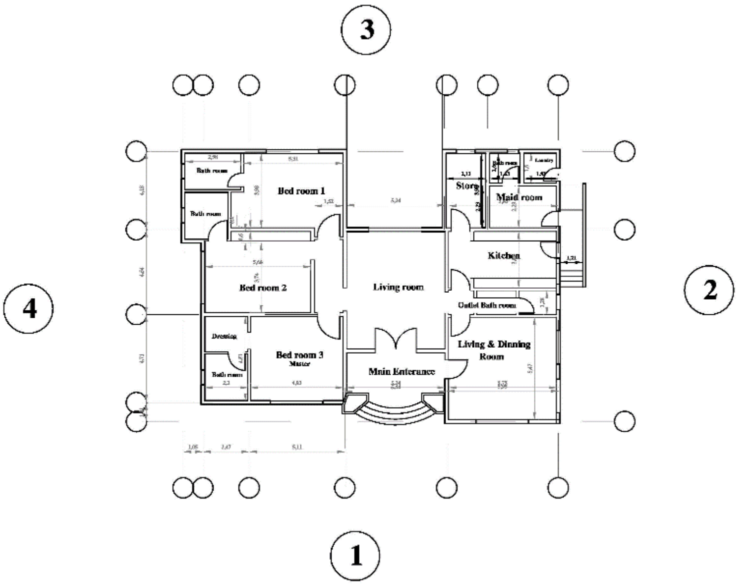
In line with these efforts for meeting the SDGs requirements in the sustainable energy production and consumption sectors in the UAE, this research is exploring the feasibility of utilizing Building Integrated Photovoltaic (BIPV) system in single-family social housing, which forms a major portion of the building sector in the UAE. While contributing to the country's SDGs 2030 Plan, this investigation aims to blend the architectural identity with the technicality of solar renewable energy in a way that achieves both environmental and socio-cultural sustainability in existing and new single-family social housing projects in the country. The importance of this research is affirmed by the fact that the exiting stock of social housing in the UAE is not receiving enough attention regarding sustainability that it deserves as most of the efforts are directed towards new housing projects. Actually, the exiting and the new mass social housing projects, mostly single-family houses, constitute a significant chance for meeting the country's SDGs 2030 Plan if the BIPV succeeded to offer reliable energy outputs. While providing electricity from a renewable and pollution-free source, and unlike the limitedly applied rooftop PV panels systems in the UAE, the BIPV has the advantage of avoiding the limitation of locating the PV panels over the roofs of the houses. It rather depends on integrating the PV panels with the architectural elements of the envelop of the house. Thus, it is freeing the roof space of the house for various domestic uses. In addition, the BIPV systems are easier for the households to maintain and clean with simple cleaning tools if compared with rooftop PV panels.

Giving the concern about the limitation of achieving the optimal tilt angels for the PV panels in the BIPV systems, this could be compensated for when these are associated with other implemented passive measures for decreasing Air Conditioning demands, as the main source for energy consumption in the housing sector in the UAE. These passive measures, which is out of the scope of this research, includes for example, increasing the envelop insulation of the house, adding shading devices above windows, implementing evaporative cooling techniques, and even considering the proper house mass orientation. In this regard and besides its role in generating electricity, the BIPV systems also work as climate screens for the outer building envelop. Therefore, the BIPV systems could provide additional savings in Air Conditioning loads, in addition to reducing the electricity costs [9]. On the other hand, the BIPV market as a segment of the overall PV market is experiencing a worldwide rapid growth, which has caused a reduction or redefinition of national support schemes for the utilization of solar energy in buildings in many countries [10].

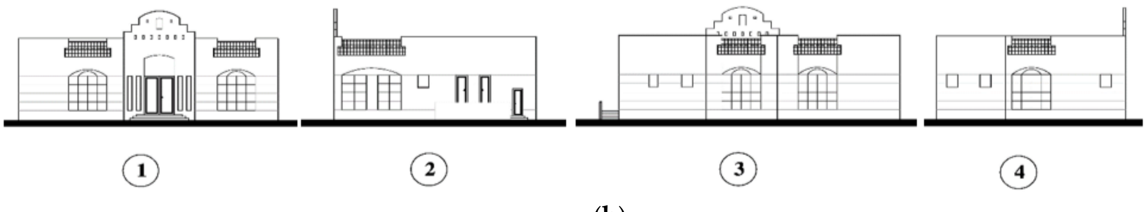
The main objective of this research is three-fold. First, is to develop a BIPV system that integrates the carefully selected PV panel types, in terms of efficiency and cost, with the architectural features and motives of an existing and frequently developed single-family house model of the UAE's social housing in a way that preserve the architectural identity of the house. Second, is to investigate the efficiency of the suggested BIPV system in meeting most, if not all, of the house electricity consumption demand. This would make the house a self-sufficient in energy through producing its own electricity need from its own BIPV sustainable and clean energy system. Third, is to briefly estimate the expected savings in the electricity bill of the selected house due to the installation of the suggested BIPV system.

2. Research Method and Procedures

A commonly developed one-floor single family house model by the Sheikh Zayed Housing Program, the chief federal social housing provider in the country, was selected to integrate the PV solar panels to its façades producing a customized BIPV system. The built-up area of this 3-bedroom house is approximately 220 m[2] and it is designed to achieve the thermal insulation requirements by Estidama including the 20 cm self-insulated Concrete Masonry Unit (CMU) external walls, the 5 cm thermal insulation in the roof, and the double-glazed windows. All of these components of the selected house envelop are satisfying the required U-values as set by Estidama. The house is designed with traditional inner spaces functions and spatial distribution that respond to the Emirati socio-cultural values. Externally, some traditional architectural motives are used including arches and canopies. Figure 1 shows simplified developed CAD drawings for the Ground Floor plan and the 4 façades of this house model.



(a)



(b)

Figure 1. The GF plan a), and b) the 4 façades of the selected house model.

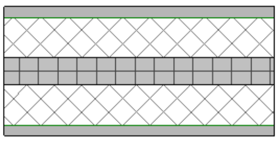
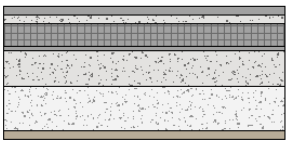
2.1. Developing the house 3D BIM Model

After developing the plan and the façades into to-scale CAD drawings, a 3D Building Information Model (BIM) of the house was developed using the Revit software. This permitted undertaking the electricity consumption simulations for of the house and later the integration of the BIPV panels with its façades. Figure 2 shows rendered views of the developed 3D BIM model of the house.

Figure 2. 3D BIM model of the house before integrating the solar panels.

In this 3D BIM model, the construction materials of the walls, the roof, and the windows of the house were accurately defined based on Estidama requirements through conventional and commonly used materials for social housing in the UAE. The CMU external walls have a total of 24 cm thickness after adding the 2 cm external and internal cement plastering layers giving a total U-value of 0.11406 W/m²·K. Meanwhile, the total thickness of the house roof reached 30 cm, including a 5 cm thermal insulation layer, and giving a U-value of 0.08756 W/m²·K. The windows were modeled as double glazed with aluminum metal framing giving a U-value of 0.6356 W/m²·K. Table 1 shows the specifications of the house wall, roof, and windows components. The simulation of the electricity consumption of the house was done by the Insight plugin in Revit software based on these inputs of the defined specification of the used construction materials. Afterwards, the house plan was divided into Zones to compute the amount of electricity needed for operating the HVAC, lighting, and other electrical equipment in the house.

Table 1. The specifications of the components of the envelop of the house.

	Wall	**Roof**	**Windows**
R-value (m²·K/W)	8.7670	11.4209	1.5733
U-value (W/m²·K)	0.11406	0.08756	0.6356
Layers	*Outer finishing:* - Plaster + paint (2 cm). *Structure core:* - Concrete Masonry Unit (CMU) (7.5 cm). - Thermal layer: rigid insulation (5 cm). - Concrete Masonry Unit (7.5 cm). *Inner finishing:* - Plaster + paint (2 cm).	*Outer finishing:* - Cement tiles (2cm). - Cement mortar (2cm). - Thermal rigid insulation (5cm). - Water damp-proofing (dpm) (1cm). - Lightweight concrete (LWC) (8cm). *Structure core:* - Cast in place concrete slab (10 cm), *Inner finishing:* - Plaster + paint (2cm)	Double panes of glass with aluminum metal framing.
Total thickness	24 cm	30 cm	
BIM Section			

2.2. Developing the BIPV BIM model of the house

The most suitable architectural elements of the envelope of the selected house were defined to accommodate the integrated PV solar panels of the customized BIPV system in a way that preserves the original architectural identity of the façades. These architectural elements included the canopies above the windows and the horizontal ribbons around the four façades and above the main entrance

(Figure 3). The inclined shading canopies above the windows have been extended around the four facades of the house to maximize the collected solar energy while still preserving the architectural motive of the original design. The inclined angle for these canopies was adjusted at 24° to match the latitude angle of Al Ain city in the UAE, where the selected house model has been mostly developed. This tilt angle is the best inclination for the fixed PV panels. The horizontal ribbon of the PV panels had a 90° (vertical) inclination angle, also to preserve the architectural style of the façades, even with obviously expected less efficiency. Consequently, a complete set of to-scale BIPV panel designs for these defined architectural elements of the selected house model was prepared. As discussed below, the detailed dimensions and areas of the PV panels and their types were defined in these designs for each of the four façades of the house. Furthermore, the proposed depth and heights of both the peripheral titled and the vertical BIPV panels were adjusted to prevent self-shading on the PV panels, as much as possible (Figure 3).

Figure 3. The 3D BIPV BIM model of the selected house after integrating the solar panels.

The selected PV module type aimed at maximizing the electricity output while preserving low cost and lightweight. After a market survey, in the time of undertaking the research in 2020, three main products were defined. Table 2 shows the decision matrix of the selected PV panel type. The best product is the SPR 100_46 Mono Solar module as it has the lowest price and weight while giving almost the same efficiency as the other two types. The standard dimensions of the selected panels were considered in the BIPV BIM model (Figure 3) and were also used in calculating the total areas of both the PV 24° tilted and the 90° vertical modules. The total calculated areas of the PV panels on the vertical elements (external walls at 90°) of the four façades of the house reached to 39.86 m^2 and to 166.5 m^2 for the 24° inclined elements (canopies). Accordingly, the overall calculated areas of the BIPV solar panels reached to 40 m^2 on the external walls and 165 m^2 on the tilted shading canopies.

Table 2. The decision matrix of the solar PV panels.

PV Panel Type	**LG Solar LG345N1C-V5 NeON 2**	**SPR 100_46 Mono Solar module**	**LG Solar LG365Q1C-A5 NeON R**
Efficiency	20,1%	20%	21,1%
Size (mm)	1686 x 1016 x 40	1037 x 527 x 46	1700 x 1016 x 40
Weight (kg)	17,1	7,20	18,5
Price (US$)	285.18	279.43	384.86
Picture			

2.3. The calculation measures for the BIPV electricity output

After selecting the PV module type, the PVWatts Calculator, a reliable PV electricity output calculator developed by the National Renewable Energy Laboratory (NREL) of the US Department of Energy [11], was used for undertaking the simulations for the expected electricity output of the suggested BIPV system. The PVWatts calculator uses hourly typical meteorological year (TMY) weather data and a PV performance model to estimate annual electricity production. The calculation was done for the four main façades of the house in the four possible orientations of it (North, South, East, and West), as well as the overall average electricity output. The PVWatts calculator considers the location of the house, the direction (azimuth) of the solar panels, the tilt angle of the panels, the expected system losses (%), the DC system size (kW), and the module type.

As discussed earlier, the location, it was selected to be in Al Ain city, the tilt angle is 90° for the vertical panels on the external walls and 24° for the tilted panels on the spandrel shading canopies. The system soiling, wiring, connection, and availability losses were estimated to be about 11% based on the weather of Al Ain city and the type of connection wires [12, 13]. The weather in the Al Ain city is mainly sunny but it is also frequently dusty with occasional sandstorms causing dust accumulation on the surface of the PV modules, especially the tilted ones. The dust layer deployment on the surface of the PV panels causes a significant power drop for the PV panels if it is not cleaned for a period of 10 days. This makes the suggested BIPV system in this research more efficient in terms of the ease of dust removal, twice a week or so, if compared with the rooftop case.

On the other hand, the high temperature in Al Ain city was another concern. The performance of the PV module is inversely proportional to the module's temperature. For example, a 1°C increase in a crystalline module temperature above its Standard Testing Condition (STC) will typically result in a decrease in its performance by 0.5%. On a polycrystalline panel, the effect of the temperature on the efficiency can be around 0.45 % for each 1°C increase. In a monocrystalline panel, like that suggested in the research, the effect is a bit lower [14]. Therefore, natural ventilation behind the PV modules is an important solution for reducing this decrease in performance associated with high temperature. As for the appropriate ventilation gap, an experimental test was conducted to prove the effect of natural ventilation on the efficiency of the PV panels in which three PV models were examined, the first one without ventilation, the second with a 10 cm ventilation gap from the supporting surface, and the third one with a 50 cm gap. The comparison results, as shown in Table 3, indicated that the best solution is to leave a small gap between the building surface and the PV panel.

Table 3. PV power variation and efficiency for different ventilation spacings [14].

Case	Climate	Efficiency	Power [W]	Power variation [W]	Power variation [%]
Without ventilation	Cold	13,29	129,25	-5,75	-4,26%
	Temperate	12,33	119,89	-15,11	-11,19%
	Warm	11,76	114,38	-20,62	-15,27%
With I0 cm ventilation	Cold	14,88	144,69	+9,69	+7,18%
	Temperate	13,90	135,17	+0,17	+0,13%
	Warm	12,78	124,26	-10,74	-7,96%
With 50 cm ventilation	Cold	15,05	146,42	+11,42	+8,46%
	Temperate	13,86	134,81	-0,19	-0,14%
	Warm	12,67	123,20	-11,80	-8,74%

So, it is not beneficial to have a bigger gap between the surface and the PV panel for the provision of natural ventilation as the effect of heat transfer by radiation between the two surfaces can be neglected and the only problem is air circulation in the gap if it is not well designed. Leaving a wider gap would also increase the cost of the installation of the BIPV system where more construction materials and higher deadloads would be required [14]. Accordingly, in this research, a gap of 10 cm between the PV panel and both the canopies and the external wall surfaces was considered for the designed BIPV system. This simple natural ventilation technique would help avoid overheating problems and hence allowing more produced electricity making the BIPV system more profitable, albeit with a slight increase in the investment cost due to considering this ventilation gap while supporting the PV modules.

The DC system size was calculated two times for each façade of the house, one for the tilted panels on the canopies and another one for the vertical panels on the walls, based on the following equation:

$$\text{Size (kW)} = \text{Array Area (m}^2) \times 1\ \text{kW/m}^2 \times \text{Module Efficiency (\%)} \qquad (1)$$

Finally, the solar PV modules were assumed 'Connected in Series' where the output voltage is the sum of all modules voltages and the output current remains as the module current. This is because the aim is to achieve a higher voltage grid connected system [15].

3. Results

The results below present the Energy Use Intensity (EUI) simulation results for the BIM model the house using Revit Insight and the estimated annual electrical energy consumption for the selected house. The results also present the calculated electricity power produced by the designed BIPV system for each of the house's 4 façades in the 4 orientations (N, S, E, and W) and the overall average electricity output.

3.1. EUI and annual energy consumption of the selected house

Figure 4 below illustrates that the average annual EUI is about 265 kWh/m²/y for the selected house. Therefore, the total energy needed for the house equals this EUI value multiplied by the house floor area of 220 m². This results in estimated energy consumption of about 58300 kWh per year. As expected, most of the energy is consumed in cooling (57%) (Table 4).

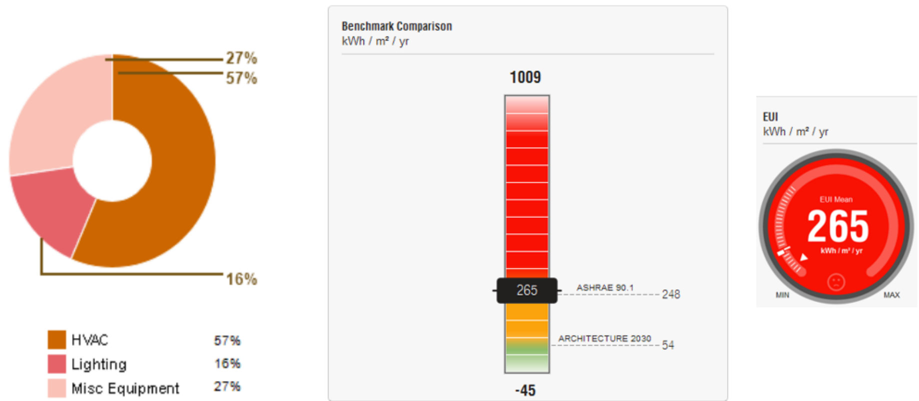


Figure 4. The EUI result for the house from Insight simulation.

Table 4. Estimated annual EUI in kWh per each source of consumption in the house.

Source of Consumption	Energy use (kWh)	Percentage %
HVAC	25,006	57
Lighting	7,152	16
Misc. Equipment	12,075	27

3.2. BIPV watts outputs

Table 5 below shows the PVWatts calculation results of the estimated yearly electricity output in kWh of both the tilted (24°) and the vertical (90°) modules of the BIPV system for the different 4 possible orientations of the house main entrance's façade (N, S, E, and W). This meant to record the electricity output of the BIPV system modules in each façade which will be affected by the architectural configurations of the canopies and the external walls, as per the house architectural design. The results were very close regardless of the orientation of the house as defined by its entrance's orientation (N=60,070, S=59,690, E=60,300, W=60,720 kWh/year) with the total average output of about 60,196.5 kWh per year.

Table 5. Yearly electricity output in kWh of the BIPV modules for the 4 house façades and different house orientations.

House Orientation 1: *Entrance at North*			
Façade	**Tilt (kW/h)**	**Vertical (kW/h)**	**Total (kW/h)**
North	11,251	1,398	12,649
East	10,930	1,226	12,156
South	19,258	2,098	21,356
West	12,727	1,178	13,905
Total (kW/h)	54,166	5,900	**60,066**
House Orientation 2: *Entrance at South*			
North	14,097	890	14,987
East	12,537	1,145	13,682
South	15,370	3,296	18,666
West	11,095	1,260	12,355
Total (kW/h)	53,099	6,591	**59,690**
House Orientation 4: *Entrance at East*			
North	10,573	537	11,110
East	13,341	2,980	16,321
South	12,592	1,355	13,947
West	16,969	1,951	18,920
Total (kW/h)	53,475	6,823	**60,298**
House Orientation 3: *Entrance at West*			
North	9,217	575	9,792
East	16,716	1,897	18,613
South	14,444	1,267	15,711
West	13,543	3,064	16,607
Total (kW/h)	53,920	6,803	**60,723**

Overall Orientations and Total Average				
Entrance at East	**Entrance at north**	**Entrance at south**	**Entrance at west**	**Total average (kW/h)**
60,298	60,066	59,690	60,723	**60,196.5**

The most generated electricity was from the BIPV modules in the South, then West façades. As expected, the energy yield of the 90° modules fixed on the house's facades produced the lowest electricity power and showed wide variations. This is because the 90° angle PV modules are more affected by the seasonal changes of the solar altitude. But on the other hand, the soiling losses on these modules are usually lower than 1% [16]. The total average of the estimated electricity output from the whole BIPV modules reached about 60,197 kWh/year which exceeds the 58,300 kWh estimated yearly average electricity consumption of the tested house model.

4. Discussion

The results of the yearly electricity output of the designed BIPV system for the selected house model obviously 'theoretically' indicate the efficiency of the proposed BIPV system. This efficiency is expected to increase further in the future when considering on-going increase in the efficiency of the PV panels and the future continuous decrease in their initial costs which have fallen over 20% over the past 5 years and is expected to drop further soon [17]. Moreover, these promising results are expected to encourage the local authorities in the UAE to include the BIPV systems into the existing governmental applications and webpages allocated for solar PV residential utilization that are currently only considering rooftop systems [18] [Figure 5].

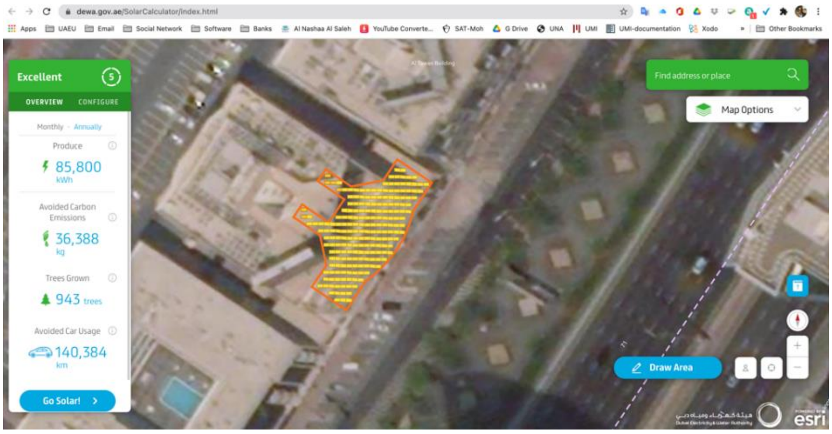


Figure 5. An example of the rooftop PV expected electricity output using Dubai Electricity and Water Authority (DEWA) Webpage for a house in Dubai [18].

From another economic perspective, and to respond to the third research objective, the proposed BIPV system with its passive and simple maintenance techniques will help achieve the building sustainability agenda in the Emirati social housing sector in Abu Dhabi, and other UAE's Emirates. Using renewable and clean energy resources will keep the energy consumption rates in Abu Dhabi Emirate at the defined Green Band level that reflects the ideal average consumption for locals by setting a daily allowance consumption of 400 kWh. Emirati residents are charged only 6.7 fils/kWh within this allowance daily limit, but if they exceeded it, they will be charged based on the Red Band with a higher rate of 7.5 fils/kWh [19]. As shown earlier, the expected electricity consumption in the selected house reached about 58300 kWh/year, i.e., about 160 kWh per day, so it is still in the Green Band for electricity consumption for Emirati citizens. At this consumption yearly average, the estimated cost for locals would equal about 3906 AED per year, when calculated at the subsidized rate of 6.7 fils/kWh. Meanwhile, this cost would go extremely high if the house is inhibited by non-locals with much less subsidization, if any, at a rate of 26.8 fils/kWh, i.e about 15,624 AED per year.

After applying the BIPV system, the cost of electricity consumption of the selected house will dramatically drop as the house will not only satisfy its energy needs, but it would supply some electricity to the national grid. As calculated above, the expected output electricity from one house equals about 60,196.5 kWh/year. If this is deducted from the assumed electricity consumption of 58,300 kWh/year, then the cost will be in a minus figure of - 127.0 AED/year (- 1,896.5 KWh/year x 6.7 fils) when this excessive amount of 1,896.5 kWh is sold out to the electricity provider with the same subsidized rate.

5. Conclusions

A simply designed system of PV modules carefully integrated with the architectural components of the external envelop of a commonly constructed single-family social housing model in Abu Dhabi Emirate was a successful BIPV solution. The designed BIPV system seems a promising alternative to the current rooftop PV solution in providing renewable clean energy resource for covering the electricity consumption of the large exiting stock of social housing as well as new housing projects in the UAE. The customized BIPV system has managed to 'theoretically' produce electricity that slightly exceeded the expected yearly energy consumption of that house. Even with the vertical 90° positioning for some PV panels in the suggested BIPV system, the overall performance has been satisfactory. Therefore, the BIPV solution could be considered better than the conventional rooftop PV panels solution in two aspects. First, it clears the house's roof for other domestic activities such as laundry and social gathering. Second, it allows the residents to easily clean the PV panels from accumulated dust that used to be a major problem that increases the PV system soiling losses in the UAE. This is besides being integrated with the traditional architectural design motives of the house façades in a way that might inspire and encourage other households to transform their houses similarly, especially if some governmental assistance is provided through, for example, partial covering of the capital cost of the BIPV system, payment for it in easy installments, and/or exempting the BIPV systems form the applied Value Added Taxes (VAT).

On the other hand, the suggested BIPV system could be integrated with the existing Dubai's and Abu Dhabi's PV simulation applications that are available for the Emirati public in the two Emirates to give the opportunity for the residents to select between the rooftop PV solution and the BIPV one, instead of the rooftop solution that is only currently available for them. The BIPV system is also applicable to new single-family social housing projects with the same applied method in this research that takes different possible orientations of the house mass into consideration. Mutual shading from surrounding houses should be considered in the design of these new housing projects, as they have been in the existing projects, where 3 to 4 m setbacks from the sides and the back, and 4 to 6 m in the front would be sufficient to prevent this mutual shading effect that decreases the efficiency of the BIPV system. All that makes the suggested transformation of the exiting conventional social housing stock into BIPV one, a viable step towards meeting the challenges associated with the UAE's 2030 SDGs Local Agenda, especially in the areas related to clean renewable energy and sustainable communities.

For further research, the results of the simulation and calculations conducted in this research are to be validated through actual transformation of an existing house model in one of the social housing projects. Also, as most of the estimates for the capital cost for installing solar PV systems are for rooftop systems, more accurate cost estimation specifically related to BIPV systems is required and should be continuously updated to reflect the recent figures in the local and international PV markets.

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Adaption of a Tropical Passive House as Holistic Approach

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Abstract: Based on the common Passive House role model, the paper elaborates and focuses on distinctive elements that can assist to pave the way for its urgent tropical adaptation on the way to combat climate change by 2050. Several attempts have been made in tropical countries to conduct green mock-up research on which parameters can better withstand the heat and humidity. Walls, windows, roofs, and even shadings have been tested in mainly so-called contrived experiments. The challenge of a tropical holistic Passive building is to bring ALL those relevant parameters into play in different seasonal and weather situations whilst expelling the interference of the hot outside air. In principle, this is happening anyway for most commercial buildings and Passive Houses in all other hemispheres alike, but it is not common for tropical residential building strategies which are in the focus of this paper. Based on this integral approach in Malaysia with sidelines of Singapore, the author can refer back to a database of 250 days. He cross-examined mainly data out of 4 typically hot months in the year 2017 in detail with 3 adjacent real mini-residential Passive and 1 "red" House(s) with the same positioning for ambient temperature and the most vulnerable part of the building envelope which is the window.
Out of the real hot months studies we receive indications that the well insulated, basically almost airtight and optimum shaded building with ventilation is cooler in almost all cases during the wet and the increasing number of transition periods. It is the most humid one, due to the lack of a moisture barrier which was not timely yet. The Passive Holistic design will work best i.e. energy efficiently in a combination of a) nighttime active usage of green cooling (i.e. cross ventilation or water-based cooling ceilings). During b) daytime, among other related modules looked in, cooling is based upon passive envelope features PLUS shading. For various reasons, compared to buildings in the colder hemisphere (such as tropical thin building envelope and no triple glazing), the payback of the Tropical Mass Residential Passive House comparing OPEX and CAPEX is reasonable with 5-6 years.

Keywords: Building Resilience and Adaptability, Energy Efficient Building Materials, Climate Change, Thermal Comfort, Testing of Passive Houses

1. Literature Review: Passive Technology and Holistic Passive Houses

In tropical countries is has become common to talk compassionately about “passive design” and “passive technology” [1]. These buzzwords ignore or suppress the fact that its output, a state-of-the-art Passive House resembles a team or an orchestra: We as builders or researchers are like its leaders or conductors, acknowledging that the ensemble is only as strong as the entirety of its modules. Conversely, passive technology patchwork is probably just halfway better compared to conventional houses. E.g. to install windows that comply with the Passivhaus standards, if other constitutive parts of its 5-8 core modules are missing, is no climatic breakthrough yet. A passive house works only as good as it should, when all its modules have a chance to work synergetically together. Accordingly, we will state that it is not so necessary to study single modules, but the whole compound of different Passive Houses, benchmarked against each other and a typical conventional “red” building.

To illuminate the lower significance and effectivity of testing single modules can be demonstrated by laboratory experiments with the isolated testing of all 4 basic parameters: the walls, the roofs/ ceilings, floors and the windows including shades.

Figure 1: Comparison of coated vs. uncoated Windows in a typical Glasshouse Experiment

If anyone intends to dwell in a living space surrounding yourself with glazes, the sun's tropical radiation will not kill the person, but diminish the heat by the air condition fully running. For the occupant, hence it will pretend that the hotness is not present. But how many "green" certified modern glazing palaces especially in commercial buildings are still constructed that way?

Isolated single experiments like these rather demonstrate typical glazing palaces. A Windows-Wall Ration (WWR) of up to 100% windows may be seasonally fine for winter gardens in the cold hemisphere during transition periods seeking any radiation. When an energy saving compared to conventional windows after 7 typical observed sunny-cloudy days of 53/76= 30% was reported [2], that might give a legitimisation and rise for glazing façades. However, they do not show the real energy saving potential of a Passivhaus with 70-80% when reasonably smaller coated windows plus smart shadings are two synergetic modules of the whole tropical passive design [3]. With other words, the question may arise, why are professionals still looking for 30% saving when much more is at stake here [4]? Maybe scientists are conditioned that way or they serve the façade industry.

Of course, first of all a wall provider wants to sell walls, as a windows provider glazing. With the exception of window frames providers, who depend on windows, not much synergy can be found. Over 8 years of visiting green building suppliers in South East Asian green expos, only one booth presented the Passive House as a whole, but it turned out that the exhibitor was just visionary on one hand, marketing his conventional insulation material on the other. Asking a shading firm to talk with a smart devices provider, stopped already after their GMs having exchanged their name cards. That is why this paper starts with a non-technical issue which is a severe lack of communication of potential passive partners, just to talk to each other, and go for strategic partnerships. The PV-seller should talk to the wall provider, and everyone else in the potential passive house premier league should play together as a team, to make the overall idea of a fast payback Passive House work.

Hence, the testing of the Holistic "original" Passive House Standard does not consist of technological single "design" solutions of green walls, windows, roofs/ceilings or floors. Like in the orchestra above, the violin cannot replace the playing of the trumpet or the drums. It resembles the research initiated here, comprising of the *entire* building, which then as an output factor stands for its measurable *energy efficiency, indoor air quality including thermal comfort* [5]. Whereas isolated passive design solutions remain patchwork, Passive Houses in their totality with all their core modules integrated at the same time require very little energy to achieve a comfortable temperature all year round. They are making conventional heating and air conditioning systems more obsolete. According to those who would like to see passive technology also happen in the neglected tropical belt [6], prior to our own research we will now derive the adapted modules for tropical passive houses as framework. They are based on the original passive house approach, but will break the rule a bit as they might go beyond the original 5 core modules of its founders in the 1980s and 1990s. They are not at all obsolete, as they represent the renowned smallest joint toolbox for the ensemble of a Holistic Passive house technology [7]:

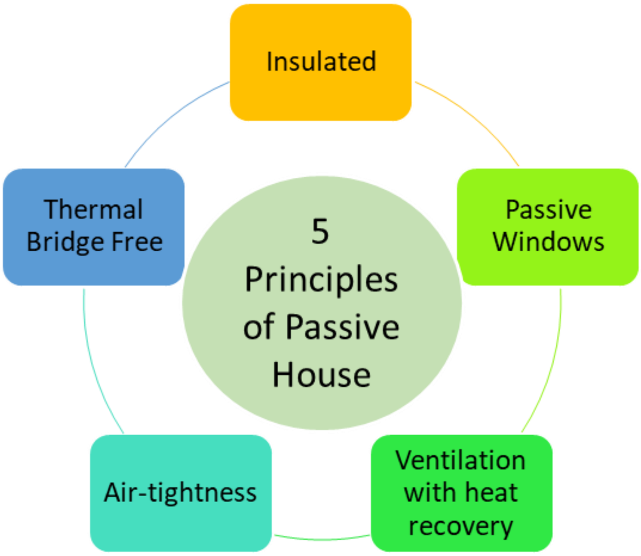


Figure 2: The Principle of 5 Elements of an original (Non-Tropical) Holistic Passive House in all Climates? [8]:

2. Tropical Holistic Passive House - a System of 7-8 interwoven Core Modules

The elements and benchmarks of a tropical Holistic Passive House go a bit beyond, not because we wanted to break with a rule or a dogma, but because this is how our research has evolved from our experiments. They have been elaborated on with the initiative of an international architecture Passive House firm from Munich / Germany. Basically they should adhere to a new entirety (totality) with the following 8 *revised* core modules of 5 real passive, and 2-3 active elements as well:

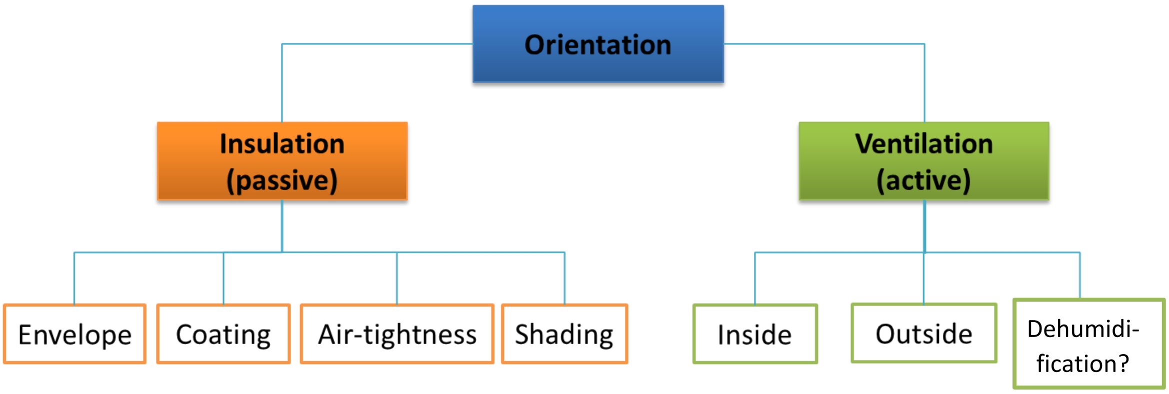
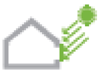


Figure 3: Passive and Active – Family Tree of the 7-8 Tropical Passive Building Core Modules

The core modules and benchmarks of a tropical Passive House with the 7-8 modules of 5 passive and then 2-3 active elements are not exactly contradictory to the original 5 criteria, but they add on to the existing ones.

Table 1: 7-8 Core Modules and Benchmarks of a Tropically Adapted Passive House

No	Element	Description
1.	 Building Orientation	Depending on the latitude of the location, in the design stage buildings the orientation will be optimised by minimising or eliminating solar exposure through the windows (passive). On islands like Singapore, the most common wind direction can come into play, but does not seem to be always predictable. In most places, relying on the cool breeze, especially during night times, is not enough to achieve residential thermal comfort.
2.	 Building Envelope	Insulated walls, roofs and low-e windows will reduce the external heat penetration including thermal bridges while maintaining the desired ambient tropical temperature range in the interior of the building or room. Double or even triple glazing does not seem to be necessary, because the temperature differential is much lower than for cold countries where this is necessary due to the high differential. Tropical countries better invest into less convective window frames with heat brakes and into shading (no.5) (passive).
3.	 Basic Airtightness	A basically (but not strict!) airtight tropical building envelope with minimized thermal air bridges will prevent infiltration of "default" too hot, sometimes too humid and polluted air, whilst maintaining the desired indoor temperature. Airtightness is not as radical as in countries with sometimes vast differences between the outside and inside temperature. It does not exclude fresh natural or mechanical ventilation from outside if needed (passive).
4.	 Reflective Coating	Outer surfaces of the building envelope are coated with brighter colours which reflect solar radiation to further reduce heat gains into the building. They contribute to lower heat gains through the wall, the roof / ceiling and the windows (passive).
5.	 Shading	External shading tools (fixed or movable) will stop direct solar gains inside the building or the room through the windows. Different compared to cold country passive standards which have been adapted to the tropics, reducing the heat gain is not about double, triple glazed sun protection windows which is considered as not necessary for the small temperature difference between the real outside and the desired inside temperature (passive with a bit of smart active for flexibly opening the shades to let natural light inside the building when direct radiation is absent).
6.	 Dehumidification?	Considered just as a comfortable option for enclosed buildings or rooms, but not applicable for naturally ventilated ones. In these cases, built-in energy recovery systems will dehumidify the supply air, reducing latent cooling load and ensuring indoor air - comfort and at certain humid periods with longer night time humidity of 90% prevention of mould growth (passive or active).
7.	 Efficient Ventilation	A constant supply of fresh air from outside keeps the indoor environment healthy. If mechanical fans are used, in polluted areas the outside air should be filtered. In conjunction with A/C during night times in some places like tropical highlands the air can be pre-cooled to gain also cool air before penetrating the interior. The ventilation system is different to the colder hemisphere: it maximises the air stream during certain night times when it is cooler outside (active).

8.	 Air Movement	Type 1: Stand, table or ceiling fan systems preferably in combination with 7. allows high set-point temperature for cooling systems while providing individualised thermal comfort for occupants by reducing the ambient felt- temperature. Type 2: Air supply for the A/C which should be often minimized as the cooling pushes in with 11 oC which is uncomfortable like a draught in the colder hemisphere (active).

This is how basically all these 7-8 core modules work together to create and maintain a decent indoor air climate in tropical climates:

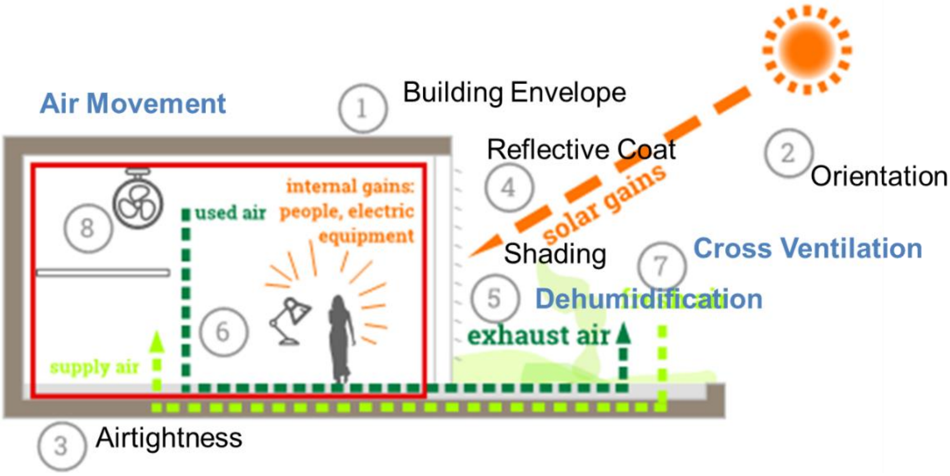


Figure 3: Interplay of 7-8 Core Modules of a Tropical Holistic Passive Design (IPHA, 2016) [9]:

3. The Emergence of Additional Module 9 and 10 – not only for tropical Passive Houses

These 2 add-on modules show that a mere passive house without active elements (namely air movement and cross ventilation in module 7 and 8) is doomed to fail. Whereas their "only" purpose in countries of the Northern hemisphere might be a minimum of fresh air supply, tropical countries' application need also cooler air (especially during the night time) and healthy air in cosmopolitan areas where air pollution protection is a much greater threat. Module 5, however, contradicts the imperative of fresh air intake, as drawing in outside air will always increase the relative humidity, especially during the night time. In addition to the potential module no. 6, two more novel "active" elements can be brought in: no 9. Building automation, and no 10. the Passive house "plus" engineered in part or fully with renewable energy, need to be considered more and more with the grid parity [10].

Table 2: Modules 9 and 10 of a Tropically Adapted Passive House

No	Element *(Cont.)*	Description *(Cont.)*
9.	Building Automation	A building with all technical services connected, in order to achieve an optimum level both of comfort and smart green efficiency. It is a type of smart building that is able to autonomously adjusts itself to those needs better than inverters (e.g. if the set point of ambient temperature where occupants are sitting, standing or sleeping, is chosen at a reasonable 28.6 °C the temperature shall always be 28.6 °C). It echoes in the extended definition of ‚Passive', where the automation system is active, but works in the background. In so doing, Conventional Passive House

		principles in combination with Digitalization will create Passive House as Building 4.0, as an enriched solution for the future.
10.	Renewable Energy	A building that deploys renewable energy whenever possible and feasible, such as, first and foremost, solar photovoltaic (PV) and solar thermal. This is considered in the "Passive House Plus" concept of the IPHA. But now as lots of other low or zero energy houses not being passive houses are emerging, despite the fact that especially PV is a trigger for the Passivhaus still being the most energy efficient building on the planet, it does not yet appear as extra module.

Many of us run smart cars run more and more as renewables, why don't we have such buildings as well where we spend 1/3 of our lifetime? Building automation is one name of the smart system. Every °C HIGHER temperature in tropical countries will save on balance around 4-7% of the cooling energy and carbon footprint required (Malaysian Government, 2011). Passive House 4.0 on the other hand, advanced information technology has rapidly digitalized our world and increased the importance of connecting all areas in passive deluxe buildings (bus system). Beyond automated temperature for Triple Green affordable Passive Houses, together with CO2 sensors are the basics for Premium Passive homes. The Passive House Standard 4.0 is the ideal solution. Applicable for all climates, materials, construction methods, designs, technical services it is not limited to a monopolist manufacturer. These Holistic Passive House principles have been fully developed to be adapted for different climates proven to be economical with reasonable payback periods.

The result is a building with all technical services connected, in order to achieve an optimum level both of comfort and smart green efficiency. The occupants as masters technically play a secondary role in controlling the building, by merely stating their needs. The building autonomously does the rest: it adjusts itself to those needs better than inverters (e.g. if the set point of ambient temperature where occupants are sitting, standing or sleeping, is chosen at a reasonable high end of 28.6 °C). It echoes in the extended definition of 'Passive', where the automation system is active, but works in the background. In so doing, Conventional Passive House principles in combination with Digitalization will create Passive House as Building 4.0, as an enriched solution for the future.

Meanwhile, the usage of renewable energy, first of all solar PV and solar thermal, play a vital role, but are often requested as "add-ons" to call the building passive in 3 stages. Classic Passive Houses allow also the less privileged to own or rent a house based on all 7-8 core modules of Holistic Passive technology. Such "triple green" houses are also affordable - resilient to be upgraded to become Plus Passive Houses with renewable energy to safe more operational costs, especially photovoltaic. We decided to go for Plus, running night time ventilation and LED-lights with affordable PV.

Finally, before we shed light on the secrets of Holistic Passive technology and follow the stream of avoiding active elements unless needed, the following table demonstrates likely differences between its cold hemisphere features and its emerging tropical features:

Table 3: Seven Elements of Colder Hemisphere compared with Tropical Holistic Passive Technology

Element	Moderate cold Hemisphere	Equator-near 7 ^{0} Tropical
(1) Windows	Triple Glazing as standard to prevent coldness at a lambda T of up to -30 ^{0} Celsius	Ideal Types: Double layer coated on window pane 2 to prevent heat transfer + Film (if sunlit) with UPVC-frame, or Single coated with UPVC-frame (if fully shaded to avoid convection of 32-36^{0}C of common outside temperature through the windows panes): BUT WINDOWS DO NOT EXPLICITELY APPEAR
(2) Insulation	Different layers of up to 40 cm exterior walls thickness	Green Walls calculated as < 22cm to insulate or fibre (blow, resilient and construction board)
(3) Green Retrofitting	…	Cladding, shutter, overhang roof, outside blinds, IAQ
(4) PV	Mono/Poly Crystalloid producing optimum yield	Higher performances by thin film technology. Parity Grid produced forecast for Malaysia in 2026/27 (cf. Millot, 2013)[i]
(5) Solar Thermal	warm water supply, link PV)	Warm water supply just for wealthier households with a certain market penetration compared to "red" water heaters
(6) Heat Gain e.g. by people/ personal computer in small size rooms	Functional more or less during all seasons except during hot summer days when automated shades are used	Always dysfunctional
(7) Cooling	Exceptional. E.g. terracotta tiles in conjunction with nighttime opening. Geothermal – cold water as slab cooling. A few fans against the slightly increasing numbers of A/C	Smart conventional A/C (or inverter?), outside nighttime "flush" ventilation in non-coastal and certain areas in low altitude, rare cooling ceilings VRF-ventilation systems – rain or well water or heat exchanger [11]:

3. Methodology

We succeeded to bridge the communication problem indicated above, by bringing people as sponsors and partners from different industries for the experiments together. Convincing industry players concerned with walls, insulation or roofs was not difficult. The sponsors that we acquired during green expos in Kuala Lumpur and Singapore were invited to install their module at the site (British-Malaysian Institute at the University of Kuala Lumpur, Malaysia). In future, we told them they might not be selling walls, windows or roofs alone, but could be part of entire buildings based on our blend of Passive House technology. Our entirety approach consisted of the construction of four mainly sponsored mock-up buildings which are; i) Three different tropical passive houses according to the 7-8 modules above and ii) One "Red" building with typical conventional house design. Each of the four mock-ups with dimensions of 2.7 m high, 3 m wide, and 3 m deep were equally constructed as life labs or rooms where at least 2 persons can stand upright, sit comfortably and even sleep inside. Hence, we will not refer to them as “test cells”, as they are real bedroom chambers or even small houses a person could live in. They are not longer laboratories, and are kept so small not only due to financial restrictions. They keep their tiny format to prove or disprove the superiority of passive technology as a whole - without disturbances due to interfering variables in more complex situations with additional different rooms.

Figure 4: 3 Green & Energy Efficient Passive Buildings based on the Passive House design (left) and the (later improved coated) conventional house (right) at the Triple Green Mock-Up Building Park with the same positioning on UniKL’s premises at Gombak/ Kuala Lumpur

The average window-to-wall ratio is 31% each for East, South and West direction, whereas North where the door is located it is 0%. Positioning was identical and shading was almost equal, a few compromises in terms of some high trees’ sun path had to be made due to space restrictions. The PASSIVE HOUSE walls of the coolest house elaborated on below are made of double layer clay bricks with a low U-value of 0.88. Meanwhile, the „RED“ BUILDING portrays the common, typical control unit of a standard low-cost house made of basically sand cemented bricks or concrete. Further details of the design of both buildings are provided in Table 4 below.

Table 4: Architectural design of passive buildings (PASSIVE HOUSES) and red building („RED“ BUILDING).

Mock-Up 3 green PASSIVE HOUSES	Mock-Up „RED“ BUILDING
	
• Almost airtight • High insulation capability walls • Ventilated roof, isolated ceiling • Solar panels for LED lighting • Coated compared to sun protection double-glazed windows • UPVC window frame • External shutters	• Open air (closed for the experiment) • Standard concrete and bricks • Uninsulated roof • Apron with drain • Single-glazed windows • Aluminium window frame • Fluorescent lights

We would like to take note that for the purpose of the experiment we had typically not closed the single glazed windows of the „RED“ BUILDING to measure the impact of the double glazing in the PASSIVE HOUSE. With all windows and doors tightly closed, the ambient temperature and relative humidity of the buildings were measured by data loggers. Meanwhile, the inner surface temperature of the single-glazed of „RED“ BUILDING and double-glazed window of PASSIVE HOUSE was measured by a digital infrared thermometer.

Out of many results over 5 years of study which yet need to be compiled, we just want to point out a few significant results of a 7 days study. We have developed a kind of enzyclopedia data, but are not able to replicate their magnitude within this restricted space. For onward readings, we would like to refer to the comprising ebook [12]. The period for the simulation was from the dry months of March to April 2016 with a total of 7 selected typical tropical sunny-cloudy days (with hardly any significant rain). As so far 2016 is still the hottest year in history, we can still claim that recent temperatures of the global Warming find their echo in our database.

The performance of the tropical residential PASSIVE HOUSE was evaluated based on the following indicators: (1) mean and maximum temperatures of ambient and window inner surface, (2) ***temperature difference ratio (TDR)***, and (3) the percentage of overheated hours based on the sigma / compliance level (measured in percentages). The three variables are adapted from Amos-Abanyie et al. (2013) [13]. The TDR formula proposed by Givoni (1999) [14] is modified in this study as the following;

$$TDR = \frac{(T_{maxout} - T_{minout})}{(T_{maxout} - T_{maxin})} \quad \text{(i)}$$

where T_{maxin} is the maximum ambient temperature, T_{maxout} is the maximum outdoor temperature, and T_{minout} is the minimum temperature outside.

4. Results and Discussions

We will restrict our findings to the comparison of 4.1. the inside ambient temperature and 4.2. the windows (as the most critical and most vulnerable part of a passive house) inner surface temperature [15].

4.1. Inside ambient temperature

The following figures 5 and 6 present the comparison just between the coolest passive building and the red building via time series plots of the *average ambient temperature within a 7-days experiment*. The difference in the range of ambient temperature between these two sets could be clearly seen: Basically, the greenest PASSIVE HOUSE's ambient temperature stays stably below the „RED" BUILDING's by 2-3 °C between the critical daily heat-up times from 10.30 a.m. to 5.30 p.m., and within the tropical residential thermal comfort level. The overheating effect of the ambient temperature above the maximum tropical residential thermal comfort level implies an "Upper Space Limit" (USL) of 28.6 °C as its benchmark. Due to its non-airtightness, the „RED" BUILDING often trails the outdoor temperature. In this particular study, on average the ambient temperature of the PASSIVE HOUSE starts to rise above the USL at 10.30 a.m. while it is much earlier for the „RED" BUILDING around 8.30 a.m. This implies a cooling energy of 2 h which is indicated by the arrows below in the chart:

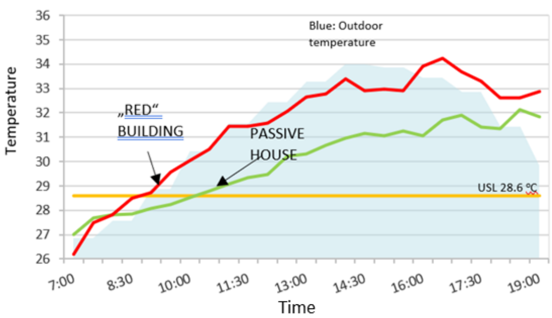


Figure 5: Time series plots of the average ambient Temperature of PASSIVE HOUSE and „RED" BUILDING against Outdoor Temperature.

The predominant hot days with little to no downpour makes the ambient temperature fall outside of the human comfort zone for most times of the day. Thus it requires active cooling measures in both buildings. Nevertheless, the cooling load will be much lower in the 3 PASSIVE HOUSES than in the „RED" BUILDING due to the lower range of ambient temperature and shorter duration of the overheated hours. In order to compare the cooling requirement of the buildings more objectively, the TDR (***temperature difference ratio)*** concept is used and calculated based on the range of outdoor and indoor temperatures between 9.00 a.m. (when the outdoor temperature steps out of USL) and 2.00 p.m. (when outdoor temperature reaches its peak). The TDR values of the PASSIVE HOUSE and the „RED" BUILDING were determined as 1.7 and 8.4 ^{o}C respectively. The much lower value of the PASSIVE HOUSE's TDR indicates the large temperature difference between outdoor and indoor. Therefore it means less cooling and carbon footprint in the tropics with the always low DELTA T (ΔT) between the inside and outside temperature, if we compare to most other climates.

4.2 Windows

Among the 4 parameters that need to be measured in an airtight building to determine the building's reaction as typical transmitters, we find walls, roofs/ ceilings, floors and the windows. The latter are the most expensive and most vulnerable part of the building envelope. Therefore, we will exemplify our study on them. They have all the functions of a wall plus should be able to get daylighting and often visibility of the surrounding like nature or built environment. We did NOT measure U-or other architectural values as mere input variables, but simply the ***IST (inner surface temperature)***. As we made radiation under tropical circumstances by using shutters a herewith *no-go* in shaded Passive Houses, we could fully focus on the rest transmitting convection heat. Conductivity was of no relevancy either, as compared to the "RED" BUILDING with typical air leakages our PASSIVE HOUSE windows embedded in high performing UPVC-frames had no air leakages and thermal bridges from outside to digest and to account for.

Again, we were not interested to investigate the windows' capabilities to defeat the heat alone standing, but to look at windows as one part of the passive house compounds as an entire solution where all parameters are purposely brought into interaction. The following figure 6 shows the comparison of window IST between (a) PASSIVE HOUSE and (b) „RED" BUILDING against the ambient temperature of the buildings. Again, the window IST of the PASSIVE HOUSE in overall is lower than that of the „RED" BUILDING. The windows in the „RED" BUILDING quickly surpass and skyrocket to a higher level after 8.00 am. The highest window IST of the „RED" BUILDING is 33.7 ^{o}C, which is 2 ^{o}C higher than the PASSIVE HOUSE. Furthermore, it is interesting to note that in both sets, the window ISTs are always higher than the base ambient temperature of the building with a strikingly almost similar increasing trends. For example, as shown in Figure 6(b), the 3 dominant peaks of the ambient temperature and window IST of the „RED" BUILDING are at close or exact time intervals which are at 11.00-11.30 am for the first peaks, 1.00-1.30 pm for the second peaks and at 4.30 pm for the third peaks. Thus, even shaded windows could be one of the most critical contributors among building enclosure components that directly affects a building's ambient temperature.

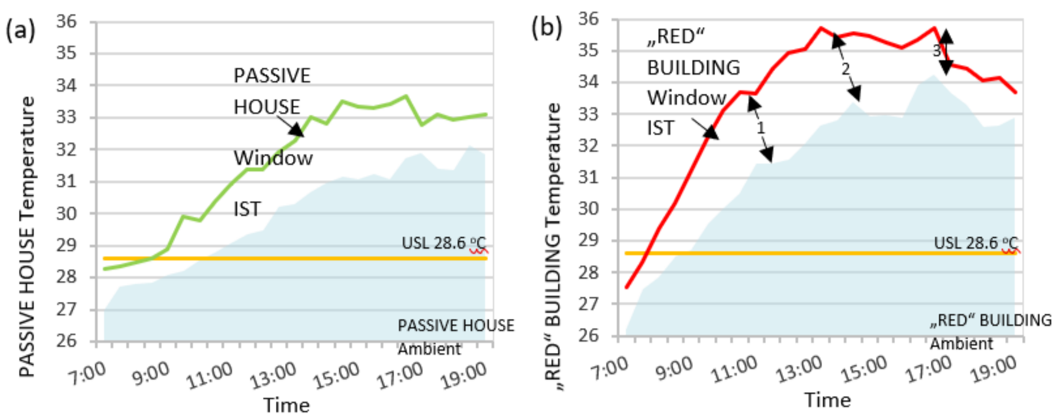


Figure 6: Window IST (Inner Surface Temperature) of (a) PASSIVE HOUSE and (b) „RED" BUILDING against the building's ambient temperature.

Furthermore, the authors measured the occupants' satisfaction level not to exceed the USL temperature levels by calculating the sigma test in stages. Both window ISTs as illustrated in Figure 7 indicate that during dry and sunny days, only 3% for the „RED" BUILDING's single-glazed windows are still in range below the USL. Symbolically just disappointing 11% of the PASSIVE HOUSE's double-glazed windows are in range that shows the little effectiveness even though the windows are professionally tropically adopted. That means during the hotter days, even the expensive sophisticated double-glazed with tinted film could not provide a barrier from heat convection by 89% of the time. This is the fact that can never be shown when the air condition is on during such an experiment, because the actual heat transmission rate of the window never shows. Finally, across the board of all 7 days, Table 5 shows the overall comparison between the PASSIVE HOUSE and the „RED" BUILDING in terms of ambient temperature and window IST.

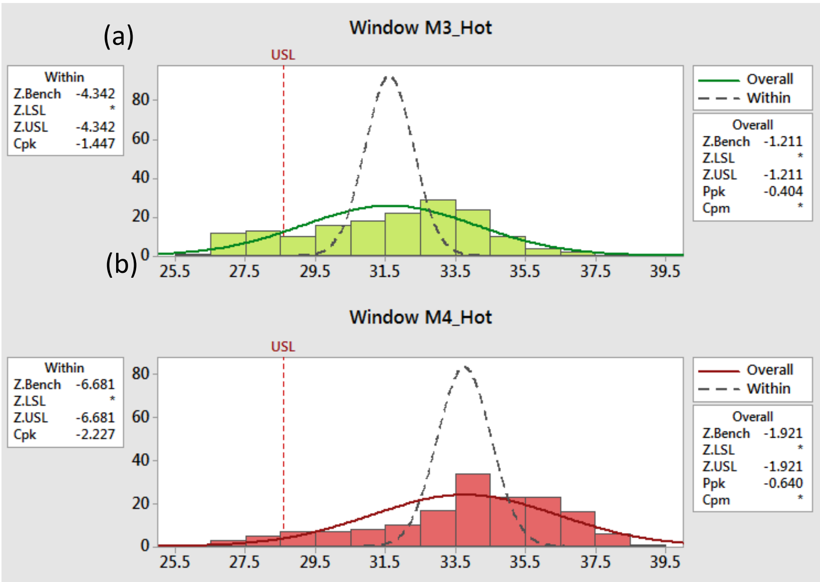


Figure 7: Sigma (customer satisfaction) scores in the 7 days comparison of window IST of the coolest PASSIVE HOUSE and the „RED" BUILDING with 28.6°C upper space limit (USL) benchmark.

As indicated in the percentages above, a Z.Bench of -1.211 means 11% likelihood that the double glazed shaded windows inside surface temperature meets the benchmark, and 1.921 means just 3% for the conventional ones typically left open during the day.

Table 5: Performance of PASSIVE HOUSE and „RED" BUILDING

Building Type/ Temperature (°C)	Passive building (PASSIVE HOUSE)	Red building („RED" BUILDING)
Ambient $_{max}$	32.1	34.2
Ambient $_{mean}$	29.9	31.6
Window IST_{max}	33.7	35.7
Window IST_{mean}	31.6	33.8
TDR-cooling requirement	1.7	8.4
Overheated hours during daytime with still necessary supply of cooling	89%	97%

Based on the results of this preliminary study, against the shortcomings of the or any (!) windows experiments, we received indications that the well-insulated, almost airtight and optimum shaded PASSIVE HOUSE tends to be always cooler than the „RED" BUILDING during the daytime. Under the weather conditions of tropical Malaysia with a residential comfort level of not exceeding 28.6 °C, the passive design will work best in a combination of night time usage of green cooling (i.e. forced mechanical ventilation or cooling ceiling), and daytime airtight plus shaded. If occupants are around, air conditions still need to operate frequently. Needless to say that about 50% of its energy can still be saved by using an energy efficient, inverter-type set-pointed air conditioner at high thermal comfort level or a non-inverter type in combination with a simple smart power interrupter system.

4.3 Calculation of Passive House Energy Balance compared to the conventional House

Apart from our experiments, the energy balance was simulated and calculated by Dr Jürgen Schnieders who is in charge of the duplication and adaption of Holistic Passive house technology with its 5 core modules to all other hemispheres apart from the moderate climate. Hence, the cooling load of our mock-up buildings was compared with Energy Balance Cooling via the PHPP (Passive House Planning Software).

A computer simulation at 24.5 °C set point (starting from 30 °C) under the annual weather conditions of Manila was conducted, as data for Malaysia or Singapore were not yet available in 2016. Even though after 5 years the weather is changing due to global warming, the result in a nutshell is striking: 80% of the cooling energy which again is the main driver for global warming can be saved for potentially air conditioned rooms. Conventional tropical A/C driven room consumes 600 kWh/m2/a, whereas the "green" room will consume only 80 kWh/m2/a. The mock-up buildings which due to resource constraints are admittedly not yet a master piece of perfection at least consume only 200 Kwh/m2/a which means 1/3 of the energy. Especially thermal bridges were still inherent in the installations. But they are real, and if 2/3 of the energy can be saved it is a leap and the rest to go further to the passive room standard is continuous improvement.

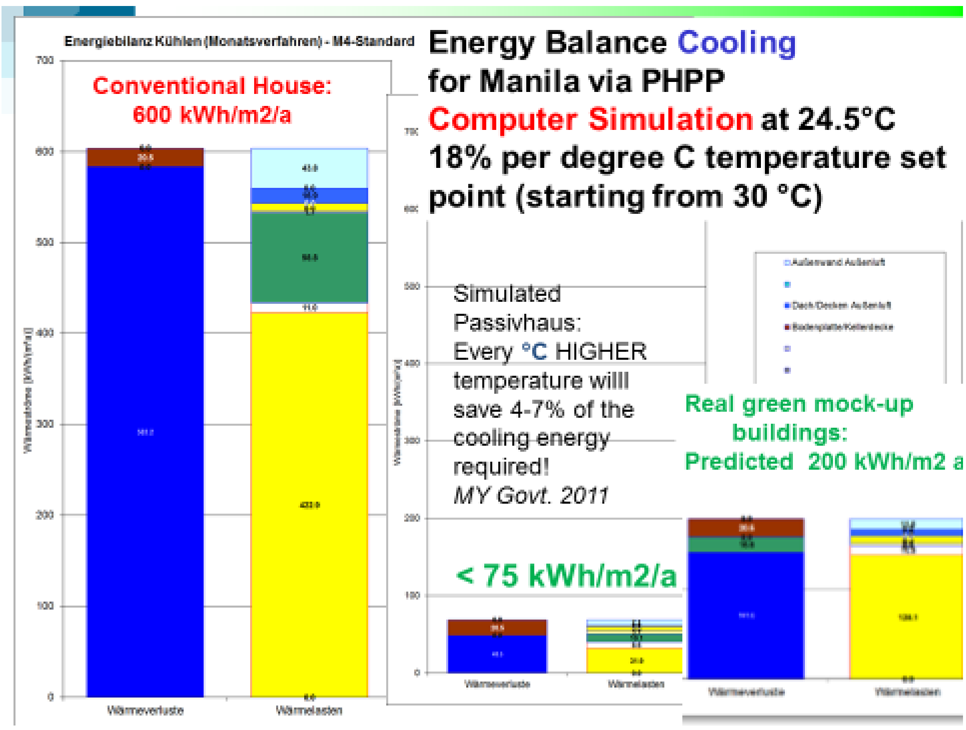


Figure 8: Energy Balance Cooling Simulation for Conventional Tropical House (Left) and Tropical Passive House with PHPP (Passive House Planning Software).

5. Conclusion

Apart from these thermal comfort experiments, further reaching conclusions can be derived from the database. The tropical passive house experiments measuring the entirety of all 7-10 modules for a tropically adapted Passive House showed under the microscope of 3*3m buildings that the cooling load compared to conventional houses can be reduced by about 80 %. If the symbolic set point is a USL of 28.6°C for accepting the highest tolerable warm thermal comfort still without uncomfortable sweating, the saving towards that goal is an energy saving of 27% during typical sunny or sunny cloudy tropical days in low altitudes.

The most important insight that comes out of our study is that this well insulated, basically almost airtight and optimum shaded passive mock-up building with 3 different kinds of systems is cooler in almost all cases during the wet and the increasing number of more rampant transition periods. The holistic Passive House appeared almost always cooler, despite the winding spiral of global warming commonly still cool enough within the range of the higher USL (upper space limit) of tropical thermal comfort compared to its "red" competitor which stands for millions of maladjusted modern dwellings in tropical countries.

The same research pattern accounts for 2/3 of all cases during the 6 remaining months of the "hot" and transition season as well. Designed for people, they appear and turn out to be heat tanks – where we can refer to a real cool alternative. However, in 1/3 of cases under observation during the hot and transition seasons of more than 3 days with no rain interference, the equation of "passive" = "better cooling" derived above could not be proven. Without air conditions OR always summer-like night time mechanical ventilation, the holistic passive building tends to become equally hot as the red building. Due to the heat stack effect, after 3 days without rain interception, the hotness surpasses its building envelope, and so it was seen as even hotter.

It is probably an illusion to believe that in hot tropical countries for billions of occupants an air condition-free future in the yet unstoppable global warming decade of the 2020s is imaginable – unless the building is located in tropical areas of higher altitudes like Karnataka/India or Cameron Highlands/Malaysia [16]. Nevertheless, we will find out in how far their daily usage can be minimized by passive and then including their own active technology of energy saving and using renewables with the 7-10 modules above.

For various reasons, compared to buildings in the colder hemisphere (such as thin building envelope, no triple glazing required), the payback of the Tropical Passive House comparing OPEX and CAPEX reasonably for tropical house buyers is about 5 years. The condition is that it can be established and calculated as a mass product [17].

Only such sellable mass (and still: customised) passive homes in all developed and developing tropical countries can assist to curb global warming with the high impact. Basically, be it an upcoming or be it a retrofitted building, no green & energy efficient alternative of sustainable built environment rather to use the ***holistic*** passive house approach for the masses is visible [18].

Finally, ending this paper with a self-explanatory picture and its brief description will tell more than 1000 words [19]. For the establishment and reputation of Zero Energy Mass Customised Homes (ZEMCH), we can learn from the globe's biggest Passive House real estate area "Bahnstadt" in Heidelberg / Germany with 3,700 units [20]. Thus, "mass" for Passive Houses clearly means affordable, not at all like the bulk of prestigious beautiful projects passive house architects tend to be so proud of, cited and awarded for. Approximately 6,800 people will live in the optically less spectacular Bahnstadt in 2022, and up to 6,000 people will work in its dedicated area which is called "Skylabs" [21]. Around 2,800 standard apartments have been built already - a total of around 3,700 apartments will be ready for occupants to live in by 2022. Energy saving is the only relevant benchmark, whereas certifications like the British BREAMS, the American LEEDS, or the Singaporean Green Mark may have a full scope of criteria, but do not point out to what counts to reduce Global Warming. Hence, typically for Passive Houses certification, in the colder hemisphere they will save 90% of conventional homes' energy. Due to the more expensive all-year-long necessary cooling efforts, the saving potential is lower, but still 80% for tropical residences and 70% for commercial areas [22]. As both standard houses will not cost more than 3-15% than conventional houses, the ROIs

/ simplified payback periods will not be more than 5 years which according to consumer standards in the West is reasonable and could open the door for viable business models [23].

Figure 9: Bahnstadt Heidelberg – so far the Globe's Largest Passivhaus Settlement [24]

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Comparative Performance Analysis of Passivhaus and Building Regulation Certified Properties Built in The United Kingdom

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Abstract: This paper compares the energy performance of Passivhaus and Building Regulations certified properties constructed in the UK. The Passivhaus criteria and construction principles are explained and the certification criteria for both standards are rationalised for a direct comparison. Relevant data was collected from case studies, building certifications, and the approved local planning submissions. The results reveal that, on average, Passivhaus properties were twice as thermally efficient from a numeric U-value standpoint, though are likely to perform even better due to the construction quality standards. This notion is backed up by the overall energy savings which on average come out to 75% compared to a conventionally built home.

Keywords: Passivhaus, Passive House, Energy Performance, Sustainability.

1. Introduction

Passivhaus is a German term that translates to passive house. Currently Passivhaus is a voluntary building design and performance standard, around the basis of low energy demand [1]. In addition to being a performance standard to aspire to [2] there are regions of Europe that in fact impose it as a necessary requirement for new builds to be commissioned and signed off. Passivhaus is a design guideline for buildings that was birthed out of Germany in the nineties. It aimed to derive a process in which buildings can be constructed such in service they draw a fraction of the energy demands that conventional construction depends on. Passivhaus has greater targets for building performance relative to mandated regulation. Though in the recent years this gap is being bridged. This research aims to define the Passivhaus design criteria and practices compared to current UK regulation. In addition to this, data will be collated of built homes in the United Kingdom and their performance for each of the design standards and compared commenting on the results.

Passivhaus takes into account the overall building performance (Table 1) instead of the performance of key building elements as the United Kingdom building regulations outlines. Overall, this contributes to a comfortable ventilated internal environment throughout the seasons that requires a fraction of the energy to operate. This reduces the energy grid demands of the building, a primarily environmentally detrimental energy source. Any fluctuations in energy pricing are not felt so harshly due to the already low energy demands. Outside of the energy efficiency Passivhaus compliant construction boasts, it also by proxy ensures good quality of work [2].

The word passive implies no need for intervention though it does require a fractional amount of energy to keep it within the comfortable range, but at least not from conventional forms such as a fully-fledged grid reliant central heating system [3]. This saves on material and labour costs as the radiators would not need to be purchased or someone contracted to install them. With the absence of radiators, this in turn frees up wall space and functional floor space as there are not any unsightly protrusions you would otherwise have to work around. The house has such low energy demands, it is as if it is passively existing due to the reduced impact on the environment.

Table 1. Passivhaus criteria [4].

Properties	Passivhaus Criteria
Annual space heating or cooling demand	Not to exceed ≤ 15 kWh/m^2a annually
Average daily heating or cooling demand	≤ 10 W/m^2
Primary energy demand	Not to exceed 120 kWh annually for all domestic appliances (Heating, cooling, ventilation, hot water, power and all other energy demands)
Airtightness	0.6 air changes per hour at 50 pascals ≤ 0.6 h
Window U-value	≤ 0.85 W/m^2K
Thermal comfort	Not more than 10% of the hours over 25°C per year

The little energy it does require can be supplemented from a variety of low impact sources. The simplest, a space heater, may suffice. Other potential sources include air source heat pumps implemented as part of the building's infrastructure or a small combination boiler that draws its energy from renewable sources such as photovoltaic panels or wood burning. With the principle of airtight construction, you may assume that internally this will result in stagnant and stale air though this is where the mechanical ventilation heat recovery (MVHR) system comes in. This manages air flow through the building as well as bringing in fresh air. This air is generally not at a temperature you would like to be directly funneling into the property. Ingeniously the system uses the thermal energy of the expelled air on its way out to heat the fresh incoming air. This is also supplemented by a small 3kW heating element [1]. Comfortable range as the term suggests is the range in which environmental variables are such that it contributes to a comfortable environment. Spaces are at 20°C-22°C with a humidity of 50-60%. The Passivhaus concept was the brainchild of a physicist, Wolfgang Feist [5]. Who then went onto the Passivhaus Institute (PHI) in 1996, an institute that was setup around Passivhaus. The standard initially revolved around four main criteria, airtightness, annual space heat demand, specific heat demand, and annual specific primary energy demand [3].

The bulk of Passivhaus compliant buildings are in European Union where the standard was conceived because the local climate results in the need to raise the temperate of spaces to the comfortable range and maintain it. But this has not stopped the standard being implemented globally in significantly hotter climates like Asia where the need is to cool the temperature of spaces down to the comfortable range instead. This proves its principles of thermal isolation between environments can be applied the world over. As passive as the house may seem, at times some intervention is required from the inhabitants to manage and maintain it, albeit simple tasks. Users would need to be able to know when it is appropriate to purge excessive heat build-up, by opening windows, how to actuate the MVHR system dependent on the season, and when to change filters [1]. Though the stress of managing such systems can be taken over by smart technologies that are able to learn about the user's energy use and preferences as well as taking into account weather and acting accordingly. For example, identifying that it is the tail end of a heatwave and the weather will soon take a turn. Therefore, instead of purging the heat, the system can choose to retain it to maintain the internal temperature during the upcoming cool weather.

2. Design and construction criteria

Table 2 compares the U-value rates for the key building elements in Passivehaus and the current Part L of the building regulations in the UK. A key criterion in achieving high thermal performance is the airtightness. This refers to how well the building controls the flow of air as a lot of heat can be lost during the exchange of air from the building. This is measured in 'air changes per hour', ach, how much air can passively flow in and out of a building, i.e. how airtight it is. Both the Passivhaus design standard and Building Regulation recommend *0.6ach @ 50pa ph* (Table 2) although the limiting value in the building regulations is 10 $m^3/h.m^2$@50 Pa.

Table 2. Passivhaus criteria & United Kingdom building standards.

Criteria	Passivhaus standard	UK Building Standard (limiting/ notional)
u-value for walls	0.08-0.15 W/m2K	0.30 W/m2K/ 0.18 W/m2K
u-value for floors	0.08-0.15 W/m2K	0.25 W/m2K/ 0.13 W/m2K
u-value for roofs	0.08-0.15 W/m2K	0.25 W/m2K/ 0.13 W/m2K
u-value for windows	≤ 0.8 W/m2K	2.00 W/m2K/ 1.40 W/m2K
Airtightness	≤ 0.6ach @ 50pa ph	10 $m^3/h.m^2$@50 Pa

Superinsulation and ventilation and the other two principle criteria considered in Passivhaus standards. Passivhaus design has an envelope of insulation that wraps around the building, this thermal isolation creates a separation between the external and internal environments, reducing the energy required to keep internal environments in the comfortable range. The insulation does not only serve to heat, but also contribute to the prevention of overheating in the hotter months. In addition to the wrapping insulation, efforts are made to keep the insulator, air, within the internal spaces. An airtight barrier that perimeters the construction limits the transfer of air. A lot of energy can be expended to raise the ambient air temperature therefore it is paramount to prevent it from being exchanged with external air that is of a significantly different degree of temperature [5]. In addition to the design itself, there are several practises to ensure the integrity of the airtight barrier. The principle of airtight construction leaves little capacity for natural convection to bring fresh air into the space. Therefore, Passivhaus buildings rely on a mechanically ventilated heat recovery system. This exhausts air from the property but allows the exhaust air, on its way out, to transfer some of its thermal energy to warm the incoming air that is being pulled in by the MVHR system. It is suggested that 30m^3 of fresh air per person, per hour is necessary though the MVHR system needs to be setup such that it is able to pass a greater volume of air through more inhabited spaces of the house. Failing to meet the airflow requirement can result in uncomfortable stale environments that are susceptible to condensation, mould, and the subsequent issues they inflict. The MVHR system is a continuously operating unit therefore it is constantly outputting noise. This places a restriction on how much noise it can produce because of how close it is to the living space. The unit itself can operate up to 35db but only a maximum sound level of 25dB can penetrate into the living space [5].

Glazing is the next major design and construction criterion. In conventional construction, glazing is a point of contention as it is where a lot of energy is lost. In Passivhaus construction it forms part of the thermal fabric. Highly insulative triple glazed windows contribute to the airtight barrier and allow the building to take on solar gain during the day and harbour the energy rather than simply being a medium that it is exchanged through. Any building openings usually involve a dense structure to support the required span, as well as a change in material to fill the opening, be it a door or window. This can lead to thermal breaks in the building fabric where energy can be lost making insulation efforts void. In construction an effort is made to prevent this due to the energy implications though special consideration in Passivhaus construction is made in the marrying of materials [5].

2.1. Energy consumption of Passivhaus

Annual space heat demand, the amount of energy required to bring the internal temperature up to 20oC in cold climates and down to 25oC in hot climates, on average per hour over the course of the year. The Passivhaus standard deems 15kWh/m2 be sufficient energy expenditure to achieve this (Table 1). Passivhaus criteria states the specific heat load ought to be at most 10W/m2, being the maximum amount of energy to be expended per usable building area per metre to bring the internal temperature to comfortable range when it is -10oC externally. Annual specific primary energy demand is the amount of energy that can utilised from one source that is capped at 120kWh/m2 for Passivhaus [4]. To put it in perspective of the current United Kingdom building performance, on average there is more than 10ach, 200kWh/m2 to maintain internal temperature and over 400kWh/m2 annual specific primary energy demand [3].

In service this allows for an average reduction of 75% in energy consumption in Passivhaus built homes relative to conventional construction [6], and over the course of the building lifecycle these savings are magnified and contribute to offsetting any extra costs incurred in meeting the Passivhaus standard. All sorts of numbers are heralded, even up to 200,000 Euros, though this is quite context dependant in addition to the initial cost of construction. Some basic estimations put it at a 14,000 Euros addition to construction cost, as it becomes more widely adopted and technology advances year on year the cost of implementation is reduced, 9500 euro as of 2015 [7]. Which can be quantified as an extra cost of 15-25% [8].

3. Research Methodology

Qualitative research is conducted to assess the initial criteria of the different building design standards, Passivhaus certification criteria and United Kingdom building regulation. This provided a side by side representation of each design criteria. Since different accrediting bodies have different methods of assessment, key elements of criteria will be outlined to attempt to rationalise areas of assessment. Performance of building elements are collated and compared. The walls, floors, roof and glazing will be the main basis of comparison and where possible data on airtightness will also be noted. The aim is to compile data on properties built to satisfy mandated building regulation and Passivhaus certification comparing their built performance. In addition to commenting on building practices that contribute to their relative performance and trends that arise. This will illustrate the significant performance disparity and encourage better design standards going forward. To make comparison of the data at a glance an arbitrary performance was used. This is an average derived from the thermal performance of the building elements: walls, floor, roof and glazing. Although not 100% accurate in terms of thermal performance and energy consumption comparisons, this strategy would give an indication on the overall energy performance of the buildings.

4. Results and Discussion

In order to be able to draw a research-based conclusion the thermal performance of 100 properties split over the relative building standards was put together and rationalised. Collectively this data illustrates that Passivhaus performs significantly better. Without having taken into account air permeability, Passivhaus achieves an overall arbitrary performance of 0.28 (Table 3), half that of Building Regulation's 0.56 (Table 4). To further refine the results the data was condensed and averaged based on region (Table 3 and Table 4, Figure 1).

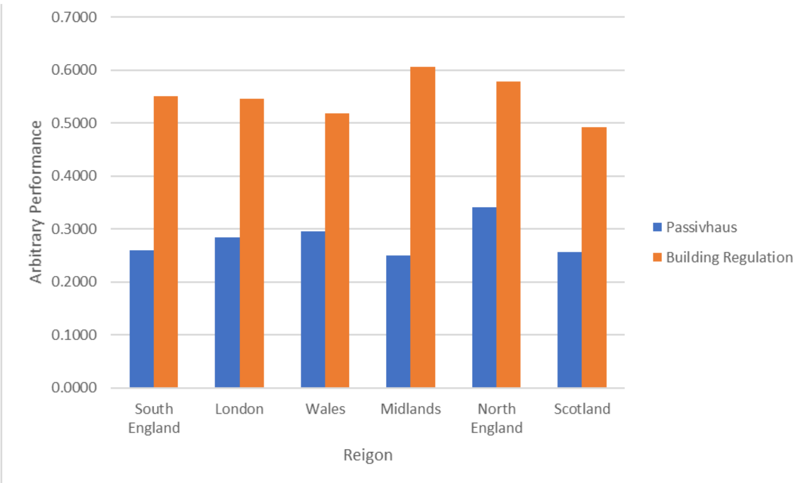

Figure 1 - Passivhaus vs. Building Regulation certified building thermal performance per region

Interestingly, the further north the building, the better the arbitrary performance, with Scotland having the lowest scores across both building standards. This could be down to the lower temperatures experienced in the north and the buildings are designed as such. Therefore, in future construction, a further assessment of homes built in the north could be undertaken to shed light on building practices for a more robust design in the United Kingdom. Additionally, the lower the element u-value, the more effective the superinsulation effect is, another driver to aspiring to the lower targets.

Table 3 - Collated results per region illustrating raw data collected on building element performance for Passivhaus certified properties

PASSIVHAUS - AVERAGED DATA FOR THERMAL PERFORMANCE							
Entries	Region	u-value for walls	u-value for floors	u-value for roofs	u-value for windows	Airtightness	Arbitrary Performance
NA	Criteria Benchmark	0.18-0.30 W/m²K	0.13-0.25 W/m2K	0.13-0.25 W/m2K	1.4-2.0 W/m2K	≤ 0.6ach at 50pa ph	NA
6	London	0.11	0.12	0.12	0.78	0.50	0.28
11	Midlands	0.10	0.11	0.09	0.69	0.48	0.25
9	North England	0.13	0.12	0.12	1.00	0.53	0.34
7	Scotland	0.10	0.11	0.09	0.72	0.46	0.26
10	South England	0.11	0.11	0.10	0.72	0.46	0.26
7	Wales	0.12	0.12	0.11	0.82	0.54	0.30

Table 4 - Collated results per region illustrating raw data collected on building element performance for Building Regulation certified properties

BUILDING REGULATION - AVERAGED DATA FOR THERMAL PERFORMANCE							
Entries	Region	u-value for walls	u-value for floors	u-value for roofs	u-value for windows	Airtightness	Arbitrary Performance
NA	NA	0.18-0.30 W/m2K	0.13-0.25 W/m2K	0.13-0.25 W/m2K	1.4-2.0 W/m2K	≤ 0.6ach at 50pa ph	NA
12	London	0.23	0.19	0.18	1.58	NA	0.55
12	Midlands	0.25	0.21	0.21	1.75	NA	0.61
7	North England	0.23	0.21	0.21	1.66	NA	0.58
7	Scotland	0.19	0.15	0.16	1.47	NA	0.49
9	South England	0.23	0.19	0.20	1.59	NA	0.55
3	Wales	0.21	0.16	0.19	1.50	NA	0.52

4.1 Thermal material performance

Data was based upon material to see if there was a trend that could highlight what building materials overall performed best (Table 5, Table 6). The materials arbitrary performance sits quite close to one another in the realm of their relative design standards. One clear thing that the data illustrates across the two design standards is that timber buildings have better overall thermal performance (Figure 7). When looking for outliers in the raw data of Passivhaus, Table 7, one of the timber buildings had an arbitrary performance of 0.21 – Entry 9. So as much as Passivhaus is the next step from Building Regulation for building performance, there are things that exist beyond that. A noted benefit of timber construction is that it is innately an insulating element whereas other materials such as concrete would have to be designed to act as a thermal mass with the aid of insulation to prevent thermal bridging. In regards to the building lifecycle, wood is a sustainable material. With additional trees being planted to offset the ones cut for construction and at the end of life the building has a wider use cases for the material involving less energy intensive procedures to repurpose it. This further reinforces timber being the future of sustainable design and efficient properties. In the Nordic region of Europe, a plethora of their towering housing blocks are timber with engineers pushing the height for tallest timber building year on year. Brick is one of the most common building materials and so a pull away from it to timber may not happen overnight despite its performance, therefore some investment into reducing its thermal transmittance could provide dividends in long term energy savings.

The performance of the materials is consistent across both building standards which is to be expected as there has been no change in the constitution of the materials themselves and their properties. Though evidently the way in which they are applied and brought together has significant implications on performance. As such some simple practices that Passivhaus dictates could be brought into the mandated building regulation, such that in time there is an improvement to the overall stock of property in the United Kingdom. This in turn could have far reaching effects on people's lives. Better personal well-being due to improved internal habiting environments, greater disposable income as less is spent on energy bills, and the initial added upfront cost of Passivhaus design standards could contribute to the economy.

Table 5 - Collated results per region illustrating raw data collected on building element performance for Passivhaus certified properties ordered by construction material

PASSIVHAUS - AVERAGED DATA FOR CONSTRUCTION MATERIAL THERMAL PERFORMANCE							
Entries	Construction	u-value for walls	u-value for floors	u-value for roofs	u-value for windows	Airtightness	Arbitrary Performance
NA	NA	0.18-0.30 W/m2K	0.13-0.25 W/m2K	0.13-0.25 W/m2K	1.4-2.0 W/m2K	≤ 0.6ach at 50pa ph	NA
3	Concrete	0.12	0.12	0.10	0.80	0.52	0.28
21	Timber	0.11	0.11	0.10	0.76	0.48	0.27
12	Brick	0.12	0.11	0.11	0.83	0.48	0.29
7	Brick & Timber	0.11	0.12	0.09	0.75	0.52	0.27
7	Steel	0.12	0.14	0.11	0.85	0.52	0.31

Table 6 - Collated results per region illustrating raw data collected on building element performance for Passivhaus certified properties ordered by construction material

BUILDING REGULATION - AVERAGED DATA FOR CONSTRUCTION MATERIAL THERMAL PERFORMANCE							
Entries	Construction	u-value for walls	u-value for floors	u-value for roofs	u-value for windows	Airtightness	Arbitrary Performance
NA	NA	0.18-0.30 W/m2K	0.13-0.25 W/m2K	0.13-0.25 W/m2K	1.4-2.0 W/m2K	≤ 0.6ach at 50pa ph	NA
6	Timber	0.21	0.16	0.18	1.51	NA	0.51
9	Concrete & Steel	0.21	0.16	0.17	1.50	NA	0.51
35	Brick	0.23	0.19	0.20	1.64	NA	0.56

4.2 Limitations and additional improvements

When gathering data on building performance for standard building performance it was at times difficult to find case studies and data to add for comparison as building performance in that context was not readily available which is understandable. Such buildings are designed using conventional methods to current building standards. The certification process that mostly interrogates the setting out of elements in the building rather than the performance of individual building components and as such the complete data for conventional dwellings was at times hard to come by. Whereas with

Passivhaus, it is quite a conscious construction, it is something you set-out to do, in having a building being able to adhere to such low energy demands and high performance.

A consideration that had to be made when collating domestic properties is that they were certified at least after the year 2010. The year when a major revision to the government building energy standards was issued as the benchmark building performance of buildings designed to United Kingdom regulation was noted from this.

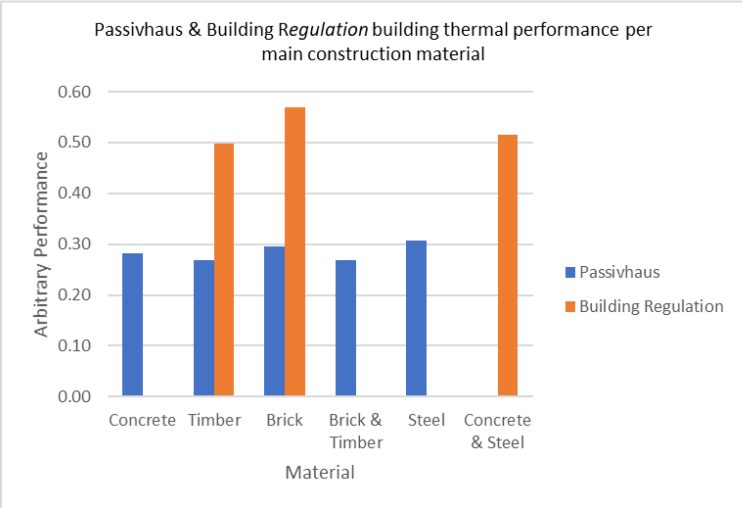

Figure 2 - Chart illustrating Passivhaus & Building Regulation building thermal performance per main construction material

As case studies highlighting building performance were not readily available for standard domestic properties, the available information on the planning portals of councils of approved construction within the areas were used in order to acquire such information. The quality of information included varied, though amongst each council there were submissions that had the full data set for comparison in terms of structural elements. Tests and regulation for air permeability are not as stringent for standard domestic homes and therefore the explicit data was scarce. The overall air permeability as an effect of the overall building performance. It means the air in the cavity is being exchanged quicker therefore is not as efficient as acting as an insulator. To add, with air comes moisture. With the increased levels of moisture within the cavity, the degradation of the insulating material occurs faster, in turn reducing its functional operating lifespan. The recommended standards for air permeability are the same across both building standards though the practice of constructing building fabrics differ (Figure 2). In fact the average air permeability figures for new build properties in the UK are significantly (up to 10 times) higher than the Passivehaus standards.

There are millions of properties in the United Kingdom therefore the number 100 for the sample size seems so minuscule. Despite this the data was quite illustrate as there was a significant gap of performance of buildings built to their relative standards. In construction there are an abundance of variables that effect the performance of the property from design to construction, in effect every building is bespoke. A larger sample size in addition to access to air permeability rates for the constructed buildings in the UK would help to have a more comprehensive picture on the overall performance of the UK housing stock.

5. Conclusion

This research outlined the criteria of both of the aforementioned design standards as well the performance of properties built to these criteria. The research highlights the disparity in the thermal performance of built homes between Passivhaus and Building Regulation, this shows that there are improvements that can be made to current mandated building regulation as there is a capacity to improve. While this means an increased cost of construction, over the lifespan of the building it will be offset by the reduced operating energy costs of the building. Additionally, the embodied carbon of Passivhaus certified homes is comparatively lower than the current building regulations which is both beneficial to the environment and easier to offset. This ongoing saving can contribute greatly to the circular economy as individuals have more disposable income. The push to Passivhaus conventions that utilise sustainable materials contributes to the environmental impact of construction, a conventionally intensive undertaking. This research illustrates the significance of better design standards and principles that ought to be aspired to when designing properties as well as taken into consideration when defining building regulations; such as implementing more insulation into the building fabric to isolate external and internal environments in all climates to maintain a comfortable range with minimal energy expenditure, in addition to an air barrier to limit the passage of air. Going forward it opens up further avenues of consideration such as using timber as the main building material. Future research could look into increasing the sample size to observe if there are different trends with a larger sample size, and to be more representative United Kingdom property stock. Also, an investigation into Scottish construction practices and that of colder climates for comparison and understanding. Finally, research into reducing the thermal transmittance of bricks would prove useful to both Passivhaus and current building practices.

Author Contributions: Hashemi designed and supervised the project; Serroukh carried out the investigations.

Conflicts of Interest: The authors declare no conflict of interest.

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Life Cycle Assessment Applied to Interior Design Engineering Process: A Reflective Observation.

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Abstract: This research deliberates a reflective observation towards emergent conceptual and technological interconnections between interior design engineering process and building life cycle assessment (LCA) methodology. The core parameter is the growing demand for sustainable livable environments and the need for an" LCA based-design" to stimulate better user-experience and behavior concerning the inherent codependency between "living space" and "living style". As architectural engineering and interior design engineering increasingly emphasize sustainable qualities of interior built environments, various questions and divergent examinations gain a foothold on interior design process modelizations and thinking process implementation. As focused approach of this research, applying LCA to interior design engineering process seems to be manifested into two complex parameters: the relevant design phase to implement LCA (earlier stages of the process, during the process, at the end), and how to fuse or synchronize the two methodologies without confusing their particularities.

Keywords: Interior design, Design process, Life Cycle Assessment, Modelization, Methodology, Observation, Sustainability, Systemic model.

1. Introduction

In the field of architectural design and construction industry, LCA has been used essentially by engineers and architects at the latest stages of the process to evaluate or to improve ecological performance or environmental weighting of the project. Additionally, in the current state of experimenting and applying LCA methodology to interior design engineering process, the limitations and prospects must be identified. Thus, in this paper we aim through observational findings and qualitative methods to examine specific "experiential" and "pedagogical" situations" relevant to interior design engineering studio and project-based learning (PBL), perceiving the traits of a conceivable "Systemic Model" that interior design engineer is supposed to chase and adopt, to apply LCA to his design process, considering relevant systematic steps, sequences, temporalities, inputs, and interferences.

2. Interior design engineering process and LCA methodology: the facets of a required synchronization

It is currently apparent that the building sector has significant environmental impacts. To properly assess these different environmental impacts induced by the construction sector, assessment tools are needed. Furthermore, in order to better understand the different issues related to a feasible "synchronization" between the methodological aspects of an LCA and the conceptual attributes of architectural and interior design engineering processes, it is necessary to reconsider the "milestones" relevant to any implementation. Moreover, recent studies confirm that environmental weight of buildings is now calculable and can be pre-defined according to two major objectives in accordance with LCA goal and scope definition. In this regard, we refer to the methodology with the publication of the first version of ISO 14040, (14041—Goal and Scope Definition and Inventory Analysis) and the updated one in 2000 (14042—Life Cycle Impact Assessment, 14043—Life Cycle Interpretation). These are the standards that have been revised, cancelled and replaced by the publication of ISO 14040:2006 [9] outlining LCA principles and framework and ISO 14044:2006 [1] for requirements and guidelines. Based on this reference, the collected data may emphasize two major aspects of a required synchronization between interior design engineering process and LCA methodology, identified as following:

- the evaluation of the environmental qualities of the project that we associate to a new design development or a "structural" renovation of the intrinsic characteristics of the built environment.
- the improvement of the environmental qualities of the project, that we associate with a re-design or a "partial" reinforcement of the ecological aspects of the built environment. Considering that the latter is currently the important part of the market and the targeted area for architects and interior designers.

Thus, to correctly assess these different environmental impacts induced by the construction sector, "adapted" assessment tools are needed for architects and interior designers. However, these tools, often used in environmental engineering according to approved methodologies and strategies in this field, are confronted with process implementation issues and challenges. Based on systemic research and advanced studies on building life cycle it is possible to identify important parameters that are related to these issues and challenges, such:

- the need for an accessible "systemic model" that evolves through specified stages of the interior design engineering process as the environmental characteristics of the interior built environment become more manageable and practicable mainly for the design development phase.
- clarifying the role of LCA of buildings with a focus on inventory analysis (as step 02 of an LCA methodology) and its interconnexion and compatibility to relevant design stage mainly for the design implementation phase.
- simplifying the LCA tools and the way to consider their use at the earlier stages of the design process where the different processes should be identified and/or quantified, such:
  - inventory analysis objectives.
  - project brief description
  - functional unit: flow chart and "cut-off rules"
  - inventory process (material production process, transport process, construction process, operation & maintenance process, end-of-life process, and other applicable processes).
- customizing life cycle impact assessment outputs (as step 03 of an LCA methodology) to be appropriate to the relevant design stage, mainly when interior design engineer is engaged in a thinking process focused on an evaluation for a decision making about detailed design phase.
- implementing differently "results interpretation approach" (as step 04 of an LCA methodology) considering project concepts, observing project goals and objectives, and tackling defined and undefined constraints relevant to the environmental weight of the interior built environment [2].

3. Design process, LCA and decision making: An observation-based approach

As an initial pre-design stage, the beginning of the design of the interior space is focused on assessing the strategic relevance of the project concept, often with a focus on functional and technical predominance appropriated to a functional approach or a user-centered approach. Thus, the ideation phase is implemented based on developing the characteristics of the space by identifying the project objectives, the program and spatial planning, the architectural configuration and structural constraints, the various scenarios and users' needs, the strategic assessment of the project orientation towards a creative, functional, ecological, or technological approach, in addition to the overall project management. All these parameters are relevant to several evaluation mechanisms associated to a decision making, recurrently detached from any ecological considerations.

Therefore, to realize this mechanism of decision-making related to the environmental qualities of the project, several “retroactions” should be implemented. These are the equivalent of the indispensable "back and forth" linked to the intuitive, reflexive and retroactive character of the creative process in interior design engineering, that learners often find difficult to manage, when considering the methodological principles of an LCA. However, the decision whether or not to integrate LCA tools into the project development process is a matter of choosing the right stage.

Thus, with reference to observed learning situations and pedagogical experiences, the interior design engineering studio learners are often faced with the challenge of synchronizing elements of two distinct but “addressable” methodologies, which we define as "conceptual flows" to be managed according to divergent temporalities and sequences. We remind that observational findings are the main “mechanism” to examine specific ”experiential” and pedagogical ” situations” focused on how learners think, act and decide in regards of the mentioned methodological challenges.

The selected project-based course and group of students involved were correspondingly determined based on the conceptual requirements of LCA implementation and the history of knowledge consideration. The methodology simulation was conducted in the sustainability engineering and design course, and smart and sustainable interiors course, in parallel to the design studio course within the architectural and interior design engineering department, at Gulf University, engaging thirteen students selected as participants.

Then, coupled with the qualitative methods used, these observations and questions led us to think about the aspects of a modelization of the “flow system” as we observed it and as it manifested itself during the mentioned experiential learning situation about applying LCA to interior design engineering process. We were able to discover three main flows in continuous interaction with three ways of thinking/of doing, prior to three systemic situations, directing a “potential” synchronization of the two methodologies (Figure 1). Note that some parameters such as inputs and cut-off rules were maintained for all projects, while others were considered as variables, entirely specific to each project concept. We noted that 05 students out of 13 were led to a decision that we define as a “first flow” and that we present as “systemic situation A” (i.e. 38,46%). 04 students were led to a second flow defining a “systemic situation B” (i.e. 30,77%). 04 students were led to a “third flow” defining a “systemic situation C” (i.e. 30,77%).

Such results, as ratio of percentage similarity, confirm, on the one hand, a level of conceptual and methodological complexity and, on the other hand, the imminent need for a conceivable “Systemic Model” that interior design engineer is supposed to chase and adopt, to apply LCA to his design process. It is also worth mentioning that the various retroactions developed by the participants were significant in the sense that they contributed to unveil this “challenging” situation in which the learners were in applying the LCA tools to their design process.

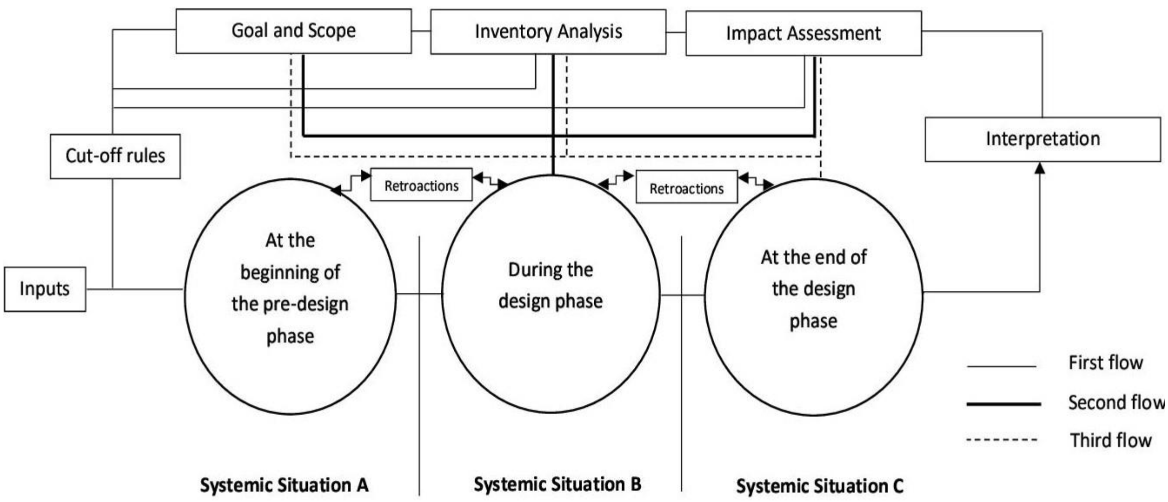

Figure1. Modelling of a “potential” synchronization of the two methodologies: An observation-based “ Systemic Model”.

With reference to the approach developed by the AIA - D200[3], we found that various multiple intersections between the questions asked prior to the design process and those related to the implementation of an LCA, such “At what level of detail can an LCA be used?” and “At what stages of the design process can LCA be useful?” (Figure 2). Additionally, the same approach underlines how precisely this methodology could be useful, such making choices among various building design options, making choices among various building structural systems, assemblies and products, identifying products or assemblies causing the maximum and minimum contribution to the overall environmental impact throughout building’s life cycle, identifying stages of building life cycle causing the maximum and minimum contribution to overall impact, an mitigating impacts targeted at a specific environmental issue. However, the approach mentioned also emphasizes challenges in the use of LCA. It was well reported that though LCA is doubtless the best tool for analyzing the environmental impact of product or project, the methodology and underlying data are still being developed. In this regard, the challenges of applying the LCA methodology to buildings are clearly exposed, confirming LCA as a complex method heavily relying on the availability and completeness of data (LCI) and methodologies for tabulating material use within the LCA tools [4].

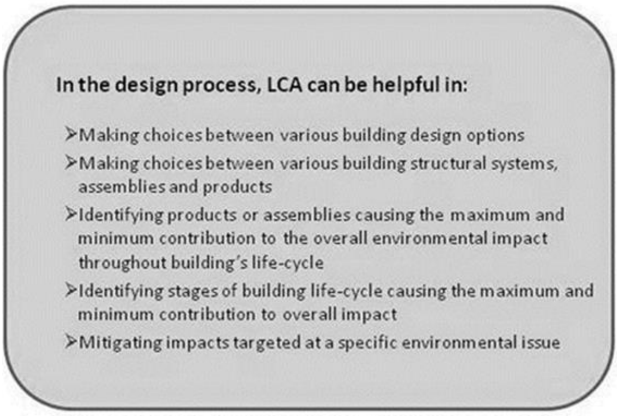

Figure 2. AIA-D200, “In the design process, LCA can be helpful in”.

Consequently, it is important to point out that interior designers are faced with a major challenge related to data and reference flows often adapted to the architectural and structural properties of the building and not to the elements of the interior space. Overall, the observations collected during the supervision of interior design studio projects or the follow-up of PBL experiments, have shown us that interior design engineering students frequently find it difficult to conceive technical and conceptual associations between the environmental qualities of the building selected for a redesign and those related to the alternatives developed for the design of interior spaces. This conceptual, methodological, and technical "confrontation" often leads them to rethink divergent "retroactions", extensions and “back-and-forth” within the design process, and even the ideation process. Learners are forced to redefine the structure of the process in a different way, and to revise the different flows in accordance with the constraints in the design brief, considering the initial parameters defined as the environmental qualities of the selected building. Thus, we specify that these aspects differ according to the scale of the project, the type or group of building. For example, for the redesign of residential building projects the management of such process was almost more accessible than the commercial building projects. This is due to the number of flows and processes to be considered in addition to the manageable complexity of the defined functional unit.

Our focus on observational findings, has led us to try to define the most important traits of three major directions, as useful parameters to generate a modelization outlining a global approach about life cycle assessment applied to interior design engineering process. These parameters are articulated as following:

- Identifying which appropriate synchronization between design process stages and LCA steps, can ease various complexities that we assert as temporalities, sequences, and relevance. Determining what LCA tool is best adapted to the interior design engineer, considering different ways of thinking and variable systematic modelizations of the interior design process.
- Examining how can results interpretation (as step 04 of an LCA methodology) be implemented in a way that transforms the obtained data into operational project requirements.

4. An experiential "learning situation" as input for observational finding

The conducted methodology simulation with thirteen students from interior design engineering program, who have participated to this experimental learning approach, has been seemed as the equivalent of a hands-on practice in which students engage in real world activities that are similar to the activities that professional people engage in [5].

The implementation process was presented as a conceptual and methodological challenge, as an experiment-based learning situation (EBL) and as an immersive pedagogical approach. The implementation showed that a critical thinking-oriented method and a process-centered approach were focused, involving students into solving of complex and innovative problem solutions, teaches them complicated processes and procedures such as planning and communication, promotes authentic research and self-directed learning [6]. In this way, students benefit from discoveries and experiments by learning through observation and interaction, while at the same time they explore the real world [7].

As previously mentioned, in accordance with the research aims, observational findings and qualitative methods have been considered as the main inputs to examine specific "experiential" and "pedagogical" situations" relevant to interior design engineering studio and project-based learning (PBL), perceiving the traits of a conceivable "Systemic Model". Thus, mixed approaches and adapted research tools to the scope and the context were designed and deployed. Such approach can use all data available to support a research project to seek convergence and justification of outcomes from different methods that are studying the same phenomena [8]. It is important to note that, at this stage, the main finding is that most participants decided that conducting such simulation as "conceptual interconnexion" between divergent areas of knowledge between two project-based courses was an opportunity to explore interior design engineering process modelizations in a different way.

They primarily consider the effectiveness of such exploration, mainly the "new" way of thinking towards the project program, the "perception" of design brief constraints and the differentiated consideration of the process inputs. The goal and scope definition has been immediately interpreted with the project requirements and the inventory analysis step was deployed in parallel with the defined design project considerations. It has been clear from the earliest design development phases that participants believed the LCA procedure implementation can draw divergent way of thinking and way of doing towards the initiating process.

5. The prospect for a modelization: A "systemic model" for an LCA applied to interior design engineering process

Through the conducted experiments within project-based courses in interior design engineering program, most of collected observations confirm the presence of a major conceptual "challenge" principally situated between the implementation phase and the inventory analysis step in an LCA.

In the implementation phase, the proposed design alternatives based on functionality and feasibility are confronted to data obtained from the inventory process. For example, the selected materials and finishes for floor covering were immediately checked based on the data table related to materials and production process. The eco-properties, the eco-indicators and the GWP value were observed, and learners were systematically compelled to review, "rethink" or reconsider their alternatives. Such, experiential situation has been considered as a base for a potential simulation or modelization. Thus, adapted retroactions were implemented, and related hypothesis were enunciated. The temporalities and the relevance of the sequences have been at the center of the hypothesis. Learners had focused questions on the logical order of use of the inventory tool and the adequate sequence of its implementation in relation to the developed step in the design process.

In interior design engineering process, the implementation phase is extremely constrained by technical and technological considerations. At this phase, students are always interested in a comprehensive development of the detailed design. Given the complexity of this phase and the abundance of flows, we observed two "systemic" situations. Some students tried to develop the implementation phase based directly on the inventory analysis. While others started to develop this phase, and then immediately compared the outputs obtained with those of the inventory analysis. In this way, two radically divergent environmental qualities of the project were revealed. The students were able to discover, through their processes centered on the analysis of relationships, that this conceptual "back and forth" is very influential in the development of the environmental qualities of their projects, and that the issue of temporality and “sequentiality” is decisive. Therefore, they took up mind mapping schemes between the tools of LCA and the key stages of the implementation phase.

However, in this experiential learning situation, another challenge was imposed to the project process. The students proposed to try the consideration of inventory analysis at the ideation phase. Consequently, a brief simulation of the process was effectively implemented. Note that a use of two LCA software was deployed, in addition to an experimentation of the use of an LCA software applied as an extension for the CAD program. Thus, other divergent levels of complexity appeared. Several confrontations between the interpretation of the design brief, the concept map, mind map and the goal and scope definition (LCA step 1). Other confrontations between the concept statement defined for the ecological aspects for the indoor environment and the impact assessment (LCA step 3). Additional confrontations between the global approach designed for the project and the interpretation of the results (LCA step 4) [9]. As well as the rather complex conceptual confrontations between the proposed ecological solutions for the living space and the analysis of the user's needs and behavior and the attributes of a lifestyle or a green attitude focused on stimulating the user experience that the students developed during a conceptualization phase. This, because when the interior design aspects are focused on a user experience and a user-centered approach, they can contribute effectively to modelize a sustainable behavior, since consumers are more inclined to engage in pro-environmental behaviors when the message or context leverages the following psychological factors: Social influence, Habit formation, Individual self, Feelings and cognition, and Tangibility [9]. The main question is always centered on what the spatial elements have as a direct impact on the user's attitude, and if the tangible elements have a role in this impact. Also, if the use of an LCA will contribute effectively to consider and analyze these elements within the building in an applicable way, as life cycle analysis is considered one of the best tools, because it examines the full range of impacts over all the phases of a building's useful life, instead of focusing on any particular stage or aspect [10]. Such “conceptual” questions about systemic modelization, experiential situations and deployed simulations, formed the basis for our reflective observation towards any potential application of life cycle assessment to the interior design engineering process. Based on these observations and experiments we were led to consider the importance of a "systemic model" upstream of an appropriate and adapted tool or set of tools, or more precisely an effective synchronization between design methods and LCA tools. The modelization we propose refer to an approach developed by the AIA (Figure 3), that emphasize obviously on feasible methodological interconnexions between interior design engineering process and LCA methodology.

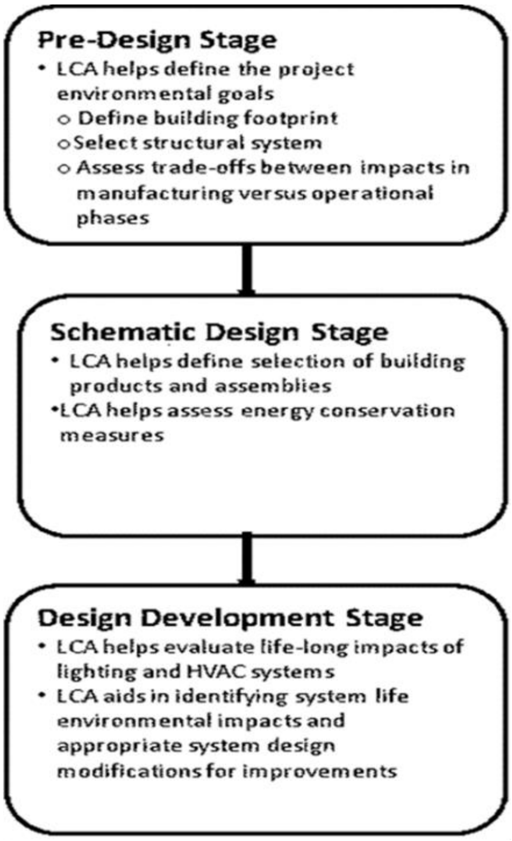

Figure 3. AIA-D200, "LCA and the design process".

Thus, with reference to the mentioned approach, in the pre-design stage, a concept based on feasibility studies is prepared. It shows the design analysis and options considered and will be sufficiently detailed to establish the outline proposal preferred. This design stage is often time constrained. [3] During this stage, LCA can help define the environmental goals of a project. Accordingly, in the schematic design stage the approved pre-design proposal is taken to a more detailed level. The tangible material produced can include site layout, planning and spatial arrangements, elevation treatment, construction, and environmental system. [3] Choices regarding selection of building products and assemblies can be made with the help of LCA. Consequently, at the design development stage, the schematic design solution is worked through in detail. At the end of this phase, detailed design drawings are produced for co-coordinating structure, services, and specialist installation. Internal spaces may be detailed to include fittings, equipment, and finishes. [3] In the design development stage, LCA can help evaluate the life-long impacts of proposed lighting and HVAC systems or other building services. The most crucial stages in a system's life can be identified in terms of environmental impact, and appropriate modifications to the system design can be proposed. Material finishes can also be compared with the help of LCA results, and the right choices can be made [3]. We note that the "systemic model" we propose supposes different reflexive extensions that can be associated to other experiential learning situations centered on project-based learning or experimental-based learning approaches and hands-on practices, which are already oriented towards the necessary application of an LCA methodology to interior design process.

6. Conclusion

The point of this research is focused on the application of the LCA methodology to the interior design engineering process through a reflective observation of experiential learning situations and guided simulations. Such an approach seems useful to decipher the paths of a possible synchronization and to generate an effective applicable "systemic model" extremely required and expected by the interior designers to be able to base their process on approved environmental assessment methods, as other related disciplines such architectural engineering, structural engineering and building services engineering. The systemic model that we intend to propose as a "draft" perspective is only a hypothesis that tends to confirm that the "scientificity" of LCA could be combined with the "conceptuality" of the interior design engineering process. Although, this research is aimed at a conceptual rather than technical level, it seems to initiate the establishment of feasible methodological "bridges" for reliable future applications. This could also serve well the emerging initiatives to link the functionality of some LCA software to popular CAD programs. In addition, ongoing research on sustainability in built environments is clearly based on practical contextual facts, such as learning, PBL and Hands-on situations, to make assessments of sustainability aspects of new and existing interior designs more manageable and the results more usable than is possible with current approaches.

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Diagrammatic Information and Environmental Parameters: Decision Making in the Early Design Phases

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Abstract: In the last decades, the initial phase of the design process has been discussed from the point of view of the construction process economy contribution. In this sense, several authors highlight the decisions made at this stage as an impacting point of influence on the direct cost of the building. This concern is repeated in the cases investigated by the ZEMCH (Zero Energy Mass Custom Homes) group in Brazil, which is focused on social housing, consequently, cost becomes a fundamental factor that must be considered on these buildings' life cycle. Furthermore, ZEMCH's workshops in Brazil have characterized the initial phase of the design process as a process that requires speed and simultaneous control of a large amount of data by the designers. Over these perspectives, the objective of this work in progress is to verify the potential of a diagrammatic artifact as an intuitive tool of visualizing information and supporting decision making in the initial phase of the urban land subdivision design process, to obtain energy efficiency during the building's life cycle. Therefore, diagramming information of the environmental conditions into a visualization tool, helps designers to deal with requirements of this phase and cause impact on the operational cost of the building. This research was conducted over the Design Science Research method, and concludes that although visualizing information with the aid of an artifact can play an important role for the practical requirements of the early design phases, the solution can be potentially expanded to other purposes such as teaching, and even for users self-awareness on the operational impact.

Keywords: Design Process; Energy Efficiency; Diagram; Social Housing; Land Subdivision Plan.

1. Introduction

This inquiry is carried out within the ZEMCH research group in Brazil, with approximately 20 years of research experience on Social Housing in this country. This group is dedicated to a wide spectrum of fields that aims at Mass Customization and Sustainability of Social Housing Projects, from the urban land subdivision to the constructive modulation of horizontal single-family buildings, predominantly in Brazil [1]. Within this spectrum, this investigation deals with the launch of the land subdivision plan, an action that defines aspects that will influence the entire building life cycle and the cost of the social housing developments. This research connects a recent Brazilian investigation [2], which developed artifacts of automated associative design with parametric tools to be used as a tool of visualization, supporting the design decisions in the initial stages of the design process. The general question is concerned with thinking about how it is possible to encourage designers of urban land subdivision for social housing development to reflect on aspects related to environmental impacts since the very first early stages.

Every decision made on the design process has a consequence and a cost, this means that every wrong decision undertaken, lead to a higher difficulty in correcting it, and so does the cost of it. This relation is commonly known as the MacLeamy curve. This curve was revisited by Bragança, Vieira, and Andrade [3] and by the American Institute of Architects [4], where they highlight the importance of decisions in the early stages in relation to the environmental impacts and life cycle costs of a building. This Institute also notes that the energy performance is very little thought of as an initial goal, forcing changes later in the process [4]. In a similar direction, Bogenstätter [5] states that decisions taken in the early stages can influence 80% of the environmental impact ratios and building's operational cost.

In the case of social interest housing projects, the concern about the costs of decision-making in the initial phases becomes more important due to the need to optimize the investment. One of the initial steps in these projects is to define the land and urban design, which in Brazil can impact up to 65% of the total cost of the subdivision (not even considering the costs of buildings) [6]. As a consequence, it is common for the designer to be concerned with the items that most interfere in the immediate cost, such as paving services, guides, gutters, and rainwater drainage that can reach between 48% and 62% of the cost [7]. In this sense, concerns about the environmental impact and costs in the building's life cycle end up not having much attention. However, still in Brazil [8], through the survey of Index of General Significance (IGS), it was possible to identify the users' requirements that are most valued in these types of Projects. In this IGS, the environment and green areas are in second place and, in third place, savings in electricity and water expenses.

It is necessary, therefore, to look for techniques that the land subdivision designer can consider during the decision-making steps, that relates to energy efficiency and impacts on the life cycle. However, there is a notable absence of more intuitive tools for this purpose. The tools are usually aimed at simulation after decision-making [9], often marked by more specialized and inaccessible knowledge. In this sense, the construction of an artifact to solve this practical problem uses the Design Science Research strategy, the objective is to transform more hermetic and specific information, into definitions (visual information-diagrams) that are easier to be accessed, while still being generically accurate and understandable to designers and stakeholders. The research is based on a basic model of social housing and the Technical Regulation of Quality of Residential Buildings (*Regulamento Técnico da Qualidade para o nível de eficiência energética de edificações residenciais* - RTQ-R). The purpose is to make it possible for the designer to pedagogically understand the main thermal performance impact factors generated by the building plot orientation and plan of land division, anticipating requirements not normally considered in these initial land development stages. This step was evaluated by a set of experts, technically pointing out the positive and negative aspects of prescriptive definitions in a diagrammatic tool. In short, in the face of so many items to be thought about, how can we transform aspects that are inaccessible to the urban land subdivision designer into ways of making decisions more intuitively?

2. Method

For the development of this research, it was adopted the method of Design Science Research (DSR), a research strategy derived from the so-called "science of the artificial" [10]. This type of knowledge production comes from the design of artifacts that fulfill clear objectives, trying to point out the best solutions to the existing problems [11]. In this way, DSR is more specifically concerned with the valid and reliable knowledge produced in the design of solutions [12,13]. The DSR focuses on the development and performance of a designed artifact, with the explicit intention to better understand the function of the solutions and how they operate in the practical world [14]. This research is based on the framework proposed by Vaishnavi and Kuechler [12], with the following steps: (1) Awareness of Problem; (2) Suggestion and development of prescriptive definitions; (3) Artifact Development; and (4) Evaluation.

This article presents with more depth details the steps 1, 2, and some aspects of step 3. Vaishnavi and Kuechler [12] call this part of the research as abduction. After identifying the research problem, this part is about understanding how to approach it. To do so, we seek to detail the chosen approach and, in addition to just reviewing the literature, an exploratory study was done to understand how experts can use their experiences in a similar context. At this moment, prescriptive definitions are reached to develop the artifact, as well as suggestions collected from experts. Thus, this part of the research was subdivided into four stages, three for prescriptive definitions, and one last of suggestions and evaluations made by experts, leveraging the awareness of the problem and the potentialities of the proposed solution. The four sub-sections are (2.1) Definition of a basic social housing unity (standard floor plan); (2.2) Characterization of basic parameters: envelope and location; (2.3) Variables score: envelope, natural ventilation, and solar radiation; and (2.4) Expert panels.

2.1. Definition of a basic social housing unity (standard floor plan)

The first step is the definition of a basic diagrammatic drawing of a standard single-storey house in Brazil. For the construction of this diagrammatic floor plan, we adopted as a reference the research made from 2012 to 2014 by Montes [1]. This author proposes a basic floor plan that is the result of a study using approximately 50,000 units, in different regions of Brazil.

The standard floor plan used this study, shown on Figure 1 (a), was adapted from Montes [1], and consists of two bedrooms, an integrated kitchen, one living, and circulation, these are considered long permanence areas (LPA). The total area is approximately 58.00 m². The study was carried out with 16 different possibilities of orientation and positioning of windows.

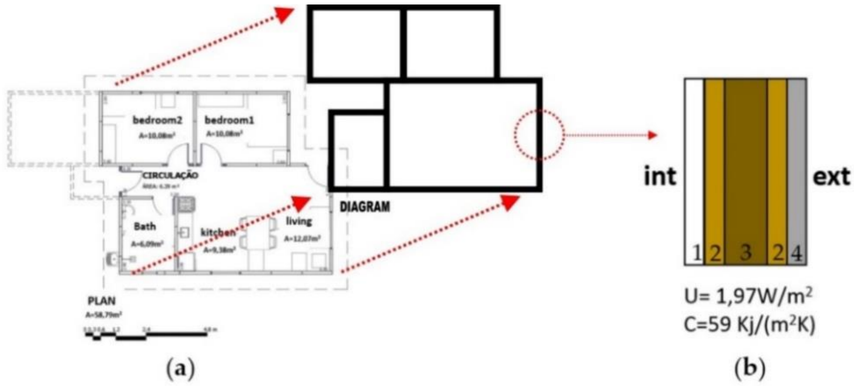

Figure 1. (**a**) modular adaptation of Montes (2016) floor plan; (**b**) Gypsum **(1)**, OSB **(2)**, pine wood + air gap **(3)**, OSB **(4)**, cement board **(5)**. U= thermal transmittance (W/m²); C – Thermal Capacity (Kj/m²K)

2.2. Characterization of basic parameters: envelope and location

The second step seeks to define the materials of the envelope and the location according to its climatic conditions.

For the envelope characterization, this work follows the discussions held by the ZEMCH group in Brazil, using the industrialized light wood frame system [15]. A modular adaptation of Montes' floor plan [1] is proposed to the constructive characteristics of this constructive system. The wall panel has the following configuration, Figure 01 (b). The floor is made of ceramic tile on concrete slab foundation (slab-on-ground – "*radier*"), the ceiling is made of ceramic tile, air gap and PVC panels, the windows present simple glass (3mm) and in the bedrooms, there are shutters. Table 1 exposes the thermal properties of the entire envelope.

Table 1. Thermal properties of the envelope.

Material	Thickness (m)	Thermal conductivity (W/(m.K))	Specific Heat (kJ/(kg.K))	Density (kg/m³)
1 Gypsum Wallboard	0,0125	0,35	0,84	750
2 Oriented Strand Board(OSB)	0,0095	0,17	2,30	681
3 Air gap + wood structure	0,05	0,045	0,70	10,53
4 Cement board	0,008	1,75	1,00	1700
Roof tile	0,02	1,05	0,92	2000
Roof air gap	Variable	Thermal Resistance = 0, 21m².K/W		
Ceiling PVC panels	0,01	0,20	0,96	1300
Slab-on-ground + ceramic floor	0,15	1,75	1,00	2200

[1] The numbers indicated on the material entry are demonstrated in Figure 1 (b).

For the local climate characterization, this research inserted the social housing unity into a specific Brazilian bioclimatic zoning. According to governmental guidelines [16], the city of Londrina, Paraná is located in Bioclimatic Zone 03, a climate with hot and humid summers and mild winters.

The survey of data for the analysis of natural ventilation was carried out based on data from the Brazilian Institute of Metrology, Standards, and Industrial Quality [17], and climate archives [16]. The predominance of the city's winds is east and the average speed is 2.6 m/s. Solar radiation was measured using the Formit© software, where the latitude (23º17'34" south) and longitude (51º10'24" west) coordinates for the location of the city of Londrina are inserted and the incident values of Wh/m² radiation on each façade were measured.

2.3. Variables score: envelope, natural ventilation, and solar radiation

To carry out the energy analysis of the envelope and to produce this variables score, the research is based on the prescriptive method for labeling buildings, using the Technical Quality Regulation for Residential buildings – RTQ-R [17]. This method evaluates the thermal performance of the envelope (walls, roof and, openings) of the building, considering the bioclimatic zone. This assessment can be performed using the prescriptive simulation method. We opted to use the prescriptive method because it is more didactic and simpler to insert the building's characteristics. In this method, first a spreadsheet is filled with thermal characteristics of the building, then the calculation method is applied, after the application results returns as indicators of energy efficiency in long-stay environments, at levels ranging from A (most efficient) to E (less efficient). This research only evaluated the performance of the envelope of the building.

The spreadsheet of the method also results in indicators such as the indicator of Cooling Degree Hours – CDH[7] –used in this research as a basis for the valuation. The more degrees the environment presents, the less comfortable the environment is.

Even though the envelope analysis is based on the application of the RTQ-R method, which already considers ventilation and insolation factors, based on the openings, for the performance calculations on the long permanence areas (LPA), this work points out as an important factor the in-depth analysis of the cross ventilation and the incident solar radiation results. Together these two variables play a significant role in the didactics of the diagram.

The natural ventilation design must promote airflow conditions between the openings located in at least two different facades (opposite or adjacent) of the building, allowing the necessary airflow to meet comfort and hygiene conditions. The characterization of cross ventilation is given by the presence of one or two openings necessarily oriented to the east façade (considering the city of Londrina) and the possibility of air to flow due to the presence of openings on opposite or adjacent facades. This analysis was performed on the different floor plan options.

The analysis of incident solar radiation aims to point out an optimal orientation according to the solar incidence for summer and winter, that is, to minimize solar radiation in summer and potentiate radiation during the winter. In this way, the Formit © software is applied to calculate the amount of incident radiation (Wh/m²) on each facade, on these two critical periods. With these values, it is possible to make a detailed analysis of the orientation influence compared to solar heat gain.

2.4. Expert Panels

Expert panels are recommended at different stages of the development process, they commonly seek to understand the meeting of different fields or approaches with uncertain issues. Melbourne's Department of Sustainability and Environment [18], suggests that using expert panels on environmental issues because results based on experience are needed. Although this methodology is

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[7] It is the indicator of the thermal performance of the naturally ventilated building envelope and it is based on the degree-hour method, which uses a base temperature, independent of comfort temperatures, consisting of a reference temperature for comparisons. On the RTQ-R, the indicator represents the annual sum of degrees-hours, calculated for the base temperature of 26° C for cooling.

discussed in this book for the involvement of citizens, the same recommendation was made in this research, analyzing a variety of informed points of view from which was able to undertake recommendations or courses of action that could enhance the problem's solution.

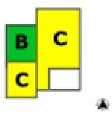
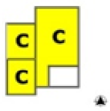
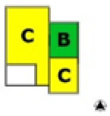
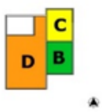
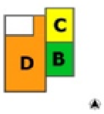
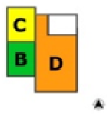
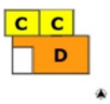
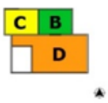
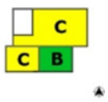
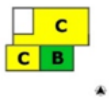
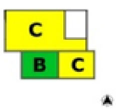
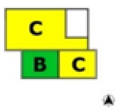
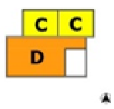
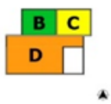
This activity was carried out with the presentation of prescriptive definitions, and its intended use in the development of the artifact, for debate between two professionals with different specialties, seeking to resolve the conflict based on greater credibility. In this moment, we consulted specialists in building fields, because the final evaluation (step 5) is planned to treat with experts in planning land subdivision. Expert 1 is a Ph.D. architect and specialist in social housing and construction technology and Expert 2 is a Ph.D architect and specialist in sustainability and in design based on thermal performance. Both experts have over 20 years of experience and work in these fields for more than 10 years.

3. Analysis and Results

3.1. Construction of the presciptive definitions

The application of the RTQ-R spreadsheet was carried out in 16 different situations, as shown in Table 2 below. The first column of this table presents four dispositions with different accesses (north, south, east, and west). The other columns show variations in the windows' positioning as well as the mirroring of the floor plan. These 16 configurations deal with all plant variations to be used in the artifact, which in the next step, together with ventilation and incidence of solar radiation, receive specific scores.

Table 2. Simulation results for efficiency levels of each LPA according to the orientation of the building and openings.

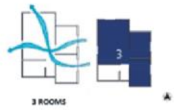
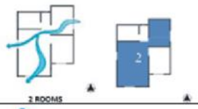
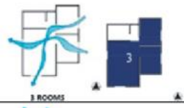
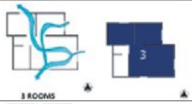
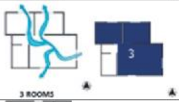
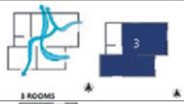
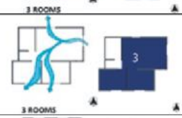
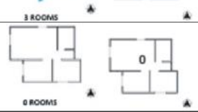
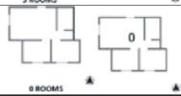
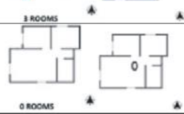
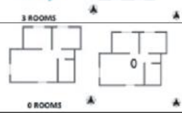
Entry Orientation	Plan 1	Plan 2	Plan 3	Plan 4
North Entry				
South Entry				
East Entry				
West Entry				 [1]

[1] The letters  (A,B,C,D,E) indicates A for best score, and E for worst score, north orientation is set to the upper position ↑ as indicated beside each floor plan, elaborated by the authors.

3.2. Natural Ventilation Scores

To analyze cross ventilation in long permanence areas, the 16 configurations were presented in relation to the direction of the dominant east wind (Table 3 - analysis). Based on this analysis, scores from 0 (no rooms with cross ventilation) and up to 3 (three rooms with cross ventilation) are given. A combination of numbers and colors is used to illustrate the variation in the amount of cross-ventilation flow in the studied environments. Color grading defines dark blue as (most efficient) to white (least efficient).

Table 3. Simulation results of natural ventilation according to the orientation of the building and openings[1]

Entry Orientation	Plan 1	Plan 2	Plan 3	Plan 4
North Entry				
South Entry				
East Entry				
West Entry				

[1]Elaborated by the authors.

3.3. Solar Radiation Score

From the analysis of the solar radiation incidence peak in each month for all 16 situations, a graph was constructed to illustrate the maximum and minimum values for the summer and winter peaks. This graph helps to understand the optimal orientation characterized by the direction of the largest faces oriented towards the minimum summer and maximum winter radiation (Figure 2).

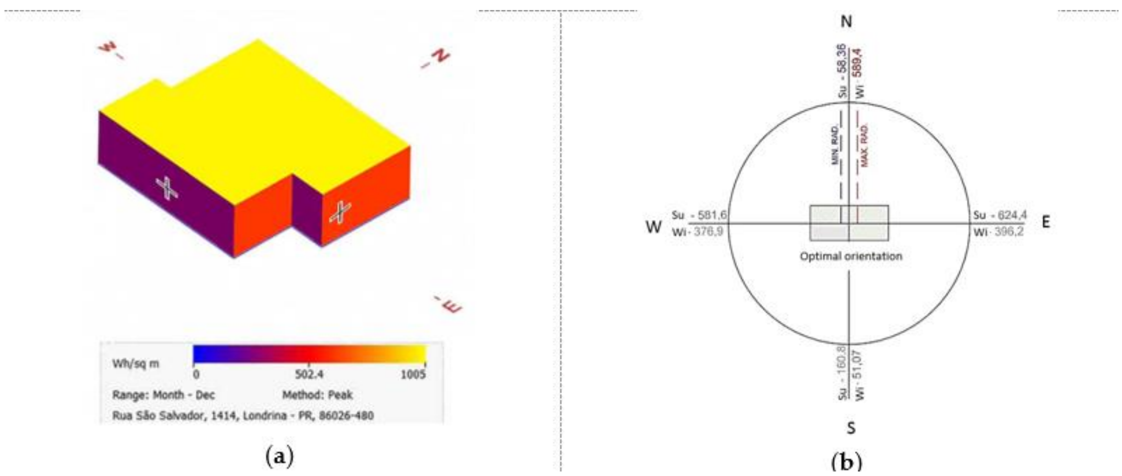


Figure 2. (a) Simulation in Formit Software (Wh/m²) **(b)** Graph for optimal orientation (Su = summer / Wi = winter) according to maximum and minimum radiation values (Wh/m²), elaborated by the authors.

Thus, building plots with smaller edges facing east and west will be identified in the diagram as guidelines for optimal orientation purposes and earned a score bonus.

4. Construction of the Diagrammatic Artifact

For the development of the artifact, it was considered aspects of the envelope, natural ventilation, and solar radiation; general scores were established to guide the designer in the initial stages of launching the land subdivision and generate the building plots. It is noteworthy that, based on the different approaches taken to the analysis of these variables, the numerical scoring parameters adopted for the construction of the artifact have only the function of guiding the visual reading, creating a numerical scale. It is observed that the values referring to the envelope have greater weight, considering that it has a greater impact. However, the artifact adopts extra scores, even though it has less weight on the generic overall score, these scores are based on the results of cross ventilation and optimum solar orientation, this was made due the need of raising a didactic awareness to the importance of these two variables considering this specific climatic high-low peaks.

4.1. Envelope

The result of the Cooling Degree Hours (CDH) performance was evaluated for each room separately. However, to favor the synthesis of the information, a joint final score was defined, referring to the performance of the entire building

In order to facilitate the numerical reading, and the subsequent construction of the artifact, multiple values of 5 for each letter referring to the performance of the rooms were established as scoring criteria, starting at 5 (worst performance - letter E) up to 25 (best performance - letter A).

The sum of the envelope values resulting from the three rooms generates a new final classification also divided into 5 scoring levels. In this case, the range of values ranges from 0 to 75 (15 points for letter E to 75 for letter A).

Table 4 shows the summation reasoning of the score established for the joint classification of the rooms in the 16 situations evaluated.

4.2. Natural Ventilation

For the ventilation results, the number of rooms with the possibility of cross-flow ventilation from openings on the opposite and/or adjacent faces were considered as a scoring factor based on the RTQ-R [17]. Five points were measured for each ventilated room as a numerical value for constructing the diagram. Therefore, as shown on Table 4, the variation ranges from 0 to 15, considering the possibilities of applying at least no room with ventilation crossings and at most 3.

Table 4. Score result of Energy Efficiency for the different plans and Score result for the natural ventilation on different plans.[1]

Entry Orientation	Plans	Sum	Efficiency	Plans	Sum	Score
North Entry	1	(B=20 + C=15 + C=15) = 50	B	1	3 ROOMS = 15	3
	2	(C=15 + C=15 + C=15) = 45	C	2	3 ROOMS = 15	3
	3	(B=20 + C=15 + C=15) = 50	B	3	2 ROOMS = 10	2
	4	(C=15 + C=15 + C=15) = 45	C	4	3 ROOMS = 15	3
South Entry	1	(B=20 + C=15 + D=10) = 45	C	1	2 ROOMS = 10	2
	2	(B=20 + C=15 + D=10) = 45	C	2	3 ROOMS = 15	3
	3	(B=20 + C=15 + D=10) = 45	C	3	3 ROOMS = 15	3
	4	(B=20 + C=15 + D=10) = 45	C	4	3 ROOMS = 15	3
East Entry	1	(C=15 + C=15 + D=10) = 40	C	1	3 ROOMS = 15	3
	2	(B=20 + C=15 + D=10) = 45	C	2	3 ROOMS = 15	3
	3	(B=20 + C=15 + C=15) = 50	B	3	3 ROOMS = 15	3
	4	(B=20 + C=15 + C=15) = 50	B	4	3 ROOMS = 15	3

West Entry	1 C / B C	(B=20 + C=15 + C=15) = 50	B	1	0 ROOMS	= 0	0
	2 C / B C	(B=20 + C=15 + C=15) = 50	B	2	0 ROOMS	= 0	0
	3 C C / D	(C=15 + C=15 + D=10) = 40	C	3	0 ROOMS	= 0	0
	4 B C / D	(B=20 + C=15 + D=10) = 45	C	4	0 ROOMS	= 0	0

[1]Elaborated by the authors.

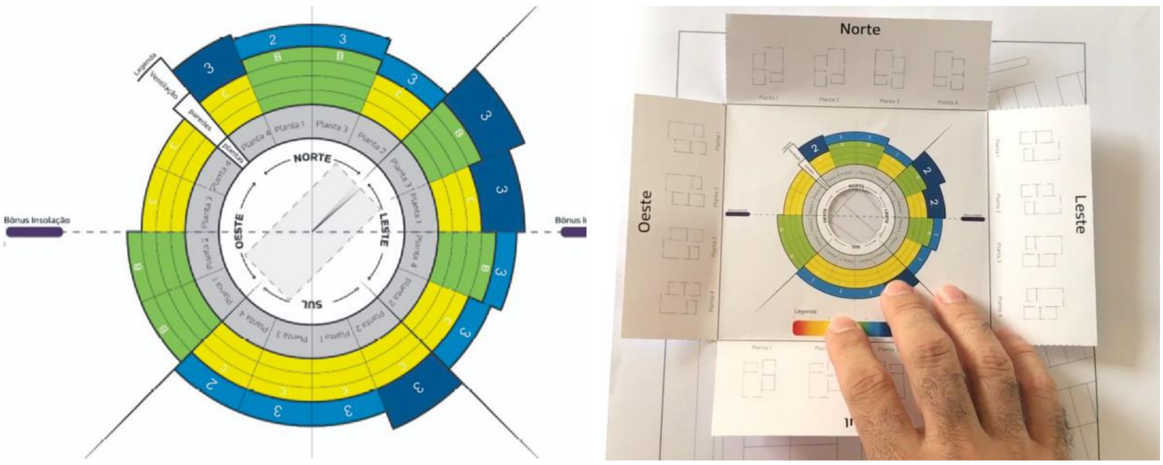
4.3. Solar Radiation

For the measurement of the solar radiation quality, 10 points were credited, the lowest score of the items evaluated. It is understood that this score is complementary to the envelope analysis, which also considered factors related to solar radiation. However, it only occurs when its longitudinal position is oriented exactly to north and south. Consequently, the fronts of the building plots, which have smaller dimensions, must face east or west.

In this case, there are only 8 situations of plants divided into 4 for the west front and 4 for the east front, which receives the possibility of extra punctuation when they are oriented exactly on the East-West axis.

4.4 The scores in the artifact diagram

The design of the diagram was carried out in order to make it clear to the designers that different orientations of the land subdivision result in buildings that can be more or less efficient. The Diagram places the score information side by side (Figure 3a). In the centre is located the building plot, that rotates varying the orientation. Then the different plant options (grey) are placed. The next concentric circles are related to the energy efficiency of the envelope (green and yellow) and next to the natural ventilation scores (blue). The dashed line (purple) refers to the optimal orientation of the building. As the designer rotates the plan, it is possible to visualize the potential efficiencies of the buildings and consequently the land subdivision's (Figure 3b).



(a) (b)

Figure 3. (a) Prototype of the diagram **(b)** Designer working with the diagram on an urban land subdivision, elaborated by the authors.

4.4. Expert Panel Assessment

After presenting the construction of the prescriptive definitions, and its expected application of a diagram, the expert panel discussion raised a few alerts and confirmations.

(a) The conflict between the necessary generalization of the information for the early stages of the project and the transmission of wrong information could induct designers to error. Expert 2 highlighted that certain assumptions which were adopted, such as that the building will have cross ventilation, can generate misunderstandings. Likewise, the orientation of windows can be positive for ventilation, but negative for solar radiation. The resulting recommendation was that, even if such a guideline is generalized, it has traceability paths for the designers' awareness of such regulation on these prescriptive definitions.

(b) Expert 2 still positively pointed out that the facilitated way on how the method RTQ-R was deployed, because RTQ-R is considered a hermetic process for the non-specialists. However, it was observed the need of thinking of ways to make simulation software more accessible to users. The experts did not express any recommendation.

(c) Expert 1 observed that, although the artifact is aimed at the urban land subdivision designer, we must find ways to clarify, in a practical way, the impact of the building materials choices in the assessment of the subdivision designs. He highlighted the characteristics of the envelopes and of the stilt houses. The recommendation was to reinforce in the usage procedure the definition of the characteristics of the surroundings as a first step of the procedure, paying attention to situations where there is the possibility of more than one type of wrapping, taking into account more customized processes.

(d) Expert 1 draw attention to the impact of these prescriptive definitions as a knowledge that could change not only designers' habits but also on users. It has the power to produce awareness about the maintenance and cost of the object in its life cycle for various agents in the social housing production chain. The recommendation was to reinforce an accessible language that everyone can understand.

(e) Both experts highlighted that the pedagogical potential of such prescriptive definitions can achieve in an artifact. They emphasized that its usefulness goes beyond its use by designers of urban land subdivision and stakeholders, it could also be used in the teaching process in architecture and urbanism.

In summary, the two experts considered that such prescriptive definitions are compatible with the culture of horizontal and single-family housing projects of social interest in Brazil.

5. Discussion and Final Remarks

This research presented a more intuitive way of considering prescriptive environmental definitions in the early design stages of land subdivision plan. The assessment of the Expert Panel makes it possible to discuss aspects directly related to the need pointed out by Attia [9], which lies on the need of producing tools that reveal more specialized and inaccessible knowledge in sustainability into eased and comprehensive ways for designers. We must emphasize that the inclusion of information in these phases need to be more generalized, considering that there are still not many details of the future building. Therefore, it is necessary to transform regulatory instruments such as RTQ-R, normally employed in final stages of the project, into more generic instructions.

The experts' assessment drew attention to the fact that such generalization implies on losses that designers must be aware of. In other words, although the experts considered the anticipation of such information to be valid, it must be carried out with the support of auxiliary material that allows a greater pedagogical understanding of the instructions. In this way, we can speculate that this artifact could be further applied to other purposes like on teaching for example, in which a generalized knowledge gets to be useful meanwhile students still don't have an in-depth understanding, or even to get users' awareness over to the whole operational impact that the early decisions taken can have over the whole building's life cycle.

Further research can aid the deployment of such generalization guidelines, where the analogic artifact can be transposed into digital interfaces like on software plugins or mobile apps. Henceforth the next step in the research is building the artifact digitally and evaluating with land subdivision practitioners and stakeholders.

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Sustainability Analysis of a Community Center Based on Retrofit Strategies and Re-design thru Python Tools and Local Standards, Case Study in Al Ain, Abu Dhabi, United Arab Emirates.

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Abstract: Over the last 50 years the cities in the United Arab Emirates (UAE) have developed rapidly. Building stock is very diverse in the country and varies from one city to the other. While Dubai has a large stock of skyscrapers, Abu Dhabi has more mix of High-rise and mid-rise buildings, AL Ain is mainly midrise and low-rise buildings. The case study is located in a villa neighborhood in the city of AL Ain.

Sustainability in the UAE includes many aspects of the structures. Energy in buildings is a major factor that contributes on the sustainability of the build environment. Almost 70% of the energy goes to the cooling of the buildings in UAE. Therefore, one of the most relevant points of this study is to find alternatives in reducing the energy consumption thru the retrofit analysis and re-design.

The climate conditions of the United Arab Emirates have hot summers and cool winters. While in the summer the life out door is difficult during the winter the indoor and outdoor can merge lowering the demand for cooling in the building. The city of AL Ain has relatedly cooler winters than the coastal cities like Dubai and Abu Dhabi. This study aims to evaluate the sustainability of this building typology in terms of energy efficiency, material used, indoor/outdoor relation, cost of the building. This evaluation is a comparison between the current building, a retrofitted building and a new design of the same build-up area. This analysis will be conducted considering the local sustainability standards such as Estidama and Abu Dhabi Realm Manual.

The methodology starts with the Building Selection Process which consists of the selected building is part of a villa compound done in the city of AL Ain. The site measurements is the following step. The material properties to be used in the energy simulation models are collected from the site survey and the weather file is taken from the Al Ain Airport. This file is used for the boundary conditions of the models. The following step is the energy simulations. The models were prepared with several scenarios as per the predefined analysis and run for simulation. Grasshopper thru rhino were the softwares used for the energy simulations and applied design. Therefore, the energy saving was calculated based on the selected matrix. The evaluation of the results and define the main contributors in the building sustainability was the last section of the methodology followed. The results of this study might give a valuable contribution in improving the design and application of this building typology in the UAE. The analysis based on the factors described might give a better understanding of the impact of each factor into a sustainable building for this kind of climate and this location. The guidelines of this research might be used from the real estate developers that design this district typology.

Keywords: sustainable buildings, energy simulation; parametric design; grasshopper, python language

1. Introduction

EnergyPlus is one of the most comprehensive and widely utilized programs, due to the numerous features it combines. Ladybug, Honeybee, and Grasshopper are usable source instruments to be implemented to connect the energy. Ladybug introduces standard weather files into Grasshopper. Honeybee attaches the visual programming environment of Grasshopper to verify simulation software packages for energy, comfort, and daylighting simulations. Regarding system modeling, the software uses the “kinetic batteries” (KiBaM) model. This sensitivity analysis study is looking to contribute towards the design of nearly zero-energy buildings [1] [2] [3].

A new design workflow methodology is proposed, integrating evolutionary algorithms and energy imitation through Grasshopper for Rhinoceros 3d, for a wide-ranging examination of performance-based design replacements in the building scale. Since then, VP systems have grew very fast, making parametric modelling accessible to the design practice through different software. Researchers decided the success of multiplicative design validates that if we make procedures and software more user friendly, this will transform the way Architects design. Another methodology called Design Procedures showed how the parametric design was applied to a temple’s columns. The DP was able to generate all original architect’s designs plus an huge number of new designs [4] [5].

Modeling and measuring BIPV envelopes done by using parametric Rhinoceros plugins such as Grasshopper and Ladybug. BIPV modules were designed as sun shading basics, also it was designed as ventilated double skin façades. The designs were proposed not only to have efficient photovoltaic energy generation typologies, but also appealingly interesting architectural landscapes. The designs with the largest area available for the setting up of BIPV systems achieved better energy balance and it was found that the modified PV models’ results were slightly better than market modules, due to having a higher proportion of their area used for PV cells [6].

The energy performance of the building was measured using Termolog Epix. Energy saving results were conducted based on a parametric methodology. The defined methodology is quite flexible especially in the phase devoted to scenario creation and evaluation. It requires an initial investment in modelling with a good level of detail of the involvements on the basic unit and its proper definition but this effort is then balanced by a speedy and quite easy to realize way to describe the benefits of each design options [7].

The optimization process starts in 3D modeling Rhinoceros and its plug-in Grasshopper. In the daylighting modeling process, the parametric building geometry is associated with the materials factor in the Radiance program, with the setting of material transparency, reflectance. In the energy modeling process, parametric building geometry is connected to the materials in the EnergyPlus program and connected to a Honeybee thermal zone component. The optimization objective is to find design options with maximum UDI and minimum EUI, so the optimal design options [8].

The model is south oriented workstation in an office building in Cairo, exposed to direct sunlight with clear sky. Each case was totally different, so the researchers try to put some solutions and then take out the best solution which was the slats should be allocated outside the room to absorb and replicate maximum sunlight. Moreover, this action will work as a shade to protect the windows from incident sunlight during the day. The modelling testing was representing maximum, equinox, and minimum of sunlight availability around the year respectively. This process was done in Grasshopper by changing the parameters of the slats, in order to create a balance between the cut-off angle, replicated light and the critical distance between the slats [9].

The version that used is a parallel network of PCs running Windows 7 and a Linux web server. The system is exposed for multi parametric modeling software like, Grasshopper or Digital Project. As a result, it was found out that the process plays a critical role in clarify the fundamental relationships between geometry and performance. It depends on the usage of GAs not only for geometry but for more widely solution space [10].

The paper discusses the parametric design, a new architectural approach to design concluded that new contemporary technologies allow the application of tools for the design and analysis of complex architectural forms. The structure was generated using graphical algorithm editor in the modeling of an urban area[11].

The parametric design was generated and analyzed through several tools such as Energy Plus, Grasshopper, Rhinoceros, and ArchSim. A simple analysis was performed to find the most effective design parameter on the energy use of the building. The paper concluded that urban context has an essential effect on building optimization[12].

Seven designers were asked to complete two architectural conceptual design tasks respectively in PDE and GME. Through analyzing the designers' actions in moving between the problem spaces and the solution spaces, it was concluded that designers work in both environments with a similar effort but, there were differences in the problem-solution values across the design stages of the PDE and the GME.[13]

This paper aims to conduct the potential for using parametric design processes to come up with a sustainable urban design. Parametric design is a good tool to achieve sustainable communities through minimum form and high-performance spaces, especially in hot climatic zones. This is done by using computer tools like Grasshopper, Rhinoceros, Galapagos Gas, and ANSYS CFD to achieve the desired parametric design. A positive result was conducted by following the proposed methodology (using computer tools) which indicates that cities in the future will be much sustainable if similar methodologies were followed[14].

This paper introduces a new design methodology where evolutionary algorithms and energy simulation are used through Grasshopper and Rhinoceros. It also gives a brief overview of the performance-based generative design focusing on building optimization and evolutionary algorithms. However, more work needs to be done but by using new software tools, tasks are simplified and modeling time is reduced[4].

This paper presents an optimization method that provides a solution methodology for building design and it is used to minimize energy consumption and maximize the daylight of an office building. EnergyPlus and Radiance were integrated to look for the window area on each wall of the building to reduce the thermal energy to the minimum. The energy analysis allows the designer to choose the best window design strategy. The study concluded that the best orientation is south, followed by the north to get the minimum total thermal energy in the area of the study (China)[15].

Parametric design is developed according to certain factors that are changing in the early design phase. This paper focuses on using the new technologies of architecture and software tools to investigate the principles of designing according to climate type. These software tools are used to generate 3d models and control the efficiency of the design in the visual space before starting the construction process. AutoDesk Ecotect, Rhino, and Grasshopper all are good examples of software tools that can produce complex contemporary parametric designs[16].

An effective design workflow where models generated through Rhinoceros are directly converted into Radiance/Daysim format to produce solar radiation maps and daylight autonomy distributions. Those results are sent back to Rhinoceros to adjust the design parameters such as window size and visualize the effect on daylight availability within the scene. This allows designers to develop their designs through high-quality feedback from schematic design to design development[17].

Teaching experiment that includes multidomain simulations as drivers into the early architectural design process has been conducted; a community center was created with low energy use and high daylight utilization, presented in case studies. Performance increases are achieved by making appropriate morphological choices only; form and energy are thus linked in a tectonic fashion. A novel design simulation process model that acknowledges both creative and analytic thinking is derived and discussed in the context of on-going integration attempts[18].

This paper proposes Parametric Systems Modeling (PSM) as a tool for building and city planning. The method outlined is based on Systems Modeling Language (SysML). It supplements geometry-based Computer-aided Design (CAD) with a non-geometric, design-oriented modeling approach that considers multidisciplinary information and parametric interdependencies. An innovative urban building-greenhouse system illustrates how the approach works for urban system design. The dimensioning of the system model determines the required land areas for sustainable supply and shows that the system configuration has features of a carbon-absorbing city and thus exceeds the concept of a zero-emission city[19].

2. Methodology

2.1. Case Study Selection

The research is applied to a north-east oriented, community centre called MREIFA Compound Club in Alain, United Arab Emirates. It is mainly serving reactional activities such as Yoga, with a total built-up area of 2000m² including the service blocks. The outdoor activities are limited to the swimming pool only. There are four covered parking lots, for both visitors and employees, surrounding the centre from each side. Moreover, around 1650m² of the outdoor area is greenery providing natural views to the visitors.

The MREIFA Compound Club has a form of flat cubes connected in the middle by circular-shaped area that has a glazed dome in the middle. It is coated with white paint to reduce the heat gain from the sun, especially because Alain has a very dry hot climate. The building openings have no shading devices but, in some areas, the exterior walls created some shading on the windows (table 1).

Table 1: Existing Building Program

Space	Area (m^2)	Space	Area (m^2)
GYM	130	Swimming pool	180
Changing area	130	Car parking	1370
Lobby	500	Pavement	2950
Yoga center	300	Service blocks	670
Supermarket	170	Greenery	1650
Bathrooms	100	Total area	8150

2.2 UAE Climate (2020 Graphs)

In the UAE the climate tends to feature a desert climate having cool winters and hot and dry summer. It has a hot and dry climate with humidity which comes from the Persian Gulf. Over the course of the year, the temperature varies between 38-42 C in summers and maximum temperature in winter is 24-26 C.

Based on the climate analysis graphs (Figure 1, 2):

1- Reduce the amount of west and south glazing to reduce heat gain and minimize overheating.

2- Increase the indoor comfort thermostat setting to reduce the amount of energy used by the air conditioner.

3- Include natural ventilation to save energy

4- Radiant barrier could help reduce the radiated heat that is gained from the roof.

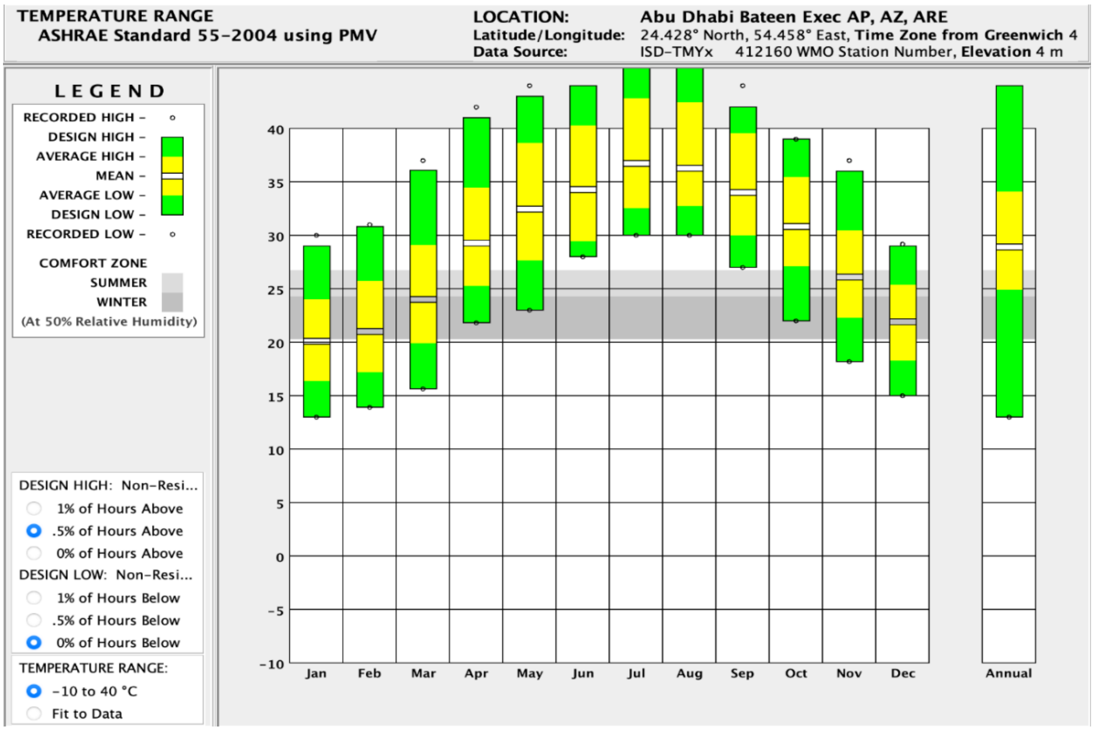

Figure 1. Temperature range for Abu Dhabi.

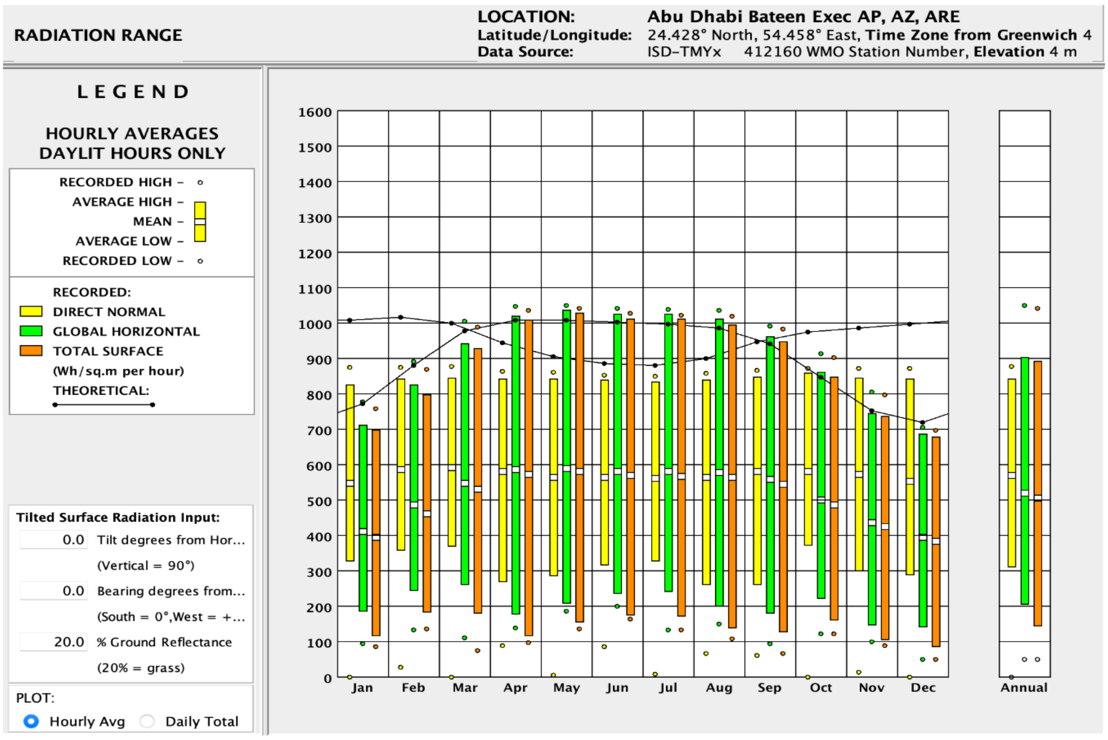

Figure 2. Radiation Range for Abu Dhabi.

3.1. Modelling and Simulations (2020 Graphs)

Rhinoceros is a commercial 3D software used widely in architecture along with a plugin called grasshopper. Grasshopper is a parametric design tool where it uses visual programming language. Moreover grasshopper simplifies design complexities that exceed conventional 3D modeling and can reference geometry objects in rhino such as points, curves, and surfaces. It can also create a geometry from scratch and bake it (create a geometry or model) into rhino. There are thousands of components in grasshopper with wide range of functions depending on the inputs and outputs. For instance grasshopper can be used for parametric design, energy analysis, structural engineering, and a lot more (figure 3, 4).

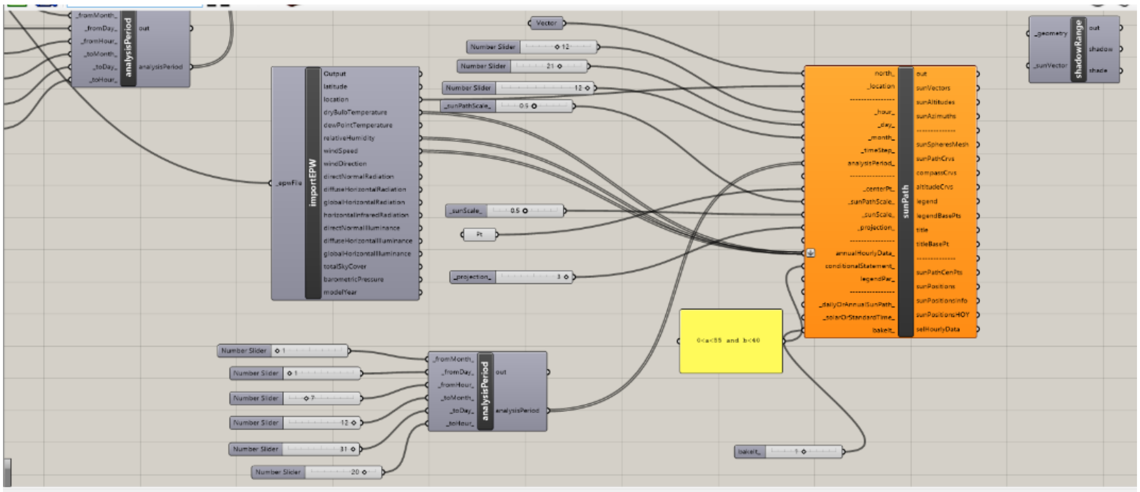

Figure 3. Python script for grasshopper plugin.

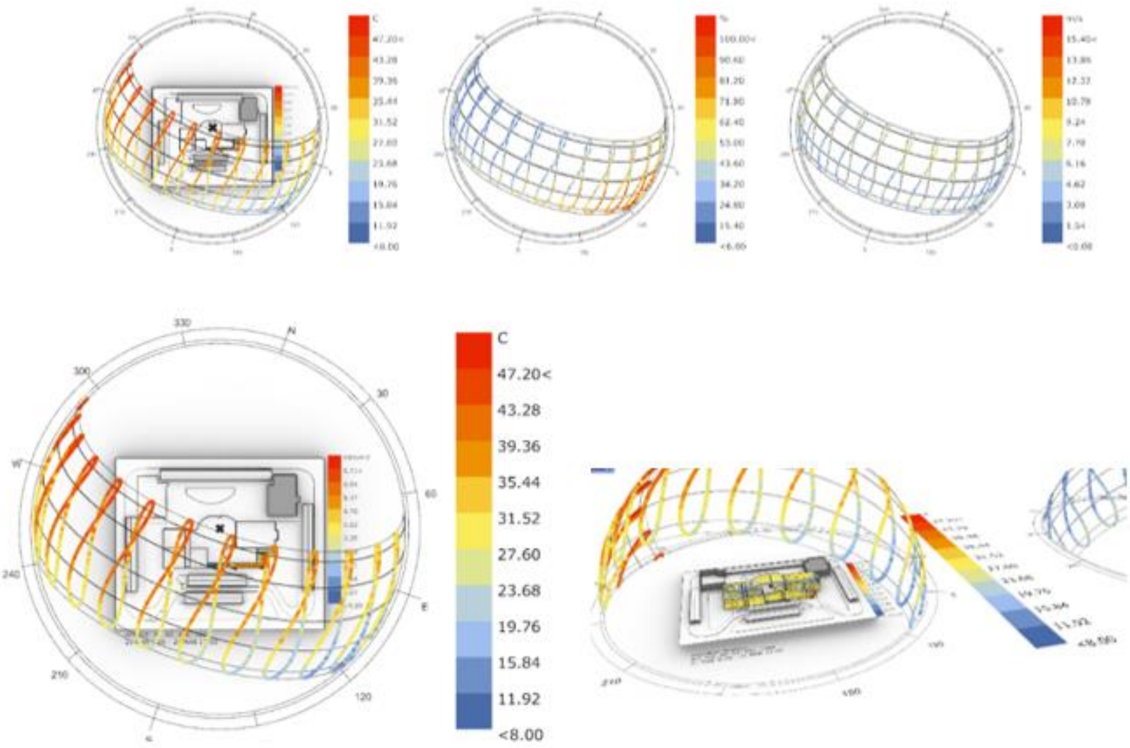

Figure 4. Radiation analysis of the base model.

The energy simulation model was done in the rhino software using the ladybug and honeybee launcher. So, the script was written from the help of previous energy simulation project and help of YouTube tutorials. One of the challenges faced when doing the simulation was the time it takes to get the energy model. Another problem was that making the openings wasn't easy so the model had to be exported to Revit, doors and windows were added in that software and the finished model was again exported to Rhino again. Moreover, the ladybug installed in my pc was different from what most people used, and other versions of ladybug couldn't be installed immediately, so it was a hard time to write the script in that program. After such problems were solved, the grasshopper ran the script once but the results were not convincing and the other problem that occurred was I wasn't able to run the script for the second time and whenever I tried to open the ES folder there was an idf file but the simulation didn't work and I wasn't able to run the simulation and an error occurred. Below are the rhino renderings of the center and the radiation analysis (figure 5, 6).

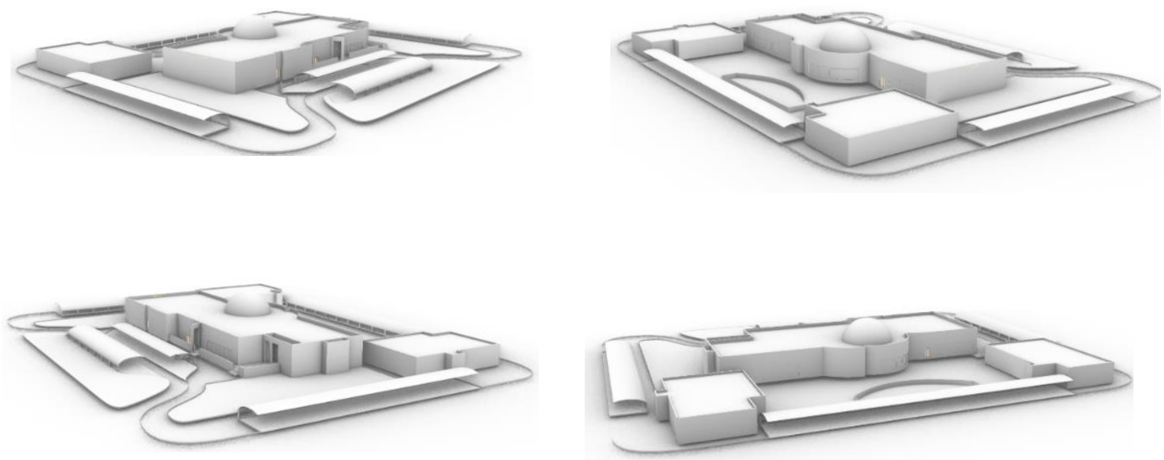

Figure 5. 3D volumes of base case.

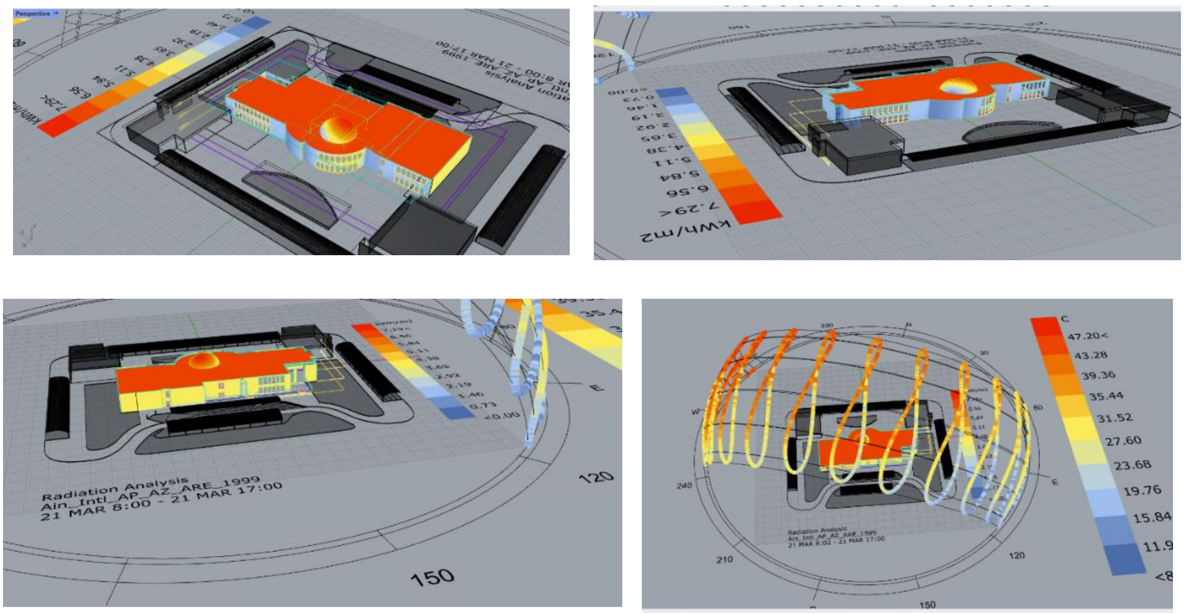

Figure 6. Grasshopper analysis of the solar radiation, base case.

3.1.1. Base Model Energy Consumption

A base model of the existing community center has been done using rhino to analyze the energy consumption without any adjustment and later on with a retrofit model and a new design. Energy simulation has been done using grasshopper and the results are seen in figure 7. Also a sun path has been studied according to the north direction of the existing community center to check the elevations that consume most energy which are the south and west. Moreover, a radiation analysis has been done for the base model to check how much thermal gain there is in the building envelope and find solutions on how to minimize this gain by creating a retrofit model as well as a whole new complete design.

Building Area

	Area [m2]
Total Building Area	1283.26
Net Conditioned Building Area	1283.26
Unconditioned Building Area	0.00

Figure 7. Radiation analysis of base model.

3.1.2. Retrofit Model Energy Consumption

A Parametric shading have been added for each opening in the existing community center to minimize energy consumption. The parametric shading was done using grasshopper by setting various of parameters such as the height and width of the opening,

A sun path has been studied according to the north direction of the existing community center to check the elevations that consume most energy which are the south and west. Moreover, according to the radiation analysis done for the base model and for the retrofit model as well, as a result the radiation energy is less in the retrofit model where shadings are added. Thus adding a shading such as a parametric shading would help minimize energy consumption. Energy simulation has been done using grasshopper and the results show that the retrofit model has less energy consumption than the base model (Figure 8, 9, 10).

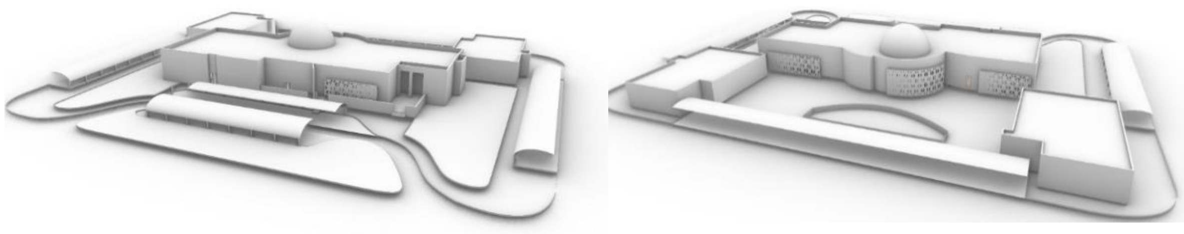

Figure 8. 3D of the retrofitted model.

Building Area

	Area [m2]
Total Building Area	1283.26
Net Conditioned Building Area	1283.26
Unconditioned Building Area	0.00

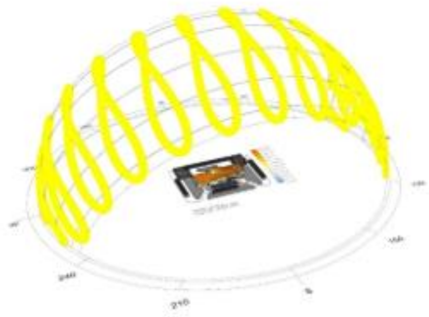

Figure 9. Solar path on retrofitted model.

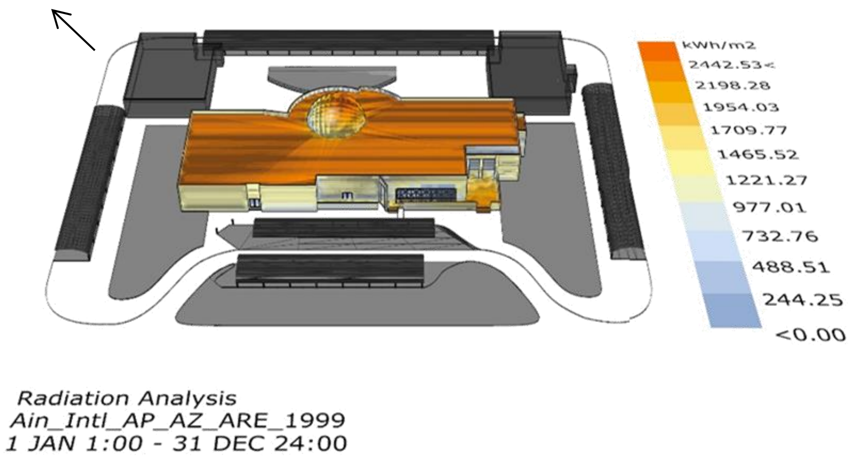

Figure 10. Solar radiation of the retrofitted model.

3.1.3. New Model Energy Consumption

The MREIFA Compound Club has been redesigned into a new model. It includes three interconnected volumes that are shared by a parametric roof, and it has been redesigned to have a more organic form to promote interrelation and harmony with the surroundings. The building has been modeled by the dynamic curves technique of Non-Uniform Rational Basis Spline (NURBS) in Rhino (figure 11). The new building follows the existing building's program, with a total built-up area of 1960m² and a height of 6m. The swimming pool has an area of 700m², and 220m² of an outdoor green area. Parking lots are also available from two, opposite sides of the center (table 2).

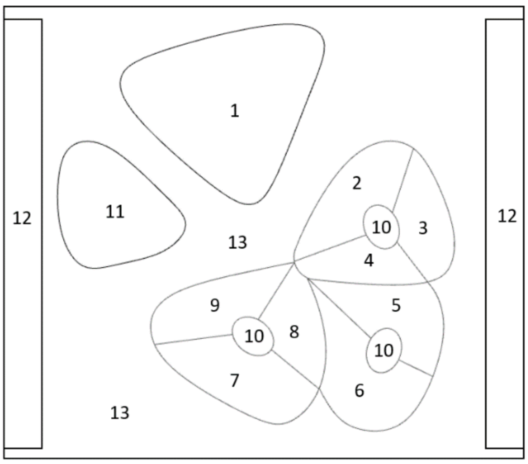

Figure 11. Site plan of the new design

Table 2. Area of the new design

#	Space	Area (m²)	#	Space	Area (m²)
1	Swimming pool	700	8	Supermarket	168
2	Gym	160	9	Spa/WC	170
3	Yoga center	276	10	Inner Courtyards	191
4	Changing Area/WC	155	11	Greenery	220
5	Services/MEP	285	12	Car Parking	900
6	Offices	290	13	Pavement	4380
7	Lobby	265		**Total**	**8160**

A detailed, annual solar radiation, or insolation, analysis has been performed on the new design via Rhinoceros 3D's Ladybug. According to the analysis results, the surfaces that are radiation-sensitive are oriented in the East, South, West, and the inner courtyards as per the color-coding. It is noted that the parametric roof provides shading and reduces the radiation levels to the model.

Furthermore, an energy consumption simulation has been generated as well through Grasshopper, Ladybug, Honeybee, and EnergyPlus plug-ins. The results of the energy use consumption were calculated for a unit area in a year. Assuming Al Ain dry and hot climate, the building is conditioned and ventilated actively throughout the year. In the Grasshopper canvas, the zones of the building were defined and selected. The function and the program of the building has been specified as well. The parametric roof was selected to be part of the site context. In order to fully run the simulation, the weather file for Al Ain has been uploaded and attached, and a period of one-year was specified, and openings were considered. The energy simulation was generated via EnergyPlus for 8760 hours, with the final results are shown below (figure 12, 13, 14).

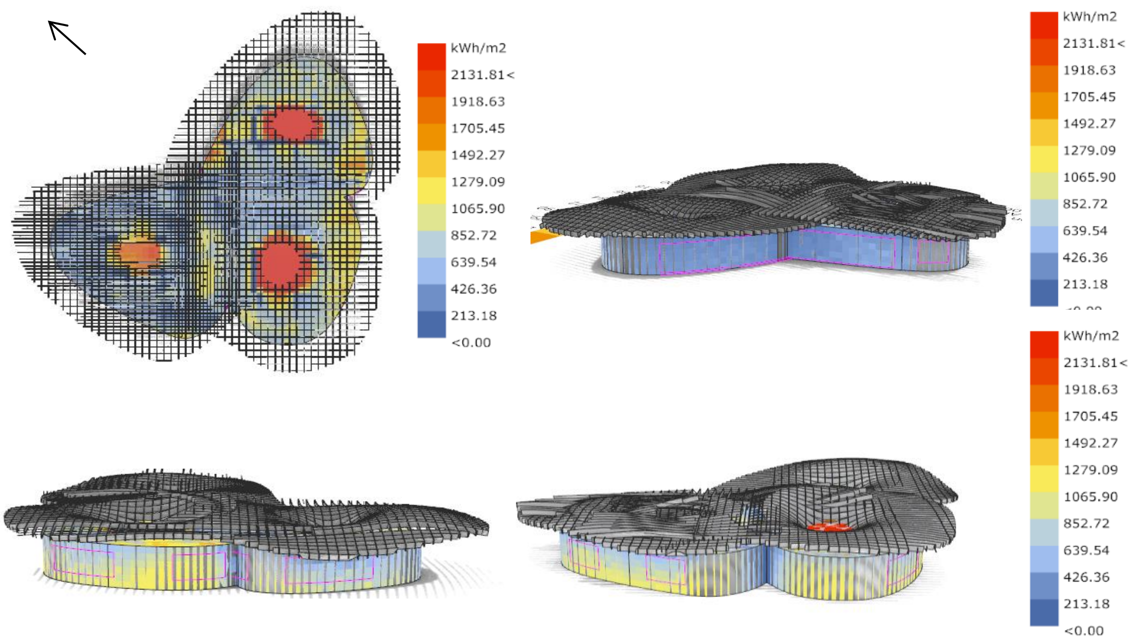

Figure 12. Rhino model of the new design, energy values.

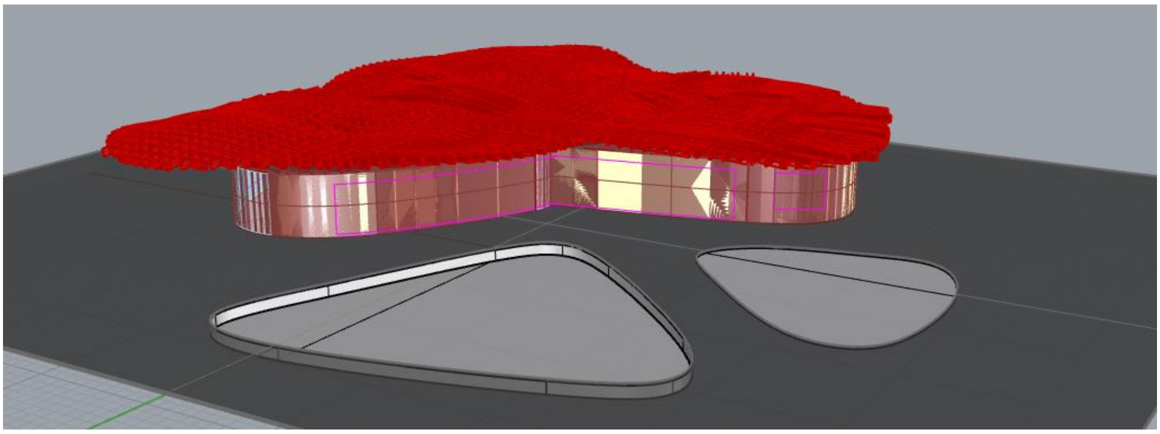

Figure 13. 3D model of the new design (view 1)

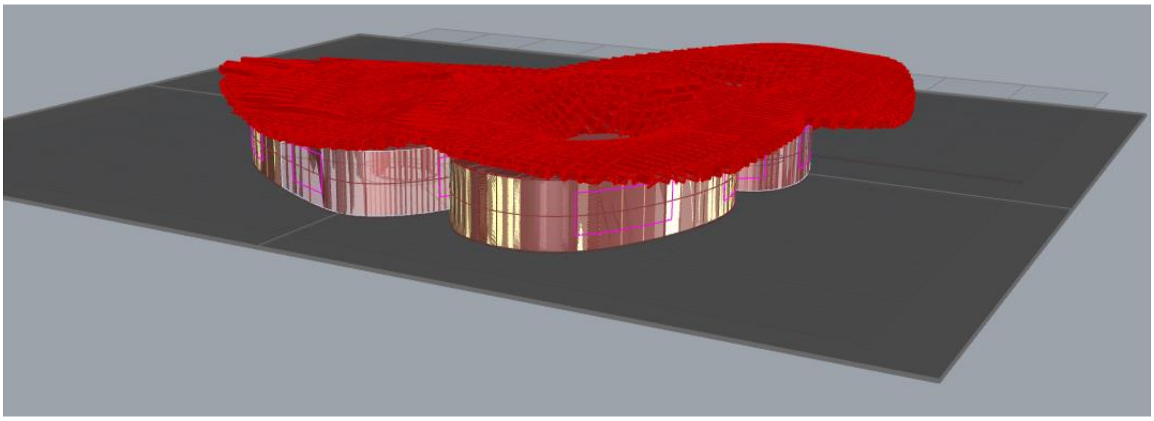

Figure 14. 3D model of the new design (view 2)

3.2. Cost estimation

Based on the Abu Dhabi official data published in the statistic center there is an estimation done on the cost of the current structure, the retrofitted one and the new design. The cost of the new design is almost 2milion aed more than the base case model (table 3). [20]

Table 3. Cost estimation of the three scenarios.

	Built up area in m2	Cost/m2	Total cost
Base case	2,469.00	3,487.00	8,609,403.00
Retrofit	2,469.00	3,907.00	9,646,383.00
New design	2,469.00	4,327.00	10,683,363.00

3. Results

The below results shown in each table shows the draft values of energy consumption. For the base case 539.40 kWh/m2, for the retrofitted case a value of 536. 70 kWh/m2, for the new design is 242.33 kWh/m2 (table 4, 5, 6).

Table 4. Energy consumption of the scenario 1: base case.

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	692190.33	539.40	539.40
Net Site Energy	692190.33	539.40	539.40
Total Source Energy	927126.34	722.48	722.48
Net Source Energy	927126.34	722.48	722.48

Table 5. Energy consumption of the scenario 2: retrofitted case.

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	739186.45	536.70	536.70
Net Site Energy	739186.45	536.70	536.70
Total Source Energy	990909.20	719.47	719.47
Net Source Energy	990909.20	719.47	719.47

Table 6. Energy consumption of the scenario 3: new design.

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	444675.55	242.33	242.33
Net Site Energy	444675.55	242.33	242.33
Total Source Energy	617771.60	336.60	336.60
Net Source Energy	617771.60	336.60	336.60

4. Discussion

The main focus of this study was to understand the impact of the building design on energy consumption. Therefore, a comparison between the base case the retrofitted case and the new building design was analyzed. The 3 buildings have the same build up area, functional areas and height. This analysis was conducted considering the local sustainability standards such as Estidama and Abu Dhabi Realm Manual. The results showed that the new design was more efficient in terms of saving energy in this specific building typology. The retrofit analysis on the second case proved to be difficult due to adapt new structure in the existing one. Also collecting material on the base case was challenging.

The software used was RHINO/Grasshopper. The modelling and analysis of each case was proven to be challenging due to the complexity of the python language. Furthermore, the energy efficiency calculation and comparison followed the preset templates of the software that later were customized as per each case.

The cost calculation followed the price enlisted in the website of the Abu Dhabi official data, the statistic center. There were some difficulties encountered to adapt the price list to the specific new material proposal. In the retrofit case, the prices were averaged based on the design selected.

However, the results are promising in understanding the relevance in designing with the sustainable principles. Adapting the building shape to the site size and orientation, using sustainable materials can be more energy efficient. This type of design can also use prefabricated structure and panels in order to reduce building construction timeline and material cost.

5. Conclusions

The aim of this study was to understand the impact of retrofit and sustainable design in energy saving on a community center in a villa compound in the city of AL Ain UAE. The analysis was carried on with 3 different models: the base case, the retrofitted model and the sustainable design model. The software used for the model analysis is RHINO/Grasshopper. This software made possible the energy calculations and comparison between the models. The models then were compared in term of cost to evaluate which option would be more sustainable on long term. Based on the results of this study a new design might be a good alternative in saving energy in long terms.

The design of a building shall be sustainable from the sketch phase. Vast areas of glass, use of glass skylight prove to increase drastically the energy consumption.

Future work is needed to validate the base model on energy bills collected from the facility management of the compound. Also alternative retrofit strategies can be explored in order to define better the cost of each case study. This study can contribute in saving energy in a large number of community centers all around the city of Al Ain and the UAE, in terms of retrofit strategies and sustainable design.

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Numerical Simulation as Alternative to Progressive Collapse Destructive Tests

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Abstract: Performing destructive tests to investigate the structure resistance to progressive collapse due to a column elimination is a very demanding and time consuming work. Therefore, verifying numerical modeling of progressive collapse of structures with available test data has been a desirable approach to develop an accurate numerical model, in lieu of demanding and costly destructive tests, that can be utilized to accurately predict the structure progressive collapse resistance. In this study, a simple fiber element-based numerical model is proposed to simulate and predict the progressive collapse resistance of such structures. The model was verified with test results for accuracy in order to be utilized in lieu of destructive tests. Reinforced concrete (RC) frame sub-assemblages with different column size, beam dimensions, and reinforcement ratios were numerically analyzed using the verified proposed model. The study demonstrates that developing a simple numerical model to investigate the progressive collapse of RC structures can be used as an alternative to destructive tests and difficult, demanding nonlinear finite element computations. The numerical results show that changing the RC frame sub-assemblage column size and beam dimensions has substantial effects as it completely changes the progressive collapse resistance and behavior of such frames. On contrast, reinforcement ratios had no effect of the structure behavior.

Keywords: Progressive collapse; RC frame sub assemblages; Fiber element approach; Numerical simulation

1. Introduction

Presently, design codes and standards do not offer clear guidelines for designing progressive collapse resistant structures. However, they focus on load redistribution capacity to fulfill a minimum level of structural integrity. In the newest edition of U.S. Design Guidelines (DoD 2016, GSA 2016, [1-2]) recommendations of designing structures with alternate load paths are proposed to diminish the non-proportional failures. Several reviews on progressive collapse experimental investigations and numerical simulation models have been described in the literature [3–6]. Regulations and guidelines were highlighted, proper detailing and damaged area under different design loads were discussed, and some recommendations for reinforced concrete, steel, and composite buildings were presented to assure robust behaviour of buildings when subjected to unanticipated loading.

Over the past decade experimental studies on the progressive collapse behaviour of RC assemblages have been reported and finite element numerical models have been proposed to simulate and predict the experimental results from testing beam-column assemblies, beam-slab assemblies, multi-story frames, full scales, half scaled, third scaled 3d structures subjected to sudden failure. Qian et al. [7] tested three unbonded posttensioned (PT) frame sub-assemblages subjected to interior column removal. Damages took place away from the side columns and concentrated at the beam ends in the locality of the middle joint. These damages were attributed to the tendon profile and lack of PT detailing. Peng et al. [8, 9] evaluated the resistances of old RC buildings with flat slab to progressive collapse due to column losses. The building lacked slab integrity reinforcement and was loaded with different load intensities until failure. It was observed that these buildings were susceptible to progressive collapse subsequent to a column removal and that they were at higher risk of collapsing when an internal column is removed. Elkholy and El-Ariss [10-13] described a technique and a numerical procedure for mitigating RC continuous beams to prevent potential progressive collapse resulting from interior column failures. The technique proposed the use of external unbounded straight cables attached to the beam at anchorage locations and deviator points, without being posttensioned. In a recent work, the authors [14] developed a simple numerical model that uses few elements and properly selected model parameters to accurately predict the resistance of structures subjected to interior column removal with minimal computational time and effort. Design of the structural members affect directly the behavior of structures to progressive collapse [15]. Also, the beam end section and support conditions have a great influence on the resisting mechanisms of flexure action, arch action, and catenary action. The gravity of properly considering these conditions in the numerical analysis of progressive is highlighted. The resisting mechanisms generated in beams could also be influenced by the following main design parameters: the beam height to span ratio and the beam longitudinal reinforcement ratio. Their influence on structure resistance to progressive collapse was also inspected by other researchers [16-18]. Keyvani and Sasani [19, 20] experimentally and analytically assessed progressive collapse resistance of a posttensioned parking garage structure by removing an interior column through explosion. The development of compressive membrane action led to an increase in the flexural capacity of garage slab, whereas the numerical models generated using SAP2000 program did not correctly simulate performance of the structure and a nonlinear finite element analysis was suggested. Likewise, Al-Salloum et al. [21] experimentally and analytically investigated the efficacy of using a retrofitting scheme of bolted steel plates to enhance the progressive collapse behavior of precast beam-column connection. They reported that elastic analysis might not be suitable to examine structures with large displacements and that nonlinear finite element analysis is recommended.

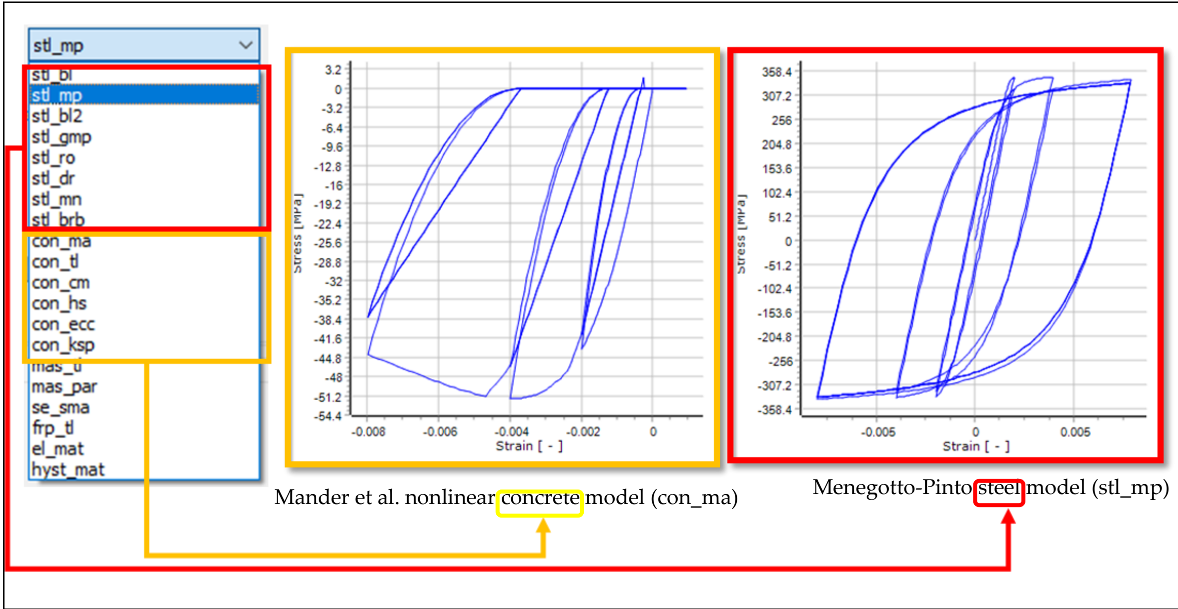
The studies presented in this literature quest have shown that there is a need to identify key parameters to optimize the accuracy of fibre-based numerical model and to examine the effect of the member dimensions and reinforcements when investigation the progressive collapse of structures. Therefore, it is of high interest to assess the impact of this design parameter on the structure ability to initiate supplementary load-carrying capacity through arch action and catenary action mechanisms.

2. Numerical Model

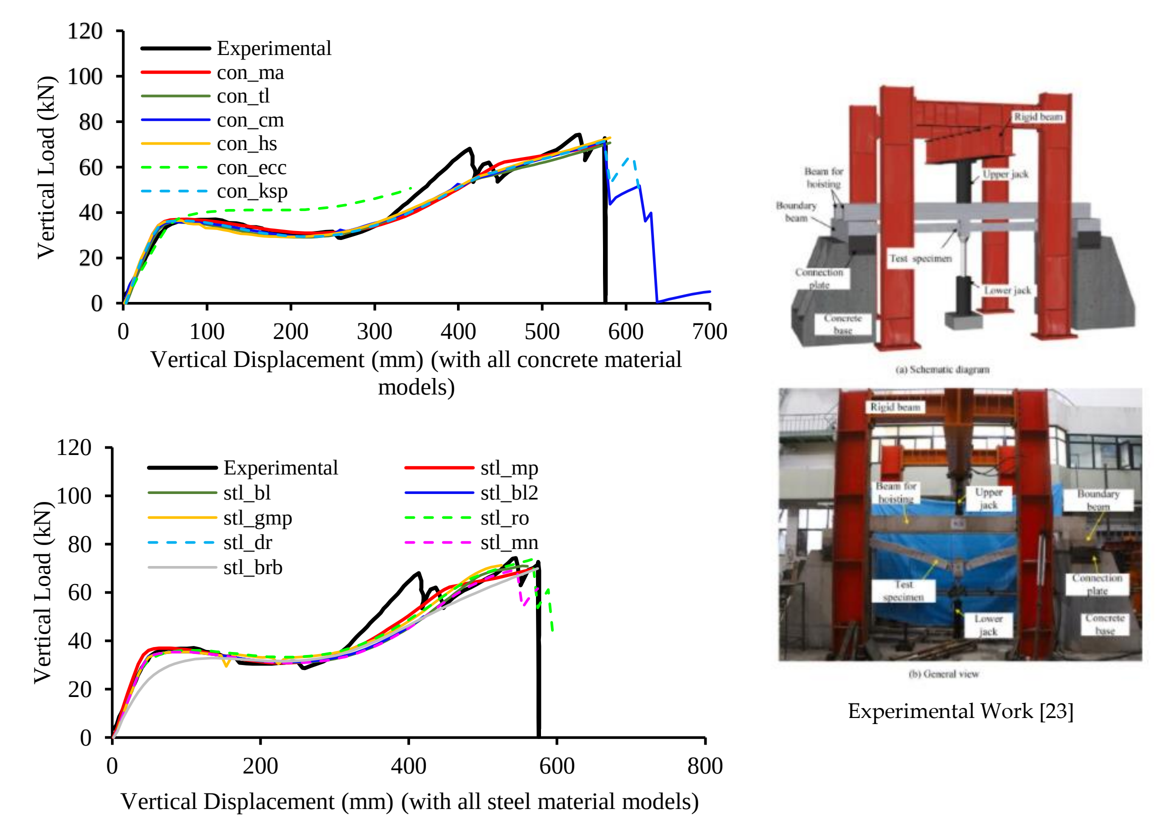
2.1 Selection of Material Properties

Fibre element-based software, SeismoStruct [22] is used in this study to generate numerical model that analyzes structures subjected to large deformations as a result of column removal. Unlike finite element models, fiber element-based model requires less elements and saves computation time.

To validate the generated fiber element-based model and get the optimal model that best simulates test behavior, RC frame sub assemblage tested by Qiang et al. [23] was modelled and analyzed. The cross-section of the members is modelled by separate individual fiber elements (typically 100–150) representing concrete and steel. The cross-section stress–strain state is obtained by integrating the nonlinear stress–strain model of the individual fires. SeismoStrcut has a large library of material models. This study examined all material models in SeismoStruct library to arrive at the optimal material properties that best simulate the test results, as shown in Figure 1. The optimal material models were found to be con_ma for concrete and stl_mp for steel bars. The numerical analysis is performed by exerting nonlinear static push-down displacement-controlled loading at the position of damaged column to simulate the structure progressive collapse. The displacement is deployed in increment and the stresses and strains are calculated for each fiber element.



(a) Defining the optimal numerical material models from the SeismoStruct library: con_ma for concrete model and stl_mp for steel bars



(b) Verifying the optimal numerical material models, con_ma and stl_mp, with experimental results

Figure 1. Optimal material properties used in the proposed numerical model.

2.2 Effects of Number of Fibers

The effect of the number of fiber elements in the member section on the accuracy of the numerical model was examined. The number of fibers chosen was varied from 29 to 249 fiber elements, as shown in Figure 2. The figure shows that varying the number of fiber elements did not have a significant effects of the accuracy of the numerical results. Therefore, the number of fiber elements in this study was taken equal to 150 elements.

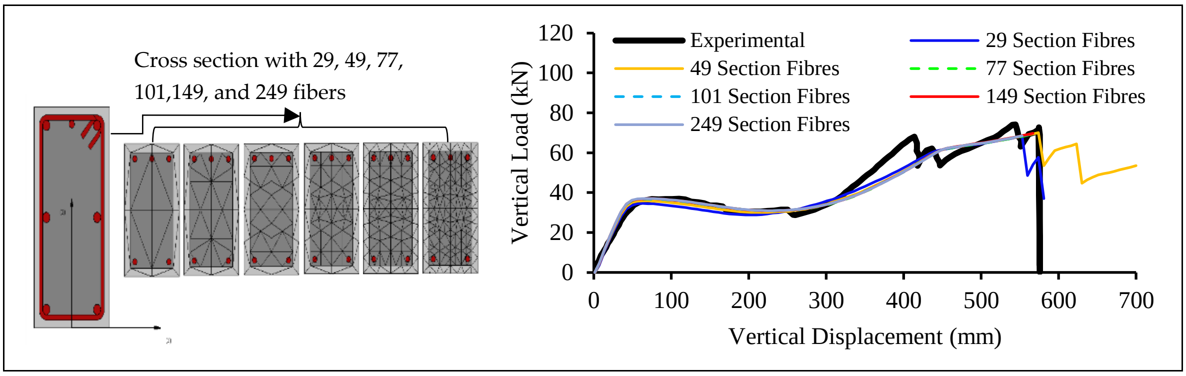


Figure 2. Effect of selected number of fiber elements on numerical results.

2.3 Effects of Plastic Hinges

On contrast, Figure 3 shows that the input length of the developed plastic hinge, L_p, as a ratio of beam spam length, *L*, has a significant effects on the numerical results. In this study the optimal ration was found to be 50%, as shown in Figure 3.

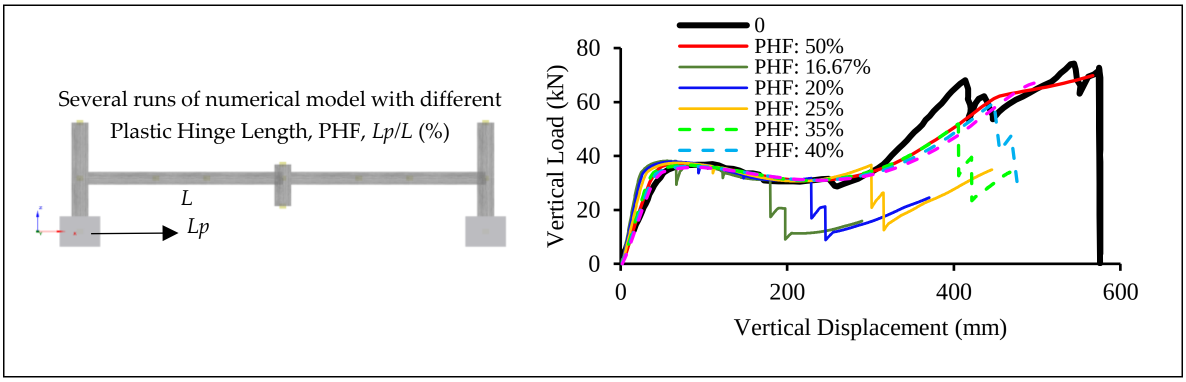


Figure 3. Effect of length of plastic hinges on numerical results.

3. Validation of Proposed Model Applications

To validate the application of the proposed fiber element-based model, a number of tests from literature were modeled and simulated as shown in Figure 4. It can be seen that the numerical model produced accurate results when compared with the test data.

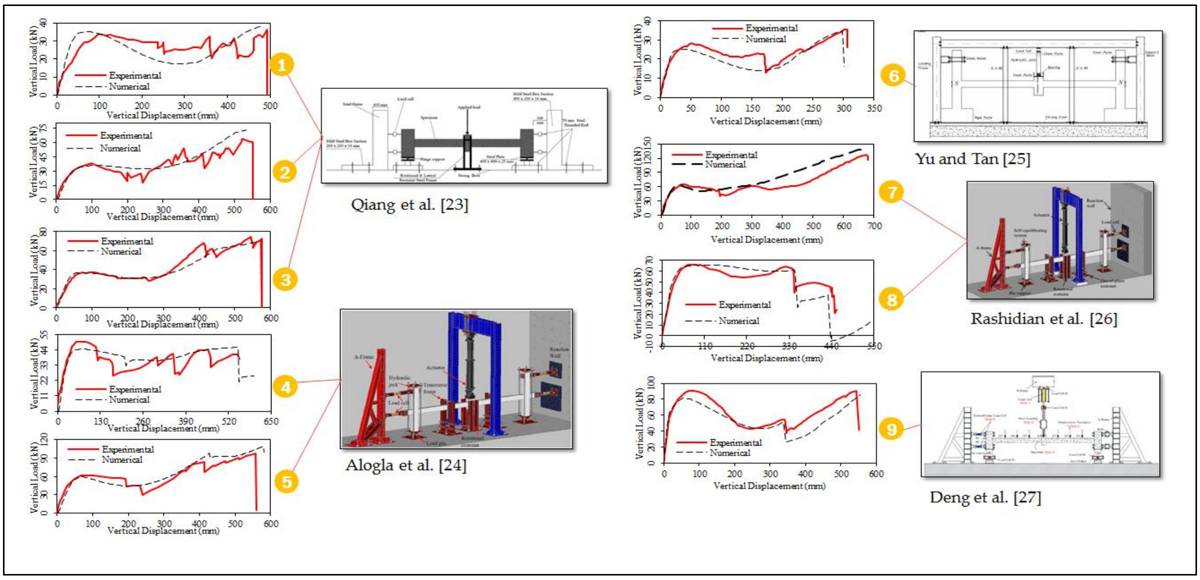


Figure 4. Validation of proposed model applications.

4. Effects of Column Dimensions, Beam Dimensions, and Reinforcement Ratios

The validated proposed fiber element-based model was used, in lieu of destructive tests, to investigate the effects of varying the column dimensions, beam dimensions, and reinforcement ratios on the behavior and resistance of RC sub assemblages to progressive collapse due to interior column removal. The RC sub assemblages (equivalent frame of one floor, Figure 5) are part of 2D frame structures with four bays in with constant span length of 5 m.

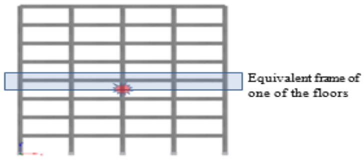


Figure 5. Structural framing of the building and equivalent frame highlighted for one of the floors.

4.1 Column Dimensions

It is clear from Figure 6 that the column dimensions considered in this study, shown in the figure, did not have a noticeable effect on the arch action developed in the structure and; therefore, the first ultimate load was not considerably affected. On the other hand, the column dimensions proved to have a major impact on the ductility, catenary action, and the structures ultimate load at failure. The column with 300 x 300 mm section underwent large plastic deformations ductility, before the catenary action developed which caused the structure to regain strength and resist much more loads before failure. The other column dimensions enhanced the catenary action of the structures but lacked the large plastic deformations and the huge increase in the strength at failure that columns with small section offered.

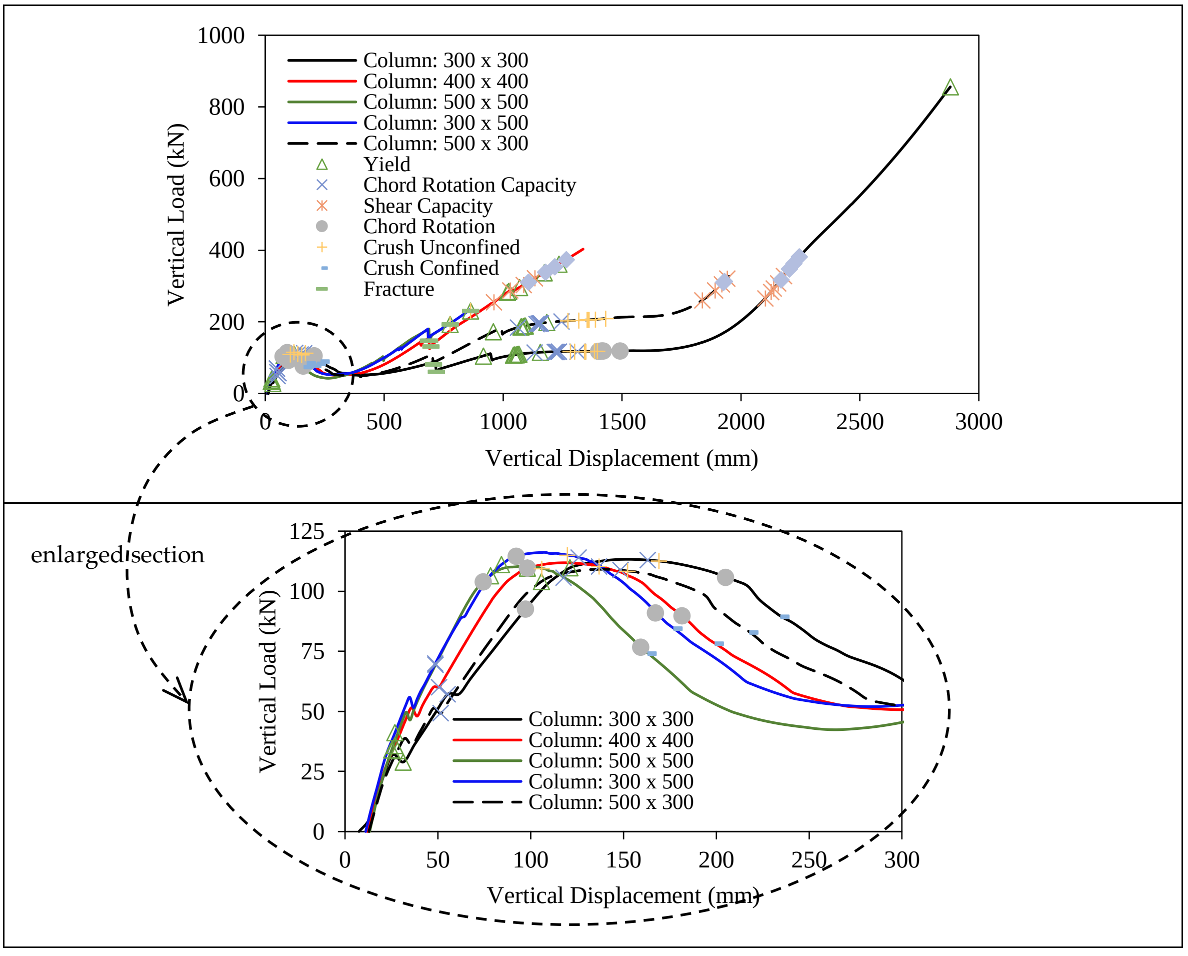


Figure 6. Effect of column dimensions on progressive collapse of RC sub assemblage.

4.2 Beam Dimensions

T-beam and rectangular beam sections with different dimensions were considered as shown in Figure 7 to examine their effects on the structure progressive collapse due to interior column failure. It is evident from the figure that sub assemblages with T-beam sections behaved better than those sub assemblages with rectangular beam sections. T-beams not only enhanced the structure catenary action and strength at failure but also boosted the arch action which increased the first ultimate load.

Credited to the horizontal resistance from the adjacent members to the removed column, slabs and beams that were carried by the removed column tolerated extra displacement due to beam compressive arch action up to a deflection at which the adjacent members can no longer provide enough restraint. Figure 7 clearly demonstrates that compressive arch action is effective at slight vertical deflections and large beam height. Also the figure shows that compressive arch action moderately increased the resistance to progressive collapse as the beam height increased. As the vertical deflection increased, the behavior of the members with less beam heights was more plastic than it was for members with larger beam heights, where the behavior was in transition mode from compressive phase to tension phase. With large deformations taking place, the axial force from the horizontal resisting neighboring undamaged members was transformed into a pulling tensile force, altering the member behavior during which strength was regained and deformations increased as shown in the figure. This behavior is a ductile one and defined as catenary action.

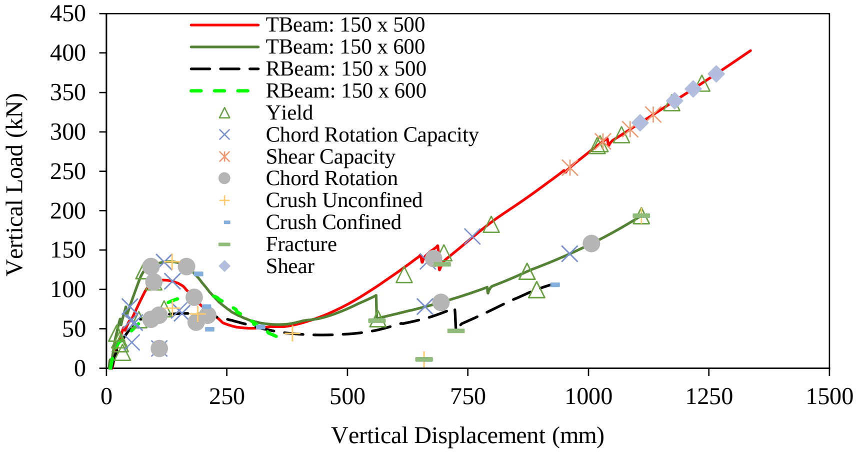


Figure 7. Effect of beam dimensions on progressive collapse of RC sub assemblage.

4.3 Reinforcement Ratios

Addition of top reinforcement at mid-span of the beams as a ratio of the positive moment reinforcement was investigated in terms of its influence on the structure progressive collapse. Figure 8 evidently shows that addition of top reinforcement at mid-span of the beams had no effect on the structure progressive collapse performance.

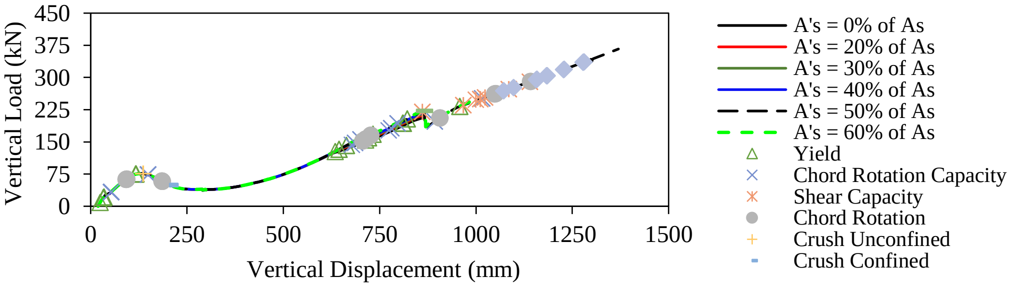


Figure 8. Effect of addition of top reinforcement at the mid-span of beam.

5. Conclusions

In this work, a simple fiber element-based numerical model using SeismoStruct software was proposed to simulate and predict the progressive collapse resistance of structures suffering a interior column loss. The model was verified with test results for accuracy was utilized in lieu of destructive tests. The study examined all material models in the software library to arrive at the optimal material properties that best simulate the test results. Varying the number of fiber elements did not have a significant effects of the accuracy of the numerical results. On contrast, the length of the developed plastic hinge, L_p, as a ratio of beam spam length, L, had a major effects on the numerical behavior of the structure. In this study the optimal ration was found to be 50%.

Reinforced concrete (RC) frame sub-assemblages with different column size, beam dimensions, and reinforcement ratios were numerically analyzed using the verified proposed model. The column dimensions proved to have a major impact on the ductility, catenary action, and the structures ultimate load at failure. The column smallest section underwent large plastic deformations ductility, before the catenary action developed which caused the structure to regain strength and resist much more loads before failure. Also, at small deflections the beam height has a direct impact on the progressive collapse resistance of the sub-assemblage as the arch action moderately increased the resistance to progressive collapse as the beam height increased. As the vertical deflection increased, the behavior of the members with less beam heights was more plastic than it was for members with larger beam heights. With large deformations taking place, the axial force from the horizontal resistance from adjacent members to failed column was transformed into a pulling tensile force (catenary action), altering the member behavior during which strength was regained and deformations increased.

The study demonstrates that developing a simple numerical model to investigate the progressive collapse of RC structures can be used as an alternative to destructive tests and difficult, demanding nonlinear finite element computations. The numerical results show that changing the RC frame sub-assemblage column size and beam dimensions has substantial effects as it completely changes the progressive collapse resistance and behavior of such frames. In the contrary, reinforcement ratios had no effect of the structure behavior.

Author Contributions: conceptualization, S.E. and B.E.; methodology, S.E. and B.E..; software A.S.; validation, S.E.; formal analysis, S.E. and B.E.; investigation, S.E. and B.E; resources, S.E. and A.S.; data curation, S.E, and B.E.; writing—original draft preparation, B.E.; writing—review and editing, B.E.; visualization, S.E., A.S., and B.E.; supervision, S.E. and B.E.; project administration, S.E. and B.E.

Conflicts of Interest: The authors declare no conflict of interest.

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Thermal Comfort in Traditional Dwellings, a Comparison between Physical Measurements and Simulated Data.

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Abstract: Summertime overheating is constantly increasing in every building, either new or old, due to global warming and climate change. The air temperatures in the UK are expected to increase by +4.4°C significantly affecting thermal comfort conditions in domestic buildings. High internal temperatures can be affected by different factors including occupants' behaviours, ventilation rates and design strategies. This paper analyses two semi-detached houses to assess risks of overheating under real weather conditions. Dynamic Thermal Simulation (DTS) is conducted, and the results are compared with the data obtained from physical measurements to assess the accuracy of the simulations in comparison to actual measurement. The results show significant discrepancies between the monitored and simulated data. Thermal comfort in the living areas exceeded the acceptable ranges defined by CIBSE TM59, particularly those facing south on the first floor. A sensitivity analysis conducted to assess the main factors affecting the accuracy of the results when conducting dynamic thermal simulations. According to the results, the ground temperature followed by U-values of the building fabrics are the key factor that could significantly affect the simulation results.

Keywords: Overheating; Thermal Comfort; Dynamic Thermal Simulation; Monitoring.

1. Introduction

Rapid urban growth in the post-war period led to an increased use of structures with cheap and simplified technologies. The dwellings built before 1970, present a very weak thermal insulation with strong transmittance values of the cladding materials. According to Barbiero [1], building sector is responsible for around 40% of the total energy consumption, and 36% of the total greenhouse gas emissions in Europe. The post-war housing era has a significant role in today's high energy consumption figures due to inappropriate energy conservation strategies. Refurbishment has therefore become a major strategy to improve energy performance of the old housing stock. To design an efficient refurbishment strategy, it is important to firstly understand the problems to avoid creating other issues such as overheating which may lead to thermal discomfort for the occupants. The global warming is making the situation even more complex as the risk of overheating is believed to significantly increase. External air temperatures in the UK are expected to rise by up to 4.2° C in winter and 5.4°C in summer by 2070 with the frequency and intensity of heat waves also expected to increase [2]. Rising external temperatures increase significantly the risk of overheating, cooling load and energy consumption in buildings, with the problem being particularly acute in office buildings. It is increasingly realised that building design and refurbishment strategies should no longer be grounded on historic climatic data but should instead focus on the potential scenarios and changes that a building might be facing during its life.

Refurbishment practices have become very common, especially in the past few years, to improve the energy performance of these buildings. These refurbishment strategies usually consist of the replacement of insulation layers in walls and roof and the renovation of fixtures [1]. According to EST [3], a sustainable and bioclimatic manner of technical improvements should be considered to reduce carbon dioxide emissions and increase a sense of well-being. Yet, buildings with limited ventilation or high internal loads are subject to a higher risk of overheating, which could be worsen by add-on insulation [4]. Moreover, the indoor temperatures are influenced by different factors such as orientation, air permeability, thermal mass and u-value ground temperature [4]. Effective use of solar shading and daylight control would significantly help to reduce risk of overheating and thermal discomfort [5]. The risk of overheating during summertime is higher due to higher exposure to solar gains [6]. Yet, according to Jones [7], similar homes may have very different indoor temperatures during the same period due to dissimilar occupants' behaviours.

More research is required to understand how buildings should be improved in a more practical way to improve their energy performance and reduce the cooling load through better design while retrofitting should be conceived to reduce the risk of overheating. To this end, this study aims to assess thermal comfort conditions in a typical semidetached house located in the suburban residential area of Loughborough, UK. Dynamic thermal simulation is conducted in EnergyPlus to assess and mitigate risk of overheating (based on the initial data provided in [8]). The purpose of this analysis is to establish whether internal temperatures would achieve comfort requirements set by CIBSE TM59 [9] standards. The results are then compared with the physical measurements and the results of other simulation packages to assess the possible reasons for differences between the measured and simulated results; with the aim to identify the most critical factors that may affect the results of simulation.

2 Case study building

A typical semidetached two-storey house constructed in the 1930s was selected as the case study building. This type house represents 16.7% of the UK housing stock, and this is the reason why they have been selected [10]. Compared to the national housing stock, 30.5% of this type houses have uninsulated cavity walls, 38.5% have similar levels of loft insulation and 80.8% are fully double glazed [10]. This pair of adjoining semidetached houses (Fig.1) are located in Loughborough (East Midlands, UK), have the same mirrored geometry (Fig.2), configuration and construction [11]. The two houses are naturally ventilated. The windows are identical in size and openings areas, as well as the floor area which is 85.4m^2 with a total volume of 209.2 m^3. These three bedrooms houses are one of the most popular types in the UK with uninsulated brick cavity walls and uninsulated suspended timber floors ventilated below by air bricks. Table 1 shows the building elements and their estimated U-values used in the simulations. The house was retrofitted in 2016 with 300mm of insulation above the first-floor ceiling and double-glazed windows and doors [12]. The main entrance is on the south façade, leading to a hallway, and the kitchen and dining room are located at the north and are separated by a wall. The dining area has a glazed door facing the garden, while the living room, at the south, features a bay window. On the first floor, there are three bedrooms, two of them are large size rooms and one is a single room (around 8m2), one bathroom and a separate small WC. The adjoining semidetached houses will unavoidably affect each other in terms of shadowing, heat transfer via the party wall and protection from the wind.

Figure 1. (Left): Case study houses viewed from the front which face south. The house pictured on the left is the West house, while the right house in the one facing East.; (Right): Case study houses viewed from the rear, this façade face north [11].

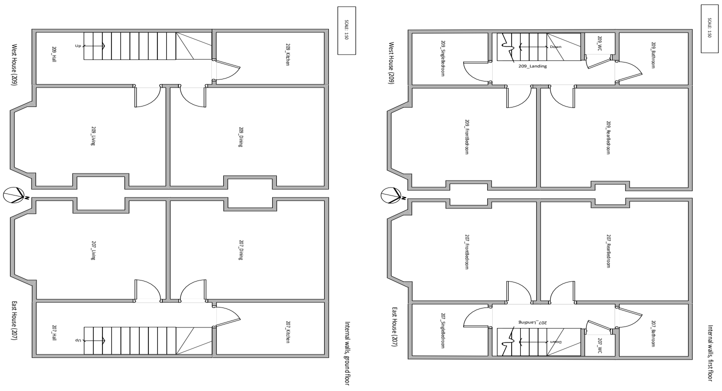

Figure 2. (Left): Ground Floor plan; (Right): First Floor plan

Table 1. Summary of the construction elements, areas and estimated U-values [11]

Building element	Description	U-value Area (m^2)	U-value (m^2)(W/m^2K)
Roof	300mm fiberglass, pitched with clay tiles over vapour-permeable membrane	0,16	45,6
External walls	Uninsulated brick cavity	1,6	89,2
Internal partition wall	Solid brick covered with gypsum plaster	2,1	53,9
Party walls	Uninsulated brick cavity covered with gypsum plaster	0,5	42,2
Ground floor (except kitchen)	Suspended timber (uninsulated)	0,8	37,6
Ground floor (kitchen)	Solid concrete (uninsulated) uPVC double glazing	0,7	5,7
Windows (north and south)	uPVC double glazing	1,4	20,3
Windows covered (east and west)	uPVC double glazing with aluminium foil on glazing and 50mm PIR foil-backed insulation board inserted into the frame	0,46	2,7
External doors	uPVC with double glazing	1,4	5,5
External doors glazing covered (east and west)	uPVC double glazing with 50mm PIR foil-backed insulation board over glazing only	0,46	0,51

3. Materials and Methods

A 3D model of the two houses using OpenStudio SketchUp plugin uploaded into EnergyPlus for thermal comfort simulations. A sensitivity analysis is carried out on air permeability, thermal mass, ground temperature and u-value; followed by thermal comfort assessment based on the criteria set by CIBSE TM59 [9] and BSEN 15251 [13] Category II threshold.

3.1 Assessment criteria

DTS is conducted in EnergyPlus to evaluate the effects of overheating and thermal comfort in the case study buildings. The risk of overheating is evaluated using three different criteria. A building is assumed to be overheated if it fails any two of the three criteria defined by CIBSE TM52. All three criteria are defined in terms of ΔT, which is the difference between the operative temperature and the maximum acceptable temperature (Table 2) [14].

Table 2. Overheating assessment criteria.

Up to 1% of occupied	Assessment Criteria	Unacceptable Deviation
Criterion 1	Percentage of occupied hours during which ΔT (ΔT = Top−Tupp(∘C)) is greater than or equal to 1°C	Up to 3% of occupied hours
Criterion 2	Annual hours when the predicted temperature exceeds 26°C	Up to 1% of occupied hours

Criterion 1

For each hour between 09:00 and 22:00 in living spaces and all hours in the day for bedrooms, the difference between the predicted operative temperature (Top) and the upper-temperature threshold (Tupp) is calculated to derive ΔT, which is rounded to the nearest whole degree:

$\Delta T = T_{op} - T_{upp} (\circ C)$

The number of hours where ΔT must be equal to or exceed 1°C between May and September is then calculated [15]. Criterion 1 is failed if the number of hours is more than 3% of the occupied hours between May and September. The final result for this criterion in the following simulation is likely to be much higher than the expectations, this is due to the chosen period. Having selected three of the warmest weeks of the year (16 June 2017 – 6 July 2017) the overheating risk percentage is very high, but it is important to keep in mind that this factor should be spread from May to September. Therefore, the risk of overheating should be essentially much lower than reported.

Criterion 2

For the UK, the CIBSE suggested operative temperature for thermal comfort and overheating criteria in free-running buildings that are broadly consistent with both deterministic and adaptive thermal comfort models for typical UK conditions [16]. The overheating criteria are that not more than 1% of annual hours during the time range 10 pm -7 am, should be above a certain operative temperature, this being 28°C except for bedrooms in dwellings, for which a lower threshold of 26°C is specified. Thermal comfort in an adaptive approach is affected by occupants' behaviours and expectations in naturally ventilated buildings. Based on this method of evaluation, it is proposed that occupants' perception regarding thermal comfort is affected by their thermal circumstances [14]. The overheating occurs when the number of hours exceeds the prefixed value assumed by Category II [9,13] upper comfort threshold (Tupp), where

$T_{upp} = 0{:}33Trm + 21.8°(C°)$

T_{rm} = running mean of outdoor air temperature (°C).

This is the equation to estimates comfortable temperature in naturally ventilated buildings.

Table 3. Summary of Simulation Conditions

Condition category	Simulation conditions
Simulation period	16 June 2017 – 6 July 2017
Location	Suburban area of Loughborough, UK
209_Window opening	Curtains open during the day, windows open if the room temperature exceed 22°C during occupied hours
207_Window opening	Curtains open during the day, windows closed at all times

3.2 Monitoring & Occupancy

To simulate the occupancy and monitor the temperature inside the house with two different scenarios, the windows were covered, and sensors were installed in the case study building. In order to minimize differences between the case study buildings, aluminium foil and 50 mm polyisocyanurate insulation boards were attached to the west and east facing windows. External sensors/loggers were installed to monitor the local weather for 21 days in summer from 16 June to 6 July. Internal temperatures were recorded, and occupancy was replicated using four pseudo-real occupants (in accordance to CIBSE TM59 occupancy schedules [9]. For the purpose of the simulation, the windows are considered to be closed during day and night, however blinds and curtains were considered to be open from 08:00 to 23:00, in accordance to TM59 sleeping schedule. The assumption was that the house was occupied 24h a day during the whole period with no exceptions. The prediction can be identified as "blind" and "open". The first term describes the prediction run through computer programs, with knowledge limited to materials, dimensions, orientation and layout. The second term, "open", is the actual measurements calculated inside and outside the buildings, which are affected also by the climate. The lighting gain was assumed to be $2W/m^2$ of the floor area, in the kitchen and living room. The internal gain is split according to TM59, in 75% in the living room and 25% in the kitchen.

4. Results

The simulation was run during the summer period to match the actual weather data collected, between the 16th of June and the 6th of July. The house located at West (209) was simulated with the curtains open during the day and the windows open only if the room temperature exceeds 22°C during occupied hours. The second house, located at East (207), was simulated with the curtains open during the day and the windows always closed during the entire day.

Table 4 shows the number of times when temperature exceeded the defined limit as well as the percentage of the overheating risk for each living space/zones in each house (kitchen, living and single, front and rear bedroom). The West house (209), thanks to the openable windows that allow ventilation, has a lower risk of overheating compared with the East house (207), where the windows are kept closed during the entire simulation period. The risk of overheating in house 207 is extremely high in most of the living spaces, especially in the front bedroom. This room is particularly overheated because of its orientation in addition to a large south facing bay window, that without any shading system allows direct sun and heat to enter the room. The rear bedroom (facing North) is also at risk, but this is mainly due to an absence of ventilation. Indeed, the rear bedroom of the house 209, which has the same properties, has a much lower risk of overheating meaning that natural ventilation is one of the most important factors that influence thermal comfort. The single bedroom in house 207 is the most overheated area with a higher number of hours exceeding the maximum standard for criterion 1 and 2.

Table 4. Risk of overheating in house 207 and 209

House	Zone	%	Criteria 1	Criteria 2
209	Kitchen	1.78	9	23
209	Living	6.34	32	49
209	Single Bedroom	7.73	39	25
209	Front Bedroom	4.36	22	9
209	Rear Bedroom	3.57	18	22
207	Kitchen	5.55	28	45
207	Living	16.66	84	118
207	Single Bedroom	3.53	178	108
207	Front Bedroom	30.15	152	98
207	Rear Bedroom	19.04	96	88

Figure 3 shows the temperature ranges in CSB 207 and 209 when the windows are open and/or closed. In 209, where the windows are openable, temperature goes above the T(max) for four days causing a moderate thermal discomfort for the occupants. However, the situation is significantly more critical in 207, as the windows are constantly closed, resulting in a drastic increase in temperature (T(max)) for a period of nine days. The temperature reached the upper limit for three days indicating sever overheating. In 209, the temperature is noticeably more stable meaning that the thermal shock between day and night is limited.

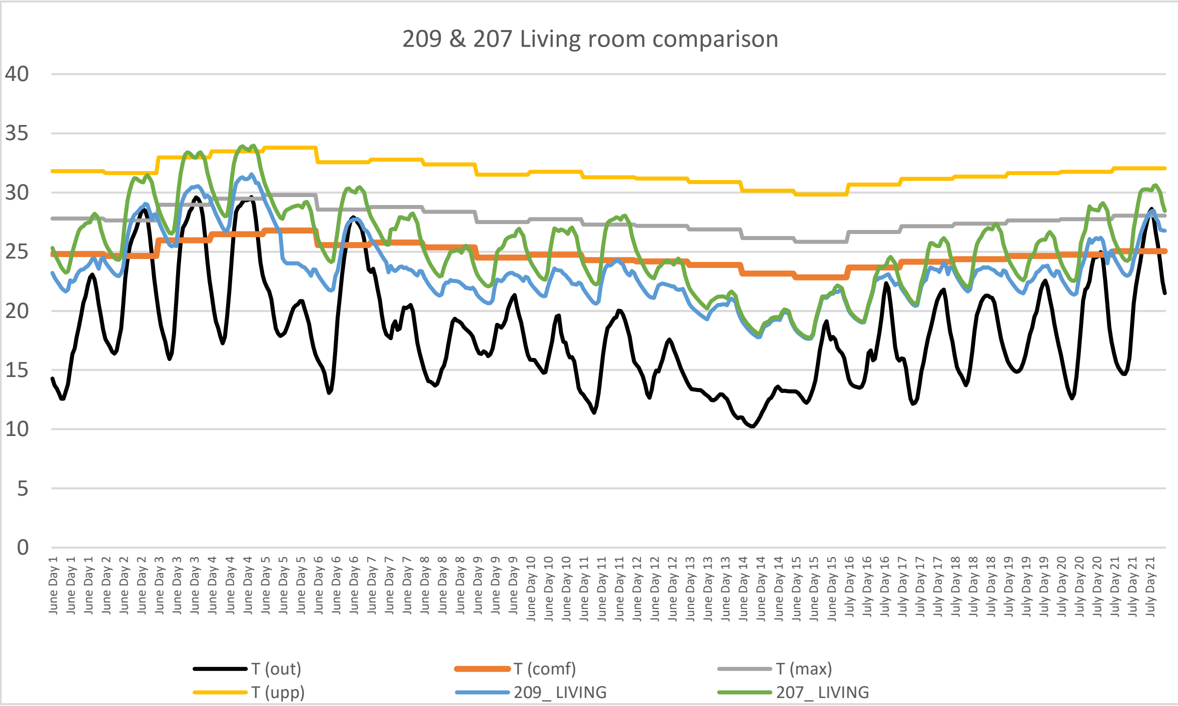

Figure 3. 209 & 207 Living room comparison.

A sensitivity analysis was considered to assess the influence of different variables on risk of overheating:

a) air permeability +/-10%,

b) U-value +/-10%,

c) thermal mass +/-10%; and

d) ground temperature +/-1°C and +/-5°C.

Table 5 summaries the results of the simulations for the above configurations. According to the results, ground temperature, air permeability (+10%) and U-value (+10%) have a significant impact on risk of overheating. Contrarily, the factors which are likely to increase the overheating risk are ground temperature (+5°C) and U-value (-10%). These factors which increase the risk of overheating are respective of 8,5% and 6,9% in the living room 209 and, 25,5% and 18,3% in the living room 207. The ground temperature, in every criterion, appear to be the most significant factor that may affect the outcomes meaning that it is critical to accurately know the ground temperature to achieve accurate results. This value is obviously more important especially for areas where the external boundary is defined as ground (i.e. the kitchen and living room in the CSB).

Table 5. Summary of Simulation result. Linked to Figure 3

209 living room	%	Cr.1	Cr.2
Air permeability -10%	6,5	33	49
Air permeability +10%	6,1	31	49
U-Value -10%	6,9	35	49
U-Value +10%	6,3	32	48
Ground Temperature -5°C	4	22	35
Ground Temperature +5°C	8,5	43	68
Ground Temperature -1°C	5,7	29	46
Ground Temperature +1°C	7,5	38	50
Thermal mass -10%	7,3	37	50
Thermal mass +10%	5,7	29	46

207 living room	%	Cr.1	Cr.2
Air permeability -10%	18	91	127
Air permeability +10%	15,6	79	111
U-Value -10%	18,3	92	133
U-Value +10%	15,6	79	105
Ground Temperature -5°C	10,5	53	71
Ground Temperature +5°C	25,5	129	177
Ground Temperature -1°C	15	76	105
Ground Temperature +1°C	18,2	92	133
Thermal mass -10%	18	91	122
Thermal mass +10%	15,4	78	115

Cr.1 = Criterion 1; Cr.2 = Criterion 2

Figure 4 shows a comparison between different bedrooms (single bedroom, front bedroom and rear bedroom) of the house 209. The temperature difference is higher during the warmest days (i.e. 17th of June to the 20th of June). During this period the single bedroom, which is south facing, is the hottest zone of the three, but the orientation does not seem to be the only reason. The high glazing to floor area ratio seems to be another major factor that increases the risk of overheating. Looking closely at the simulation result of 209, the front bedroom (Table 6) the factor that mostly reduced the overheating risk is ground temperature (-5°C), followed by the air permeability +10% and the U-vale +10%. According to the results, the ground floor areas are mainly affected by the ground temperature while the rooms located on the first floor are more affected by the air permeability and the U-value.

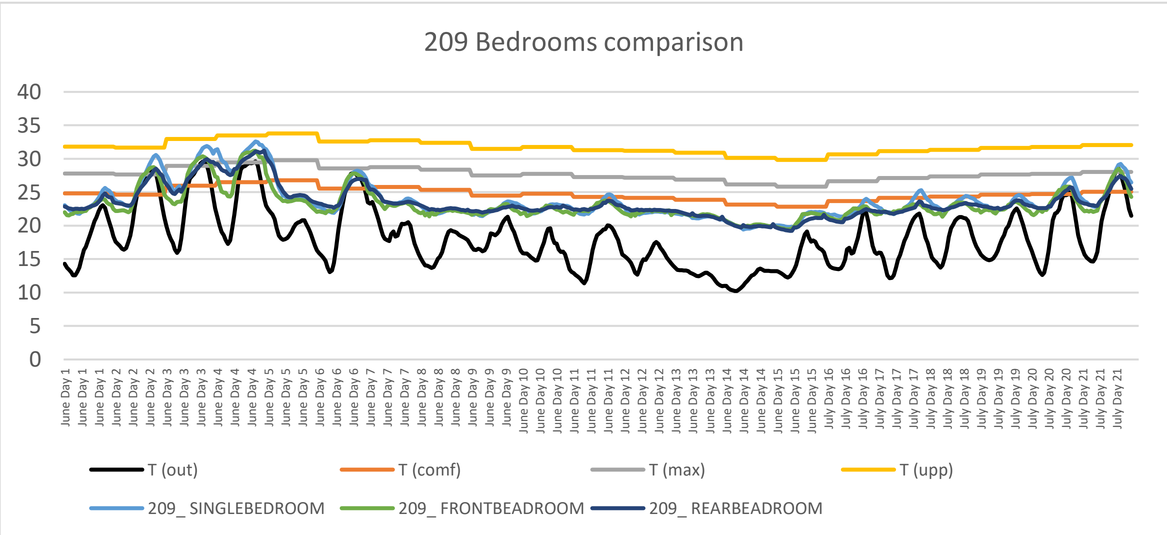

Figure 4. 209 bedrooms comparison.

Table 6. Summary of the Simulation result. This table is linked to Graph N.2 and N. 4

209 single bedroom	**%**	**Cr.1**	**Cr.2**
Air permeability -10%	7,9	50	40
Air permeability +10%	7,5	38	59
U-Value -10%	7,5	38	58
U-Value +10%	7,9	40	60
Ground Temperature -5°C	7,5	38	57
Ground Temperature +5°C	8,1	41	60
Ground Temperature -1°C	7,5	38	59
Ground Temperature +1°C	7,9	40	60
Thermal mass -10%	7,9	40	60
Thermal mass +10%	7,5	38	58
209 rear bedroom	**%**	**Cr.1**	**Cr.2**
Air permeability -10%	3,5	20	39
Air permeability +10%	3,3	17	37
U-Value -10%	3,1	16	38
U-Value +10%	3,5	18	38
Ground Temperature -5°C	1,7	9	32
Ground Temperature +5°C	4,3	22	43
Ground Temperature -1°C	3,3	168	37
Ground Temperature +1°C	3,9	181	39
Thermal mass -10%	4,1	21	40
Thermal mass +10%	2,7	14	36
209 front bedroom	**%**	**Cr.1**	**Cr.2**
Air permeability -10%	4,5	23	33
Air permeability +10%	4,3	22	33
U-Value -10%	4,3	22	33
U-Value +10%	4,5	23	33
Ground Temperature -5°C	4,1	21	33
Ground Temperature +5°C	4,9	25	35
Ground Temperature -1°C	4,3	22	33
Ground Temperature +1°C	4,5	23	33
Thermal mass -10%	4,9	25	33
Thermal mass +10%	4,1	21	33

[1] Cr.1 = Criterion 1; Cr.2 = Criterion 2

Figure 5, shows the comparison of the simulation results with the physical measurements. The physical measurements are tested inside the house thanks to the equipment that also took into consideration the pseudo-real occupancy, assuming that the houses were occupied 24h a day with no difference between weekdays and weekends. The analysis of the measured results focuses on the period from 16 June to 6 July 2017. Between 17 and 21 June, there was a five-day warm spell during which the outdoor temperature reached an hourly peak temperature of 29.7°C on 18 June with a peak global solar irradiance of 936 W/m2 on 5 July. The final day of the experimental period, 6 July, was also warm. Between these dates, the outdoor temperature rarely exceeded 21°C. The graph shows how the simulation produces results which are easily influenced by factors such as the infiltration rate and the U-Value. The physical measurements do not have a wide thermal excursion as shown in the simulation, but the temperature is kept constant. This is a key point because keeping the temperature constant, the thermal comfort inside that dwelling increases. During this simulation, the ground temperature is the most significant source of uncertainty, that also determinate the big difference between the simulation and the actual test. With it, the infiltration rate represents an important factor that varies with the wind pressures and indoor to outdoor temperature differences. Moreover, many other important factors which determinate the credibility of the simulation are the U-value that directly affected the predicted peak room temperatures and the air permeability. The last factor taken into consideration is the thermal mass of the internal walls; improving the quality of this factor, also the simulation outcome will drastically change.

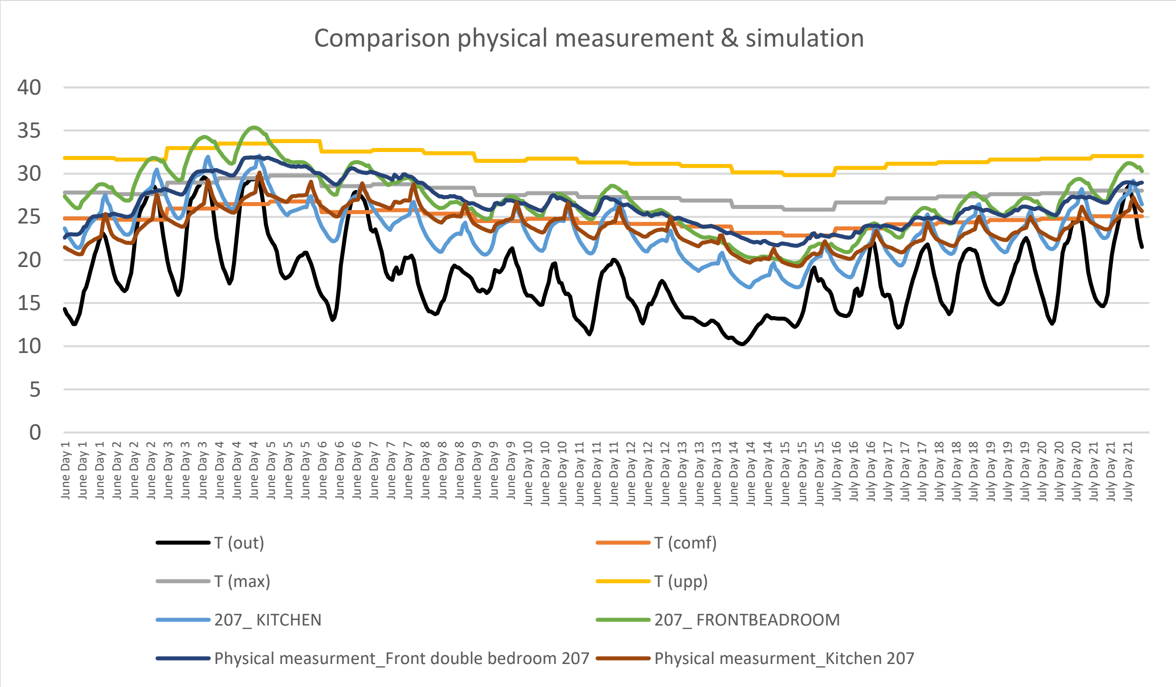

Figure 5. Comparison physical measurement & simulation.

Additional simulations were run (Table7) to study the effects of each single factor on risk of overheating in each room. According to the results the 207 single bedroom is always the room mostly at risk, while the north facing 209 kitchen has a very low risk of overheating. Moreover, the ground floor rooms, in general, are cooler during the summer due to their direct contact with the ground as well as the buoyancy effects. Behavioural effects were simulated by means of opening and closing the windows in house 209. In house 209, the curtains are open during the day and the windows are opened when the room temperature exceeds 22°C during occupied hours. Analyzing and comparing the results reveal that in the 209 front bedroom, the simulated and the physical measurements are very similar when the temperature is equal or lower than 22°C. On the contrary, when the temperature exceeds 22°C and the windows are open, the difference between the simulated and physical measurement increases significantly.

Comparing the results of the 207 kitchen reveal that the situation is different in comparison to the bedrooms explained above. In this case the physical measurement is constantly higher than the simulated result and, the gradient is also much more linear, due to the closed windows which prevents a thermal shock keeping the temperature always above the 22°C.

Table 7. Summary of the Simulation result.

207 kitchen	%	Cr.1	Cr.2
Air permeability -10%	6	31	47
Air permeability +10%	5,5	28	44
U-Value -10%	6,1	31	48
U-Value +10%	5,3	27	44
Ground Temperature -5°C	1,1	6	23
Ground Temperature +5°C	13,6	69	95
Ground Temperature -1°C	4,5	23	37
Ground Temperature +1°C	7,1	36	53
Thermal mass -10%	6,5	33	49
Thermal mass +10%	4	24	42
209 kitchen	**%**	**Cr.1**	**Cr.2**
Air permeability -10%	1,7	9	24
Air permeability +10%	1,7	9	21
U-Value -10%	1,5	8	23
U-Value +10%	1,7	9	21
Ground Temperature -5°C	0,5	3	10
Ground Temperature +5°C	4,4	21	39
Ground Temperature -1°C	1,5	8	19
Ground Temperature +1°C	2,1	11	25
Thermal mass -10%	2,1	11	25
Thermal mass +10%	1,5	8	22

[1] Cr.1 = Criterion 1; Cr.2 = Criterion 2

Table 8 shows how each criterion affects the result giving the percentage of overheating risk for every room simulated. Looking at the results from a different point of view reveal that the ground temperature is the factor which mostly affects the outcome of the simulation, therefore is crucial to accurately calculate and consider this input to avoid major discrepancies.

The 209 kitchen is always the room with the lowest overheating risk due to its location and orientation on the ground floor and facing north. Similarly, the 207 single bedroom is always the room prone to overheating due to being on the first floor and facing the south. The risk of overheating in 207 single bedroom is also linked to its high solar gain to volume ratio.

Table 8. Summary of the Simulation result.

Air permeability -10%			
	%	Cr.1	Cr.2
207 Kitchen	6,1	31	47
209 Kitchen	**1,7**	9	24
207 Living	8	91	127
209 Living	6,5	33	49
207 Front Bedroom	33,5	169	185
209 Front Bedroom	4,5	23	33
207 Rear Bedroom	21,4	108	151
209 Rear Bedroom	3,9	20	39
207 Single Bedroom	**37,3**	188	214
209 Single Bedroom	7,9	40	60

Air permeability +10%			
	%	Cr.1	Cr.2
207 Kitchen	5,5	28	44
209 Kitchen	**1,7**	9	24
207 Living	15,6	79	111
209 Living	6,1	31	49
207 Front Bedroom	26,7	135	169
209 Front Bedroom	4,3	22	33
207 Rear Bedroom	16,2	82	127
209 Rear Bedroom	3,3	17	37
207 Single Bedroom	**32,3**	163	186
209 Single Bedroom	7,5	38	59
U-Value -10%			
	%	Cr.1	Cr.2
207 Kitchen	6,1	31	48
209 Kitchen	**1,5**	8	23
207 Living	18,2	92	133
209 Living	6,9	35	49
207 Front Bedroom	33,1	167	185
209 Front Bedroom	4,3	22	33
207 Rear Bedroom	21	106	150
209 Rear Bedroom	3,1	16	38
207 Single Bedroom	**37,5**	189	213
209 Single Bedroom	7,5	38	58
U-Value +10%			
	%	Cr.1	Cr.2
207 Kitchen	5,3	27	44
209 Kitchen	1,7	9	21
207 Living	15,6	79	105
209 Living	6,3	32	48
207 Front Bedroom	26,7	135	171
209 Front Bedroom	4,5	23	33
207 Rear Bedroom	17,2	87	131
209 Rear Bedroom	3,5	18	38
207 Single Bedroom	**32,5**	164	187
209 Single Bedroom	7,9	40	60
Ground temperature -5°C			
	%	Cr.1	Cr.2
207 Kitchen	1,1	6	23
209 Kitchen	**0,5**	3	10
207 Living	10,5	53	71
209 Living	4	22	35
207 Front Bedroom	23	116	155
209 Front Bedroom	4,1	21	33
207 Rear Bedroom	11,7	59	107
209 Rear Bedroom	1,78	9	32
207 Single Bedroom	**29,3**	148	175
209 Single Bedroom	7,5	38	57
Ground temperature +5°C			
	%	Cr.1	Cr.2
207 Kitchen	13,6	69	95
209 Kitchen	**4,1**	21	39

207 Living	25,5	129	177
209 Living	8,5	43	68
207 Front Bedroom	37,3	188	208
209 Front Bedroom	4,9	25	35
207 Rear Bedroom	25,1	127	164
209 Rear Bedroom	4,3	22	43
207 Single Bedroom	**41,1**	209	229
209 Single Bedroom	8,1	41	60
Ground temperature -1°C			
	%	Cr.1	Cr.2
207 Kitchen	4,5	23	37
209 Kitchen	**1,5**	8	19
207 Living	15	76	105
209 Living	5,7	29	46
207 Front Bedroom	28,1	142	173
209 Front Bedroom	4,3	22	33
207 Rear Bedroom	17,6	89	132
209 Rear Bedroom	3,3	17	37
207 Single Bedroom	**33,3**	168	192
209 Single Bedroom	7,5	38	59
Ground temperature +1°C			
	%	Cr.1	Cr.2
207 Kitchen	7,1	36	53
209 Kitchen	**2,1**	11	25
207 Living	18,2	92	133
209 Living	7,5	38	50
207 Front Bedroom	31,3	158	182
209 Front Bedroom	4,5	23	33
207 Rear Bedroom	20,2	102	147
209 Rear Bedroom	3,9	20	39
207 Single Bedroom	**35,9**	181	205
209 Single Bedroom	7,9	40	60
Thermal mass -10%			
	%	Cr.1	Cr.2
207 Kitchen	6,5	33	49
209 Kitchen	**2,1**	11	25
207 Living	18	91	122
209 Living	7,5	38	50
207 Front Bedroom	30,9	156	181
209 Front Bedroom	4,9	25	33
207 Rear Bedroom	19,6	99	140
209 Rear Bedroom	4,1	21	40
207 Single Bedroom	**34,9**	176	203
Thermal mass +10%			
	%	Cr.1	Cr.2
207 Kitchen	4	24	42
209 Kitchen	**1,5**	8	22
207 Living	18	91	122
209 Living	5,7	29	46
207 Front Bedroom	29,5	149	175
209 Front Bedroom	4,1	21	33

207 Rear Bedroom	29,5	149	175
209 Rear Bedroom	2,7	14	36
207 Single Bedroom	**35,5**	179	198
209 Single Bedroom	7,5	38	58

[1] Cr.1 = Criterion 1; Cr.2 = Criterion 2

5. Conclusion

The summertime overheating in the UK homes is becoming a major issue. Simulations are great tools to assess the risk of overheating in new and existing buildings; however, the accuracy of simulations depends greatly on the input data. The aim of this research was to compare the results of physical measurements with computer simulations to test the accuracy of data and then suggest solutions to reduce the gap between simulations and actual conditions when it comes to thermal comfort in residential buildings. The results of this research show that the ground floor areas are mostly affected by the ground temperature whereas the U-values and of the building elements and the air permeability figures are more significant on the upper floors, although the ground temperature is still influential. Therefore, arguably, the ground temperature is the most important variable that should be accurately calculated and considered in simulations to achieve accurate results and reduce discrepancies. Further research is required to assess the effects of a combination of different variables on the outcomes.

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Session 11:

Social Sustainability and Impact

Assessing Emotional Affordance of the Brand Image and Foreign Image Based on the Emotiv Epoc+ Using Case Studies from Dubai

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Abstract: This paper is concerned with investigating the effect of contemporary architectural styles on the unconscious human emotion. In particular, it looks at the traditional visual context versus the international visual context within the built environment. United Arab Emirates (UAE) is one of the countries that has applied little restrictions on the adoption of the architectural styles, the case that makes it an appropriate place to conduct this kind of studies. The main aim of this paper is to investigate the emotional affordance of a number of participants when they observe a visual context of a 'Brand Image' and compare it with another visual context of 'Foreign Image', both were selected from the city of Dubai. A physiological method used to examine the emotional quality of the studied visual contexts, it depends on EMOTIV algorithm which translates the electrical waves extracted from the brain cortex into six brain performance metrics. These metrics include: Stress; Engagement; Interest; Focus; Excitement; Relaxation. A sample of 29 subjects of laypeople participated in this study, including locals and nonlocals (aged 19-45) the participants were divided into three groups; Al Ain locals, northern emirates locals, and nonlocals. The results showed that the brand image provides the observers with better emotional quality than the foreign image for local participants from Al Ain and nonlocal participants, while the foreign image provided no statistical significance for the three groups. The findings of this study contribute to the emotional studies in the field of meaning in architecture. It also validates the effectiveness of the physiological method to investigate the emotional responses to architectural styles. The outcomes of this study supported that designing new buildings based on local traditional architecture is meaningful and contributes to the wellbeing of the local society.

Keywords: Contemporary architecture, Emotional quality, EMOTIV, EPOC+, EEG.

1. Introduction

The urban context has been one of the main debates between world-class architects within the last seven decades and up to this moment. Architects like Rem Kollhass, Zaha Hadid, Frank Gehry, Daniel Libeskind, and others, denounced the concept of respecting the context in designing new buildings, they were inspired by Jacques Derrida Deconstructive Theory. While architects such as Tado Ando, Peter Zumther, Renzo Piano, Michael Graves, and others, were desperately calling for respecting the context [1]. On one hand, the debate between architects not yet concluded and it is usually based on endless theoretical arguments which lack the scientific evidence. On the other hand, science-based studies would provide helpful evidence to better guide the theoretical debate. In the last decade, increasing number of studies have explored the relationship between the built environment with either human emotions, perceptions or cognitions. In this field, at least four subfields are directly related to environmental perception and architectural styles, those fields are: place attachment studies [2-4], psychological restoration studies [5], scientific aesthetic studies [6], and the built environment and psychology. This paper is based on the previous studies and dissertations in the field of the built environment and psychology that have specifically studied the emotional quality of laypeople when exposed to traditional and modern visual contexts. Examples of these studies include those by Agiel [7] and Agiel, Lang and Caputi [8], who explored the existence of emotional connection between the visual context and people and its impact on people attachment to the place. Mastandrea, Bartoli, and Carrus, found that the stimuli of classic architecture were quickly processed and were connected with positive words without difficulty as compared to the stimuli of contemporary architecture [9]. Also Stamps and Nasar, reported that popular styles are preferred over avant-garde styles [10], while Stamps reported the reverse [11]. Chokor and Stamps concluded that people preferred modern buildings to popular buildings [12-13], while Groat, Devlin and Nasar, Purcell and Nasar, and Rodriguez concluded the reverse [14-17]. Those studies have explored the emotional connections and preferences of laypeople based on their conscious feedback; as the participants feedback was collected by the participant's self-assessment with Likert scale method except for Agiel dissertation that was based on participants' conscious and subconscious interpretations with the Personal Construct Theory method. The results of studies that rely on the conscious interpretations have been somewhat inconsistent. The present study, which is a part of thesis for master degree, explores the unconscious interpretations from participants. Unconscious interpretation is the data that is collected without the participant interference and it is based on measuring the physiological attributes of the participants. The unconscious interpretation has never been previously explored in this area of research. The research question in this study is presented as; do the architectural styles that have a relation with the past afford a better emotional quality than the ones that do not? The authors assume that the architectural styles that have a relation with the past afford better emotional quality than architectural styles that do not have this relation. This study contributes to the knowledge on meaning in architecture, and it provides scientific evidence to enhance the architectural debate on theory and practice.

2. Research Methodology

This explorative research was conducted by experiment to explore laypeople's emotions and brain performance in response to a specific attribute within a built environment. The empirical study consisted of five components should be specified to complete the study successfully: the change in environmental attributes; the stimuli and the stimulation method used; the measurement tool used to explore the effect of the change in attributes; the participants affected by the change of this variable; and the affected emotions. These components are discussed by Nasar in his research experience in this field [18].

The change in environmental attributes and the stimuli: Two contradictory environments in terms of their historical significance were selected; brand image and foreign image. Al Fahidi Historical District (also known as Al Bastakiya) [19] was selected as a brand image and City Walk was selected as the foreign image

Response measures (measurement tool): Typically, there are three tools for measuring emotions: (1) self-reporting (e.g., the Self-Assessment Manikin, questionnaires, or interviews); (2) behavioral analysis (e.g., facial expressions such as the Facial Action Coding System or facial electromyography); and (3) physiological methods (e.g., cardiac rhythm, physiological signals, or respiration) [20]. A physiological method, specifically EEG signal analysis, has been used in previous research on emotions and the built environment [21-22] and in multiple studies to detect human emotions and test their credibility [20, 23-27].

Respondents: Three groups of participants from different origins but living in Alain city (Alain locals ($n = 7$), Northern Emiratis locals ($n = 12$) and nonlocals ($n = 10$)) have been recruited because the historical value is something argued to be relative to the participant origin [28], also it is found that the public preference would be affected by the geographic location of the participants [16,29-31].

Affected emotions: Using an EPOC+ headset, the following six emotions (performance metrics) were measured: excitement, interest, stress, engagement/boredom, focus, and relaxation. These emotions are defined on the Performance metrics [32].

Experiment: The researcher had difficulty convincing people to participate because of the duration and nature of the experiment, which involved fixing an EEG device on participants' heads. This latter aspect also determined the gender of participants, who were all males, because women in

UAE typically do not allow strangers to see their hair or have physical contact with their heads This was conducted in a quiet room with participants seated on chairs. The room temperature was 24–26 C and lighting was moderate. Some experiments were abandoned because of unexpected noise or connectivity issues. Participants were exposed to a short brief about the experiment 5 minutes before the start of the experiment. The procedure involved fixing the device to the top of participants' heads and connecting it to the laptop, which took 5–10 minutes. After obtaining a sufficient signal, four scenes were randomly shown to participants on a smartphone-based virtual reality headset, which converted a split window of a 360-degree photograph on a smartphone screen to a virtual reality environment. Each scene comprised three major angles, and participants were told to focus on the buildings in each angle for 10–13 seconds until the EPOC+ device gave a reading (the EPOC+ device collects readings from the last 7 seconds). After each reading was obtained, participants were instructed to view the next angle. The smartphone screen was mirrored on the laptop screen so that the researcher was aware of the angle that participants were observing. The entire procedure, from the participants' observations of the first scene to the last (45 min on average), was recorded by both audio and laptop screenshots, the participants didn't show any kind of dissatisfaction after finishing the experiments, maybe because they were prepared for such period. However, Laptop screen videos were also recorded also.

Wilcoxon signed-rank test was used to objectively analyze the collected data to validate the following research hypothesis: *The architectural styles that have a relation with the past afford better emotional quality than architectural styles that do not have this relation*. The Wilcoxon signed-rank test is a non-parametric analysis method —does not assume the normality of the data— that does account for the magnitude of the observations [33]. Bootstrapped paired t-test method was also used for analyzing the data for more robustness. Statistical methods were used because of the nature of the collected data from the EPOC+ device and because validation requires a highly credible and quantitative method.

Three sets of analysis were conducted on the data collected from each group of participants, which are reflected in three boxplot graphs, Wilcoxon signed-rank test and paired t-test with bootstrap were made for each set of analysis. In the first analysis, we compare the EEG results from the daytime brand image scene with the foreign image scenes. In the second analysis, we compare the EEG results of the nighttime brand image scene with the foreign image scenes. In the third analysis, we compare the EEG results of the daytime brand image scene with the nighttime brand image scenes. The Two statistical tests gave concordant results for all comparisons considered.

3. Results

In some cases, the experiment was interrupted by unexpected noise from the air conditioner or doors opening and closing. However, this was addressed by ignoring the results from interrupted experiments and repeating the measurements. Some of the nominal values might be a result of the low sample size.

3.1. Al Ain City Locals

The results of the three statistical analyses are reflected in a boxplot graph divided into three zones, each representing a set of statistical analysis. Figure 1 shows the differences in EEG readings derived from the brand image and foreign image scenes. The zero-value line indicates no change in readings. In the left-hand and middle zones, a positive result indicates that the brand image readings were higher than the foreign image readings, while a negative result indicates that the foreign image readings were higher than the brand image readings. In the right-hand zone, a positive result indicates that the daytime brand image readings were higher than the nighttime brand image readings, while a negative result indicates that nighttime brand image readings were higher than the daytime brand image readings. Boxplots in red indicate that the performance metric was statistically significant based on the p-values.

Therefore, the significant changes for Al Ain locals from the Wilcoxon signed-rank test may be interpreted as follows. The focus of Al Ain locals when observing the daytime brand image scene compared with the modern scenes was, on average, higher for the daytime brand image scene (Mdn = 65.3) than for the modern scenes (Mdn = 57.8). The Wilcoxon signed-rank test indicated that this difference was statistically significant (T = 27; Z = −2.197; p < 0.029). The excitement of nonlocals when observing the daytime brand image scene compared with the modern scenes was, on average, higher for the daytime brand image scene (Mdn = 65.3) than for the modern scenes (Mdn = 41.2). The Wilcoxon signed-rank test indicated that this difference was statistically significant (T = 26; Z = −2.028; p < 0.044). The excitement of nonlocals when observing the night-time brand image scene compared with the modern scenes was, on average, higher for the night-time brand image scene (Mdn = 60) than for the modern scene (Mdn = 41.2).

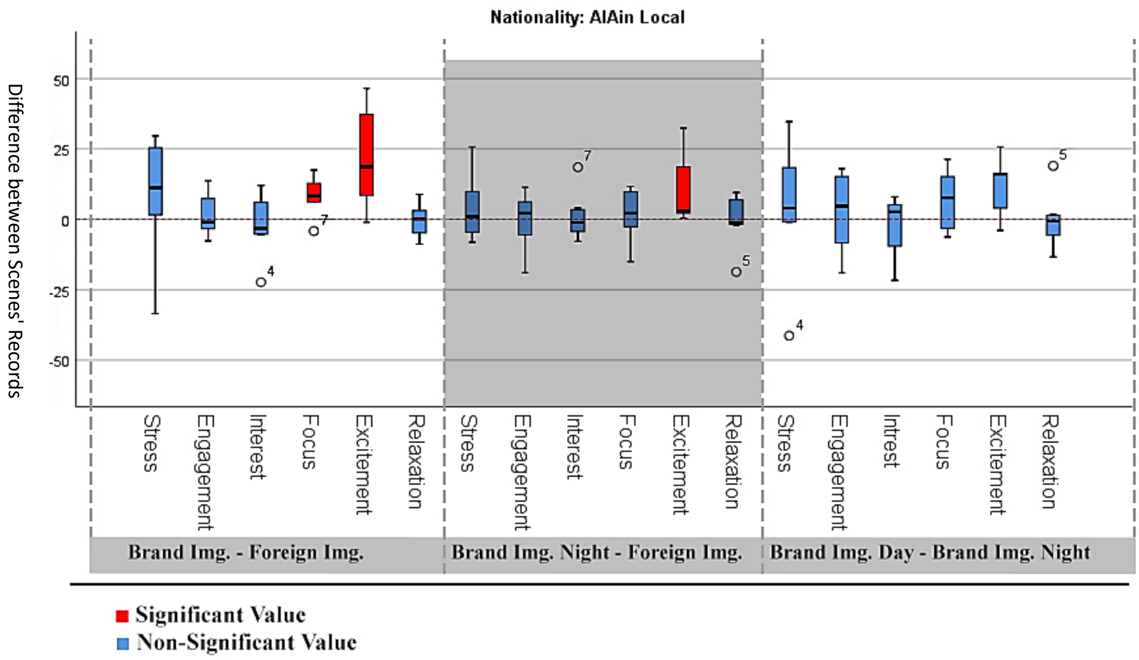

Figure 1. Wilcoxon Analysis of EEG Data from Al Ain Locals.

A Wilcoxon signed-rank test indicated that this difference was statistically significant (T = 28; Z = −2.366; p < 0.019). The *p*-values from the bootstrap for the paired t-test are (p < 0.026) for the focus when observing the daytime brand image scene compared with the modern scenes, and (p < 0.037) for the excitement when observing the same scenes.

3.2. Northern Emirates Locals

Figure 2 shows the differences in EEG readings between the brand image and foreign image scenes. The zero-value line indicates no change in readings. In the left-hand and middle zones, a positive result indicates that the brand image readings were higher than the foreign image readings, while a negative result indicates that the foreign image readings were higher than the brand image readings. In the right-hand zone, a positive result indicates that the daytime brand image readings were higher than the nighttime brand image readings, while a negative result indicates that nighttime brand image readings were higher than the daytime brand image readings. Boxplots in red indicate that the performance metric was statistically significant based on the *p*-values.

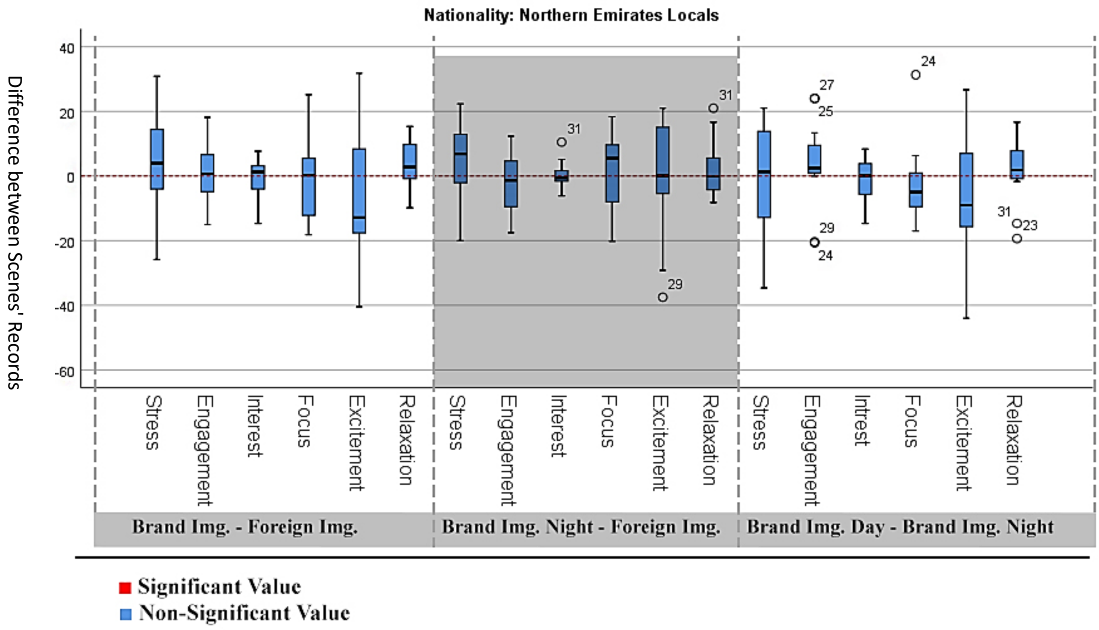

Figure 2. Wilcoxon Analysis of EEG Data from Northern Emirates Locals.

3.3. Nonlocals

Figure 5.5 shows the differences in EEG readings between the brand image and modern scenes. The zero-value line indicates no change in readings. In the left-hand and middle zones, a positive result indicates that the brand image readings were higher than the foreign image readings, while a negative result indicates that the foreign image readings were higher than the brand image readings. In the right-hand zone, a positive result indicates that the daytime brand image readings were higher than the nighttime brand image readings, while a negative result indicates that nighttime brand image readings were higher than the daytime brand image readings. Boxplots in red indicate that the performance metric was statistically significant based on the *p*-values.

Therefore, the significant changes for nonlocals may be interpreted as follows. The focus of nonlocals when observing the daytime brand image scene compared with the modern scenes was, on average, higher for the daytime brand image scene (Mdn = 62.3) than for the modern scenes (Mdn = 52.8). The Wilcoxon signed-rank test indicated that this difference was statistically significant (T = 104; Z = −2.5; p < 0.013). The interest of nonlocals when observing the nighttime brand image scene compared with the modern scenes was, on average, higher for the nighttime brand image scene (Mdn = 65) than for the modern scenes (Mdn = 56.3). The Wilcoxon signed-rank test indicated that this difference was statistically significant (T = 106; Z = −2.613; p < 0.010). Relaxation of nonlocals when observing the nighttime brand image scene compared with the modern scenes was, on average, higher for the nighttime brand image scene (Mdn = 42) than for the modern scenes (Mdn = 29.3). The Wilcoxon signed-rank test indicated that this difference was statistically significant (T = 95; Z = −1.988; p < 0.048). The *p*-value from the paired t-test is (p < 0.016) for the focus when observing the daytime brand image scene compared with the modern scenes. The *p*-value from the bootstrap for the paired t-test is (p < 0.041) for the focus when observing the daytime brand image scene compared with the modern scenes. The *p*-values from the bootstrap for the paired t-test are (p < 0.022) for the interest when observing the nighttime brand image scene compared with the modern scenes, and (p < 0.040) for the relaxation when observing the same scenes.

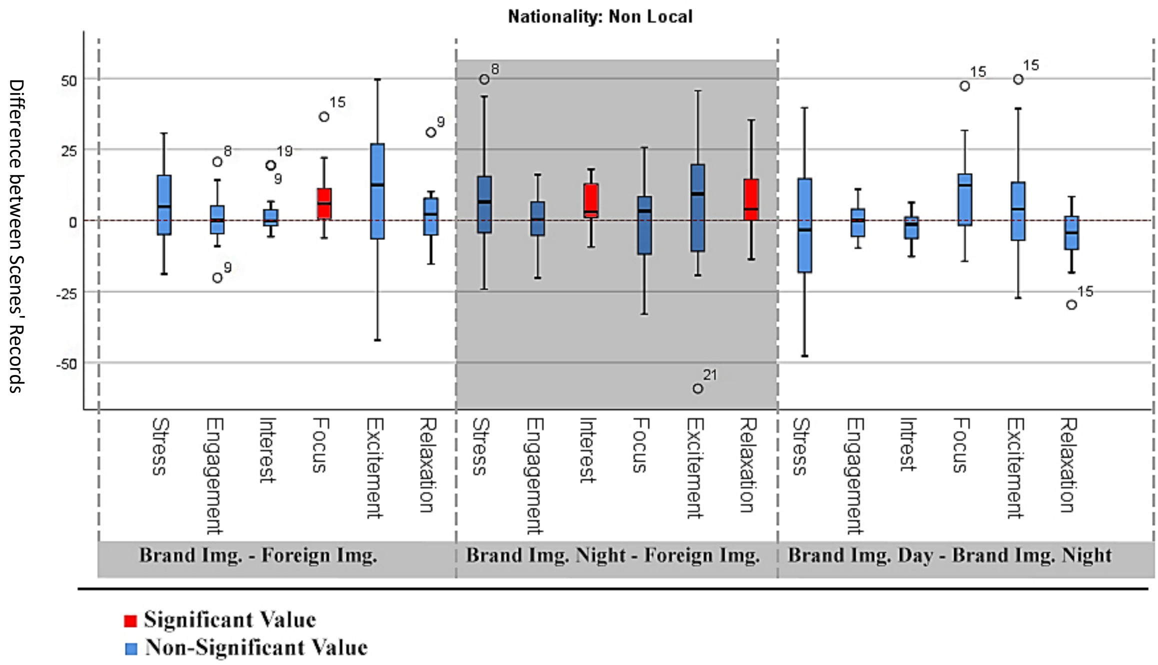

Figure 3. Wilcoxon Analysis of EEG Data from Nonlocals.

4. Discussion

The results of Al Ain local group supported Agiel's findings [7], which showed that Tripoli, Ghadames, and Yefren locals were emotionally connected to their vernacular architecture. The present study provided a new indication of an emotional connection with the local brand image. It shows a significant increase in locals' focus and excitement when observing UAE's coastal brand image. This result might be because the local northern emirates have different preferences based on their local architecture, influenced by the mountain brand image, which used to adopt stone as construction material rather than mud and coral as used in Dubai and Abu Dhabi. However, the results may have been attributable to the young age group of participants, who were all in their early twenties, and that would impact their knowledge about their brand image. In either case, this group of locals could be the subject of future studies to investigate their emotional connection with the nearby brand images of architecture.

On the other hand, the non-locals group results are interesting because they show that participants from another region have a solid emotional connection with the UAE's coastal brand image in terms of focus, interest, and relaxation. This connection may be attributable to the similar building materials and colors used in the participants' regional vernacular architecture and UAE's coastal brand image. Indeed, one participant stated that the buildings reminded him of the vernacular buildings in his region. However, when comparing these results with those of the Al Ain locals, it can be seen that the Al Ain locals showed significant focus and excitement, while non-locals showed significant interest, focus, and relaxation. These differences may be an indication of the differences in perceptions of traditional architecture by laypeople.

5. Conclusion

The argument in this manuscript relates to the effect of architectural styles on laypeople's emotions, a topic that has had limited research. Researchers such as Jack Nasar and Arthur Stamps have studied laypeople's architectural preferences. Some years later, Agiel studied the emotional connections of participants with the brand image (traditional architecture) based on Personal Construct Theory. In the present study, emotional effects were studied using a physiological approach. The purpose of this study was to explore the effect of architectural style on six emotions by analyzing responses of the brain cortex as per the limitation of the used tool. The EPOC+ tool provided the possibility of measuring six emotions based on EEG waves.

The findings show that traditional architecture affords a better emotional quality for laypeople living in conservative environments. Participants from Jordan, Egypt, and Al Ain city had a better emotional connection with UAE's coastal brand image architecture. In contrast, participants from the Northern Emirates were not emotionally affected by the coastal brand image architecture of the UAE.

These results might help develop the architecture practice in the UAE and develop the UAE building code. However, this recommendation should be considered once a broader study confirms the results of this study. However, the results are valuable for providing a general concept of people's emotional connection from UAE, Jordan, and Egypt with UAE's coastal brand image architecture. It also opens the door to future studies in the same field and context.

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Assessing Perceptions of Autism Spectrum Disorder (ASD) School Children in Al Ain to Artificial Green Elements - A Pilot Study

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Abstract: Recently, the Global Health statistic demonstrated a continuous rise in Autism Spectrum Disorder (ASD) worldwide and specially in the Gulf Countries. United Arab Emirates (UAE) has the second highest rate of Autism prevalence. Therefore, UAE Zayed Higher Organization for People of Determination under governmental administration established Al Ain Autism Center for ASD children. Many studies have emphasized the influence of the positive effects of green spaces on the academic performance and skills of school children. However, we observed that there is very little use of the green spaces in Al Ain schools. Therefore, the present study will help increase greenery and as a result, positive emotions on ASD children. The difficulties to maintain the natural plants in buildings and their high cost are the greatest drawbacks. Reviewed studies suggested that indoor plants' presence can provide several benefits such as stress-reduction, children's health, and well-being. This study aims to examine Autism Children's Perceptions of artificial green elements. We hypothesize that artificial green elements will have the same positive impact as real green elements on the psychological and emotional health of ASD children's perception. To conduct this study, a sample of 4 Autistic Participants was compared with the sample of 5 Non-Autistic Participants, aged between (5–11 years). They were selected from different schools of Al Ain. This study was conducted using Personal Construct Psychology (PCP), which enables the children using qualitative grids to construe their meanings. The findings of this study will contribute to developing the existing school design for ASD children in UAE. In this pilot study result, autistic children enjoyed spending a long time with all green elements, while the third corner that doesn't contain green elements was ignored. In particular, artificial green elements reflected a good response during the experiment.

Keywords: Autism Spectrum Disorder (ASD), Personal Construct Psychology (PCP), Artificial Green Elements, Al Ain School

1. Introduction

Autism spectrum disorder (ASD) is a spectrum of neurological conditions and low brain performance [1]. It is one of the childhood ailments which continue lifelong [2]. In early childhood, abnormal conditions are identified for ASD children, which cause defects in different functions in the brain [3], [4], [5]. Autistic children suffer problems of eye contact and speech skills, social interaction, adaptation, and cognitive ability [6].

Previous studies demonstrate that green spaces have a positive effect on the overall mental health of humans and children [7], [8]. Children who suffer from disorders ASD need an exceptionally care and attention. Consequently, ASD should be under corporate responsibility from society's point of view and designer to build a suitable environment. Building a safe and comfortable environment has a positive effect on them [9]. Many benefits link the natural environment with human wellbeing, sound of the falling water, coming close to wildflowers, and having green scene are factors to influence children positive feelings and social integration [7], [8] , [4].

Studies focused on the benefits of green plants for autism; however, there is less usage of indoor green plants in Schools of Al Ain. The reason may be because of the high cost of caring for natural plants and constantly changing them according to the climate, and these are the difficulties of maintaining natural plants in buildings. Empirical studies directed towards the perceptions of autistic children on artificial plants have not been investigated. The aim of this study is to advance the understanding of school design for ASD in hot climatic regions by investigating the applicability of artificial green plants on the cognitive development of autistic children. This study was conducted based on Personal Construct Psychology (PCP) using qualitative grids. Many studies have demonstrated this method approach to suitable for children studies especially who are affected by ASD [10]. Therefore, this method used to examin the artificial indoor green plants if can contribute in a similar manner to the real plants in the perception of ASD children.

2. Methodology

2.1. Personal Construct Psychology

George Kelly (1955), a psychologist, proposed Personal Construct Psychology (PCP) and its analytical compound Repertory Grid Technique (RGT) as a suitable method for dealing with personality and cognition problems. Kelly applied this method with his patients to help them organize their everyday human relationships and interactions with the used environmental elements. This method effectively deals with people and their responses, feelings, behaviors, and experiences individually and as groups [11] , [26]. Personal construct psychology has three main components to obtain and create a better understanding of the individual. These three components are: Elements which represent the stimuli, Construct which describe the human responses, and RGT for data collection [12]. Qualitative grid (QG) is an effective and flexible method for deeper understanding of interpersonal construing systems. It includes adjustable tables with labels or drawings, where the participants enter the responses immediately in the cells.

2.2. Empirical Study

2.2.1. Participants

The participants were chosen from all nationalities residing in Al Ain City. Nine participants with autism diagnosed from simple to moderate based on Zayed Higher Organization assessments. Another group of Non-Autistic Participants were chosen as not previously diagnosed with any disorder – used as a control group. The age of the selected participated children is between 5-11 years females and males, as shown in the Appendix A.

2.2.2. Elements

Based on studies at least three elements should be presented to the interviewee to consider how two elements are similar and different from the third [10], [13]. Consequently, in this study three elements were selected as stimuli, including Artificial Green Elements (AGE), Real Green Element (RGE), and Brown Carpet as the Stander Condition (SC). See Appendix A.

These elements were used to complete individual interviews lasting for 20-30 minutes; both researcher and specialist were presented during the interview with the participants. Due to over sensitivity of autistic children, the classroom was free from all distractions.

Selection of the elements exhibited a unique scope in the assessment, and they are as follows: Firstly, the real plants, grass, and green elements were chosen, similar to the artificial ones in terms of color, size, and appearance. Secondly, all elements were considered to be safe, clean, and suitable for autistic children's use. Thirdly, the selection of real plants avoided thorns and insects.

2.2.3. *Constructs*

According to the PCP, the fundamental unit to analyze and describe an object or element from the surrounding is called construct. To construe is to create a personal meaning into an object. The construct explain how the individual feel and imagine her/his situation, and it can be developed by using short sentences, words, or drawing to express the response to the used elements [11]. In this study, constructs include words, and short sentences representing a specific character and meaning of elements. The researcher observed the children behavior and documented their words and actions with the help of the specialist.

2.2.4. *Procedure*

Before the study started, we received approval from the UAEU ethical committee – reference ERS_2021_7279. The procedure was divided into two stages: the preparation stage and the interviewing stage. In the preparation stage, we installed the artificial green elements, real green elements, and the brown carpet in three corners in the classroom in the selected ASD school. On the interview day, the school assigned a specialist to help us to deal with the ASD participants. Once the children entered the classroom, they were asked to look at the three corners and describe them. Next, we asked the participants to choose the preferred corner and explain why this corner is different. After that, the participants were asked again to select one corner from the remaining two corners and explain why. Finally, we gave the participants two sticks with happy and sad faces to evaluate each corner based on their emotions.

3. Results & Data Analysis

This study's results were categorized and discussed based on the perceptions/responses of the participants towards the visual impact of the real green corner, artificial green corner, and the control corner using qualitative grids. Then after comparing the responses between the Autistic Participants and Non-Autistic Participants, the hypothesis was proved. Finally, the researcher evaluated the nine qualitative grids based on the participant's responses to the environments chosen by them.

3.1. Response of Participants having Autism

As indicated in Table 3 in Appendix A, the participant ASDP-01 expressed his understanding of the displayed elements like (grass, plants) in a few words. He described the third corner as a brown Carpet. He recognized the natural plants and grass when he noticed the sand into the plants. After that he spent a few minutes on the carpet in the third corner, he described it as not comfortable, and he said there is no green plants. Then he tried to touch the elements on the AGE corner and noticed that it is not real. Next, he stayed a few minutes close to the real plants and said that "we can eat fruits from these trees". After this, he was asked to evaluate the corners with a happy face for the good corner and a sad face for the bad corner. He chose the (RGE) as the good corner and the (SC) as the bad corner. Finally, these steps concluded that ASDP-01 prefers to have artificial green elements instead of having no green elements at all.

ASDP-02 had less ability to describe the three corners. He described the two green corners as flowers, but he could not recognize the type of the elements due to the severity of Autism he had. Furthermore, when the specialist tried to let him experience the three corners, he enjoyed the two corners with green elements more than the third corner without green elements. Finally, he was given two sticks with a happy face and a sad face. The happy one evaluated the good corner, and the sad face evaluated the bad corner, depending on his feelings. He was trying to put the happy face for both the corners, which had the green element (AGE), (RGE), and he put the sad face on the third corner (SC). As a result, ASDP-02 preferred the presence of green elements, no matter real or artificial, in the school environment.

The result of ASDP-03 was similar to the participant ASDP-02 in the ability to describe the displayed elements. Therefore, he described the two corners (AGE) and (RGE) as grass, and he also started to jump on the grass, but he could not recognize whether they were real or artificial, even after touching it. The child did not want to spend time in the third corner with no green plants. In the last step, ASDP-03 decided to put the happy face on the corners with green elements and ignored the third corner. Finally, the participant felt more satisfied to connect with the green elements.

ASDP-04 suffered from hyperactivity, and his assistant tried to keep him calm, but he could not control him in the experiment classroom. Participant ASDP-04 started to cry and jump in the classroom. He was not able to follow the assistant's instructions.

3.2. Response of Non-Autistic Participant

As showed in Table 4 in the Appendix A, the participant NASDP-01 described the two corners as an artificial corner with plants and grass and the real corner with real plants and grass. He noticed the presence of sand on the grass and in the plants' boxes. NASDP-01 started to walk between the two green corners (AGE) and (RGE). Then he said that the (AGE) doesn't have sand and insects, and it is clean. He did not like to sit on the real grass because he was afraid that the grass might have some insects. In the last step, he chose to give the happy face for the (AGE) as the good corner and the sad face for (SC) as the bad corner. To conclude, although NASDP-01 did not feel comfortable in the (RGE), he still preferred it more than the corner with no green plants at all.

NASDP-02 was asked to look at the corners for a few minutes; he tried to focus on the sand of the real grass and stated that it was real grass. Then, he described the third corner as a brown carpet. Then, the researcher gave him two sticks; a happy face to evaluate the good corner and a sad face to evaluate the bad corner. The participant decided to give the (RGE) the happy face and the (SC) the sad one.

The participant NASDP-03 was asked to describe the presented elements. So, he stood near to the first corner (AGE) and described it as; plants and grass. The second corner (RGE) as; plants, grass, and sand. Third corner (SC) as; a brown carpet. Then, he was asked to choose his favorite corner and explain the reason. He chose the (AGE) and described it as soft and clean with no sand. On the other hand, he noted that (RGE) was not clean because of the sand. Therefore, he preferred the (AGE) corner and evaluated it as a happy corner. The (RGE) corner was his second choice for the happy corner and the sad face for the third corner, which had no green elements. Therefore, NASDP-03 preferred to have artificial green elements or real green elements rather than space without greenery and plants at all. The presence of green elements made the participant look happy and showed positive reactions.

NASDP-04 was the only female participant in this study. She explained the three corners almost the same way as others did. She described the (AGE) as; plants and grass, the (RGE) as plants, grass, and sand, and the third as a brown carpet. She mentioned that the (AGE) could live forever without any care and maintenance. Whereas (RGE) will die if we do not take care of it every day. Therefore, she evaluated (AGE) with a happy face as a good corner because it had plants and grass with a long life. The sad face chose for the third corner (SC), where there were no green plants.

NASDP-05 described the three corners (AGE), (RGE), and (SC) as; (plants, grass), (plants, grass, and sand), (brown carpet), respectively. He defined that the artificial grass was clean and safe to be used for playing. In comparison to the artificial green elements, real green elements were a source of insects and sand. For these reasons, he had decided to choose the (AGE) as a good corner and evaluated it with a happy face. Thus, it was noted that NASDP-05 felt satisfied, comfortable, and safe with the artificial green elements rather than the real green elements. On the other hand, he evaluated the third (SC) corner with a sad face and was unhappy to spend time there.

4. Discussion

As stated in the results and data analysis, the non-autism participants had similar perceptions like the autism participants. All participants who were non-autism and autism participants preferred either (AGE) or (RGE) but not (SC) as their favorite corner. 60% of the non-autism participants were afraid of the real grass and imagined that it had insects. Participants of both categories who preferred the (AGE) (70%) said that the real grass was not clean due to the sand. 25% of the autism participants and 70 % of the non-autism participant noticed the presence of sand on the real green elements and recognized that they were real elements. Besides, only ASDP-01 was able to imagine the real trees which provide fruits. 1 out of 9 of the total participants was a girl NASDP-04 who mentioned the difficulties of maintenance and daily care of the real plants.

Moreover, the participants showed that they paid the whole attention to the two green corners (AGE) & (RGE) and were impressed by the presence of plants. Adopting a similar point of view with research indicates that the presence of green plants would affect human's emotions, perceptions, and behavior [14]. As investigated from the cases above, both ASDP & NASDP participants spent more time in the two green corners, where they were happy and enjoyed playing on the grass. All participants expressed their feelings and perceptions and connected them positively with indoor plants and grass. A significant change in mood was observed in the children when exposed for a short period to green plants and grass. Similar to above finding, [15] investigated students and found them happy, less stressed, and with better social interaction among green spaces. The included studies heavily support the positive findings when children affected with autism and children not affected with autism access green spaces [5], [6], [16], [17].

5. Recommendations for the actual study

These are several recommendations that are needed to be implemented in the actual study. A couple of measures should be taken into consideration while choosing the real plants. First, make sure that the soil of the plants doesn't have any insects and fertilizers. Secondly, the plants should be free of thorns. On the other hand, there is a need to choose only the autistic children diagnosed as moderate or simple autism spectrum disorder; it would be much easier to deal with them. Besides, it is recommended to have specialists during the experiment to help deal with ASD children.

6. Conclusions

The present study aimed to explore the contribution of artificial green plants in Autistic and Non-Autistic Participation's perceptions and emotions. The study was conducted based on the PCP using qualitative grids. Three elements were selected as stimuli, Artificial Green Elements (AGE), Real Green Element (RGE), and the Brown Carpet as the Stander Condition (SC). The findings showed the attractiveness of children from both categories to the two green corners (AGE) & (RGE), and they were impressed by the presence of green plants. Children in this study spent most of their time in the two green corners and expressed positive emotions with the green elements. The number was limited in this study; however, the Artificial Green Elements reflected positive emotions more than Real Green Elements. Moreover, the effectiveness of the PCP method with autistic children has been demonstrated in this study that helped mitigate the communication difficulties.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The participants' categories, age, gender with codes.

Table 1. The Participants and Codes were used in this study.

Category		Code	Age	Gender
Autism Participant (ASDP)	ASDP – Simple Autism	ASDP-01	11	Boy
	ASDP – Severe Autism	ASDP-02	5	Boy
	ASDP – Moderate Autism	ASDP-03	11	Boy
	ASDP – Moderate Autism	ASDP-04	11	Boy
Non-Autism Participant (NASDP)		NASDP-01	7	Boy
		NASDP-02	8	Boy
		NASDP-03	9	Boy
		NASDP-04	9	Girl
		NASDP-05	9	Boy

Qualitative Grids' elements with symbols.

Table 2. The Elements and Symbols used in the study

Elements in the Study	Symbols
Artificial Green Elements included fake grass, Faux Potted Rubber Tree, and Faux Potted Fiddle Leaf Fig Plants.	AGE
Real Green Element included real grass, Epipremnum aureum, and Ficus elastic Abidjan	RGE
Brown Carpet as the Stander Condition	SC

Response of Participants having Autism

Table 3. Perceiver Element Grid in the ASDP-01

Participant		**Elements**		
		Artificial Green Element (AGE)	Real Green Element (RGE)	Control/Stander Corner (SC)
ASDP-01	Describe what you can see	Plants & grass	Plants & grass	Brown carpet
	Choose your favorite corner & why	Not real	Get fruits from the tree, notice the sand on the real grass.	Not comfortable to sit. Absence of nature

	Select the smile you feel is representing the corner.	Happy Face 	Sad Face 

Table 7. Perceiver Element Grid in the NASDP-01

Perceiver		**Elements**		
		Artificial Green Element (AGE)	**Real Green Element (RGE)**	**Control/Stander Corner (SC)**
NASDP-01	Describe what you can see	Artificial plants grass	Reals plants, grass	Brown carpet
	Choose your favorite corner & why	No sand, no insects, clean	Doesn't like to set.	
	Select the smile you feel is representing the corner.	Happy face 		Sad face 

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Crowd Control and Visitor Flow in South Indian Spiritual Sites aimed at Customer Satisfaction

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Abstract: Customer satisfaction assumes an essential job for any organization. Particularly, service-oriented industries have been emphasizing a lot to develop satisfaction over their customers thereby can acquire better progress in global competitiveness. An effort made to assume devotional amenity as a service-oriented industry. Here, temples in south India have been considered as mass service industries. Customers' satisfaction is the major challenge is to be successfully put in place the organizing structure, systems and process which tackles the root causes of dissatisfaction. This research paper attempts to minimize the waiting time leading to satisfaction of customers. Various factors lead to customer dissatisfaction addressed by Multiple-Criteria Decision Making (MCDM) that enables the researchers, industrialists, strategists and statistical analysts to take decisions trendy intended. Analytic Hierarchy Process (AHP) is one of the most popular methods to solve uncertainties and inconsistencies in such decision-making process. This work may contribute solutions to uncertainties thereby improves the lean process and leads to the satisfaction of customers by reducing the total waiting time from the entry till they worship. The results show that there is a thirty percentage improvement by using the proposed method.

Keywords: Customer Satisfaction; Multiple-Criteria Decision Making; Analytic Hierarchy Process.

1. Introduction

In India, service sectors account for fifty percent of Gross Domestic Product. Tertiary sectors like trade and public service rising constantly over a period. Service sectors also are known as service industries include a wide range of business all over the globe. Trade, Hotels, Transport, Storage and Communication, Education, Health Institutions, Agricultural etc. come under these service sectors [1]. Customer Satisfaction plays a significant role in service industries. Country economic development depends upon service sectors. Consumer loyalty is the key factor for effective and depends profoundly on the practices of service providers. Customers ought to be overseen as resources, and that customers fluctuate in their needs, decisions making, preferences and purchasing conduct [2]. Here, Decision making is considered as a complex part of an organization structure, particularly in manageable aspects would linearly proportionate to customer satisfaction. Complexity in decision making lies both in customers as well as in manageable members of any organization.

If the rate of customers increases gradually then managers shall act accordingly in a strategic and organized way to eradicate dissatisfaction among customers. Scientific methods has to be adopted by the decision-makers to make effective decisions, where this applies to customers and managers too. Most of the times customers will have inconsistency in their requirements, they often may not decide if they have multiple options. Here, the problem persists in the selection of suitable option it's called multiple criteria or multiple objectives. As said at earlier, decision making is a complex situation, a scientific method of decision making to be adopted for this kind of problems.

Multiple Criteria Decision-Making process (MCDM) is the most popular scientific process have been using since a long time to solve uncertainties in decision making that helps finding out consistency in taking a decision [3]. Multiple Criteria Decision-Making process has a variety of scientific techniques based upon applications. Among those, the Analytic Hierarchy Process (AHP) is one of the popular scientific techniques developed by saaty (1980). AHP is a strong and helpful tool for managing qualitative and quantitative decision-making behaviour [4]. This system is considered to make decisions with multiple criteria, it hierarchically formulates the problem. The ultimate objective or goal to be formulated in initial level, criteria and sub criteria are to be formulated sequentially and subsequently in next levels. Finally, in the last level alternatives are to be formulated in the hierarchy structure of AHP.

In this work, alternatives are treated as different options of customers or managers that create uncertainty decision making. India is a pilgrimage place, ancient and historic holy places located in this country over the centuries. South India is a place where having the world largest pilgrim temple towns. These pilgrimaged places considered as service industries for this work. Here, customers to these holy places are assumed to be customers of service industries or sectors. Pilgrimage places are influenced by a greater number of visitors in many ways, it impacts stress on basic services, accumulation of huge quantities of customers creating high levels of complications in managing the crowd, providing accommodation facilities and amenities for customers [5].One of the world largest south Indian temple has been facing a lot of problems due to the influx of visitors throughout the year, which results in interrelated pressures due to increasing population are of direct pressure and indirect pressure. Direct pressure is due to increasing visitor flow and indirect pressure due to frequent visitors from nearby urban places.

These pressures affect the temple services in three interrelated ways, at very foremost thing stress exerts on basic services like water supply, accommodation, sewage, solid waste, population management in a queue system etc., secondarily, pollution, inadequate infrastructure, contaminations etc., and third one degradation of natural resources, loss of biodiversity in a rapid manner. Initial two factors related to the frequent and rapid flow of visitors, other due to failing to provide the facilities to the customers. Lakhs of people visiting in normal days but on special days like festival seasons, weekends, peek days the count may exceed bigger than usual to these holy cities every year. Large Scale of movement of visitors to the world-famous holy places in south India would tend to high potential influence on the temple services to customers [6]. Customers may have inconsistency in decision making or planning process will lead to high potential flow. This reflects in pilgrim waiting time then resembles dissatisfaction. In addition to these factors, lack of organizing skills, inconsistency in the system, adequate resources are intensifying the degree of dissatisfaction in customers as well as for organizers. This potential flow is somehow predictable, controllable and manageable. Unfortunately, it would not be done due to uncertainties in organizing system; restricting and managing the flow process. Finally, these factors increase the factor of dissatisfaction.

2. Literature review

Customer satisfaction is a key factor that plays a predominant role for successful and depends on service providers, there are two satisfaction levels of customer satisfaction index (CSI) models for analyzing customer satisfaction and loyalty, it helps tourism factory organizers improve customer satisfaction effectively [2]. Analytic Hierarchy Process (AHP) is one of the prominent tools in the decision-making process, this process helped in identifying difficulties of small and medium scale enterprises to get transform to industry 4.o [7]. Mass customization is used in production management with industry 4.0 in industries [8-9]. Multi criteria decision-making methodology is developed for conceptual design evaluation through the internet of things [8]. From this literature survey, it is identified that multi criteria decision making process used for taking effective and consistent decisions. In this study, the Analytic Hierarchy Process (AHP) method is used for effective decision making in queue management. Since customer satisfaction is our major focus the decision making heuristics such as AHP will be useful in these situations. Especially in the light of minimization of waiting time, there is a scope for this algorithm that can be used in such a mass application. In the following sections, the detailed steps of the proposed work are given.

3. The problem statement in the view of crowd control

The major work focused on this research is to control the crowd of people at a time gathered for worshipping in the same place. Even though this approach could be applicable anywhere, for the purpose of understanding the methodology, the spiritual sites have been considered for data collection. In this study the popular place, Thirupati in south India is taken for data collection so that the illustration becomes easier in case study.

The following information reflects that the crowd of people gathered at an entry point towards the sanctorum at the same period.

For every one hour the approximate number of persons at various entry points are around 2000 to 3000, so in a day the average number is about 50000. This is happened round the clock in a day for all seven days a week. Now the work is focused on how to control over the crowd till it reaches the sanctorum and make them comfortable at the place where they worship.

The popular method Analytic Hierarchy Process is used to make decision at several points to distribute the line of people in a more comfortable way by minimizing the waiting time [10-12].

4. Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process is one of the tools used for Multi-Criteria Decision Making (MCDM) process was developed by Pro. Thomas L. Saaty in the year 1980 [6]. It is an efficient and effective process in determining the qualitative and quantitative decision-making process. It yields sound decisions when multiple options are available with us. Through the hierarchy process, it determines a suitable decision based on priorities given to it. In detail explanation, it is a step by step process of identifying the good decision.

4.1 Algorithm steps

Step-1: Formulate hierarchy process of goal and criteria.

Step-2: Draw pairwise comparison matrix (PCM) among criteria from 0 to 9.

Point Scale	Explanation
1	: Equal importance
2	: In between Equal and Moderate important
3	: Moderately importance
4	: In between Moderate and strongly important
5	: Strongly important
6	: In between strongly and very strongly important
7	: Very strongly important
8	: In between very strongly and exactly important
9	: Exactly important

Step-3: Calculate Normalized and Criteria Weights for pair wise comparison matrix.

Step-4: Calculate maximum eigen value (λ_{max} = average of weighted sum/criteria weights).

Step-5: Calculate Consistency Index (CI) = $\frac{\lambda_{max} - n}{n-1}$; n= number of criteria considered.

Step-6: Check Consistency Ratio (CR) = $\frac{Consistency\ Index(CI)}{Random\ consistency\ Index\ (RI)}$

Step-7: If calculated CR < 0.10 then solution is consistent and results of comparison are acceptable, Priorities can be calculated further.

4.2 A case study on mass customized service industry:

The objective is to achieve the satisfaction of customers by reducing waiting time and idle time by the lean process in temples which resemble services rendered by the industry for customers to make them delight. Generalised booking phenomenon of various temples in south India has shown in figure.1. Customers usually prefer to opt for special worship called “Ritual”. These rituals are categorised based on importance. In general, a particular type of special worship like Ritual-1 has the most significant place compared to other rituals. Customers believe that getting the opportunity to participate in ritual- 1 is a fortunate thing in their lifetime. Generally, Ritual – 1 has huge competency in booking and next to ritual – 2, 3, 4... like so forth. Whereas rituals are the combination of shrine visit. Customers will prefer rituals, if not available then they prefer for visiting the shrine.

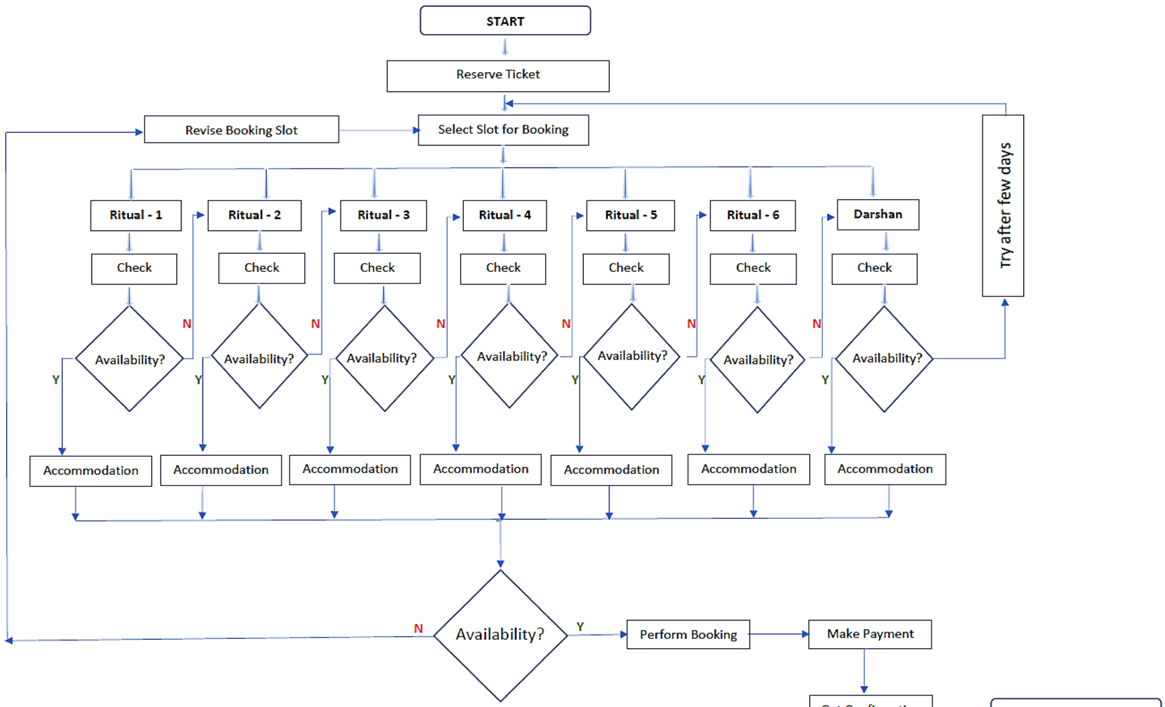

Figure.1. Flow chart represents generalized booking phenomenon

South India is a pilgrimage place located with most familiar and crowdy temples like " Sree Anantha Padmanabha Swamy temple, Sri Sabarimala Ayyappa Temple, Kerala; Sri Ramanathaswamy temple at Rameshwaram, Annamalaiyar Temple at Thiruvannamalai, Madhurai Meenakshi temple, Sri Ranganathaswamy Temple, Srirangam, Tamilnadu; Sri Venkateshwara Swamy Temple, Tirupati, Andhra Pradesh” etc. Customers usually visit these temples throughout the year, in the festival or special days crowd at these temples is unimaginable. Based on observations, the existing entry and exit process in these temples are more or less similar to one to other temples. The process of allowing customers into these temples is through various queuing systems. In this work, an effort made to reduce waiting time in queue thereby can achieve smooth flow which results in customer satisfaction. Based on the customer requirements for their visit to these temples, the temple managements have generic organizing structure to serve the customers. Queuing system is one of the major criteria that play a significant role in managing the huge crowd. The crowd may be predictable in normal and weekdays but may not be in special and peek days. Even though they have good organizing structure to manage the flow but there exist few gaps, like following the traditional queue management techniques. There is a necessity to invite scientific methods to avoid the rule of thumb. The existing generic queue system and waiting time is as shown in Table.1.

Abbreviations:
Y : Yes
N : No
Qi : Queue number (i=1, 2, 3, …)
WQij : Waiting location; (i, j=1, 2, 3, …); (i= queue number & j= Customer Stage)
MQi : Merging Point of Queues (i=1, 2, 3, …)

Table.1. Waiting Time for different queues

Type of Visit	Senior Citizen	Physically Handy Capped	Infants	Rituals	Paid Visit	Visit by walk	Free Visit
Queue Assigned	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Customers (Day)	700	700	200	800	17500	20000	35000
Waiting Time (hrs)	2	2	3	5	4	8	12

As shown in Table.1, for every queue system has a certain waiting time, the waiting time varies with sudden increase in float of customers. Here, the average waiting time for each queue is taken into account. Usually, on a priority basis, all queues undergo different locations. Flow process of all the queues at various locations shown in figure.2. Here, location -1,2,3,4,5,6,7,8,9 & 10 represents entry/reporting, identity check, physical inspection, metal detection, waiting point, merging of Q5, Q6 form as single que, the queues Q1, Q2, Q3 and Q4, Q5, Q6, Q7 merging takes place separately form two queues at location-7, physical & metal Scanning, final queue merging, shrine visit & exit points in a current process flow respectively.

The flow process is categorized into two types. In the first category, Q1, Q2 & Q3 are classified. Whereas in the second one remaining queues from Q4 to Q7 are classified. These two categorized queues would have different paths but these two combines at final merge location -9. Flow process is shown in figure.2 and time were taken by each queue from one location to further location is shown in Table.2, it includes transit time from one stage to another stage at specified locations. For instance, except Q4 remaining almost all queues have sequential stages at all locations. Q41 means the fourth queue at its first stage at location-1 that represents ritual. In ritual, customers first perform rituals then they will be sent directly to the waiting locations. In the fourth queue first stage is at location - 1 and the second stage is at location - 5.

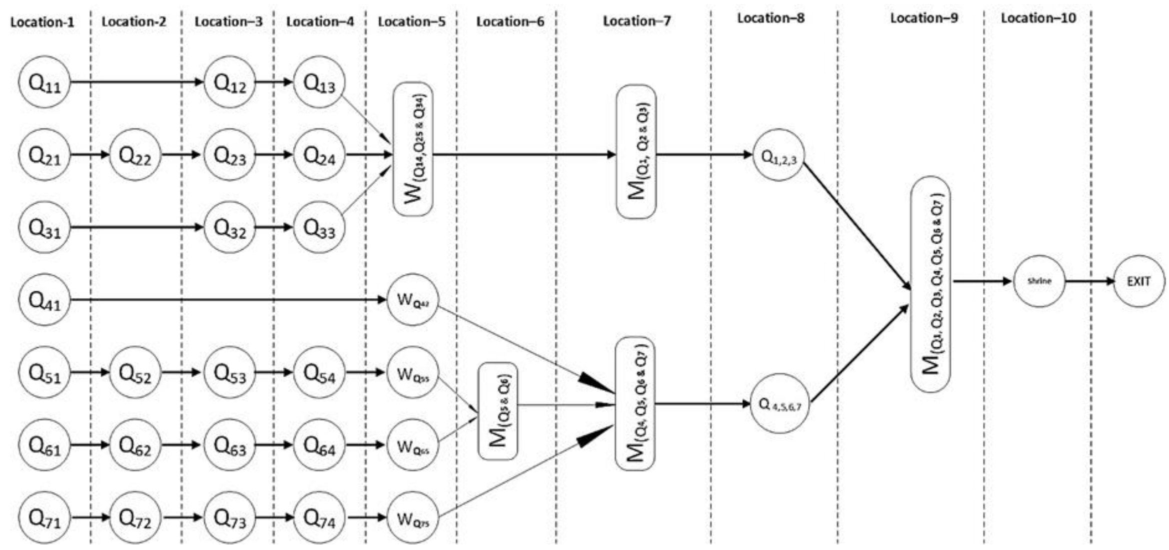

Figure.2. The existing process flow of categorized queues at various locations

In figure.2, it is mentioned as Q41 to WQ42 means the fourth queue at its second stage that will undergo the waiting location which is located at location - 5. The lead time of queues from Q1 to Q7 is shown in below Table.2. From the table, Q7, Q6 & Q4 have more lead time compared to other queues. The seventh queue(Q7) has waited almost 12hrs to complete shrine visit. From table.2 and figure.2, queues at its final locations those will combine as a unique queue called final merging point of all the queues at location-9 before entering into the shrine location to have shrine visit. So, from a location -8 to l0 waiting time remains the same for queues in the first category and also for queues in the second category. But, unfortunately, even though customers waited for the longer duration their shrine visit time falls below two minutes i.e., each customer can make shrine visit on an average of one second only at final location-10.

Average shrine visit time per customer = $\frac{Shrine\ visit\ hour * 60\ min}{Total\ Pilgrims\ per\ a\ day}$ …….from Table.1

$$= \frac{20\ x\ 60\ min}{74900}$$

Average shrine visit time per customer = 0.0160213 min ≈ 1sec.

Customers waited for 12hrs can able to see the god/goddess at temple shrine with an average of one second only. This leads to customer dissatisfaction.

Table.2. Lead time of existing process flow in between entry and exit points

Queue No	Location 1 (min)	Location 2 (min)	Location 3 (min)	Location 4 (min)	Location 5 (min)	Location 6 (min)	Location 7 (min)	Location 8 (min)	Location 9 (min)	Location 10 (min)	Lead Time (min)
Q_1	5	-	15	10	20	-	10	30	28	2	**120**
Q_2	10	5	5	10	20	-	10	30	28	2	**120**
Q_3	15	-	20	25	50	-	10	30	28	2	**180**
Q_4	150	-	-	-	20	-	30	60	38	2	**300**
Q_5	10	20	20	15	40	20	15	60	38	2	**240**
Q_6	20	30	30	20	230	25	25	60	38	2	**300**
Q_7	40	20	30	20	450	-	60	60	38	2	**720**

In this paper, the objective is to minimize the waiting time in queue for achieving customer satisfaction. This can be done in three ways; the following are proposed methods to reduce the waiting time of customers:

i. Analytic Hierarchy Process (AHP) for effective queue management.
ii. Replace the traditional process with scientific methods.
iii. Implementation of the current online booking for individuals.

Initially, by replacing the traditional process with scientific methods, that is by adopting new technologies like automated full-body scanning instead of physical and metal detection in inspection phase and current booking allows the users to upgrade their booking if anyone failed to report beyond grace period. Automated full-body scanning provides better results compared to existing technologies in terms of safety, reliability, efficiency and its effectiveness.

In present booking system there is no scope for cancellation if unable to reach or report in prescribed time. In identity checking location, there is a scanning system that registers customer entry in the database. In this location, if anyone would have failed to report even after the grace period then the slot become ideal. It may not use to anyone; a lot of customers are compromising in the booking location due to unavailability of slots then mere chance is to join with free shrine visit which results in an indirect increase of waiting time. If there is a provision to cancel their ticket then others would get a chance to book. In addition to that, if people fail to cancel their visit or report in an allotted time then it can find out at the scanning Location. There is a provision to maintain the automated system, the benefit from this automated system is it can communicate the unreported customer list and also their slot with the server. Simultaneously, the server can communicate the same information to the customers. So, with this process, customers can upgrade their booking. Which results in, customer whoever compromised with free shrine visit because of unavailability of slots and also who dislike waiting at the queue for a long time may also upgrade their booking if available. This is known as the Current Online Booking System which helps in the gradual reduction of waiting time. Customers will get simultaneously much satisfaction for getting shrine visit more quickly, smoothly and also due to up-gradation process waiting time of free shrine visit also can be reduced indirectly.

It is observed that waiting time at waiting locations is more, process of merging the different queues from different waiting locations plays a key role in crowd management. Whereas this leads to brainstorming process for decision-makers which queue is to be released to merging Location, this may be considered as Multi-Criteria Decision-Making process. This means, various parameters have to be considered from the waiting location to merging location but these parameters may vary with time. In this process, Queues are chosen as multiple criteria in the decision-making process. The decisions to be taken would be scientifically consistent then it is feasible to apply the proposed method to the real-world applications. To measure consistency or inconsistency in the decision-making process, there is a necessity to adopt the best suitable scientific method. The proposed scientific method considers the Analytic Hierarchy Process (AHP) in the decision-making process during queue management. In addition to AHP, up-gradation is recommended in the inspection process and also in booking process. These processes will definitely minimize key issues of waiting time which results in smooth process flow and customer satisfaction.

5. Results and Discussion

The first stage in the Analytic Hierarchy Process is to formulate goal or objective at level-1. As mentioned earlier, the objective of this paper to achieve customer satisfaction by minimizing waiting time. So, minimization of waiting time is considered as objective or goal. In the second level, criteria have to consider. Here, queues from Q1 to Q7 are considered as criteria. Based upon criteria considered in the next step pairwise comparison matrix (PCM) is formulated and shown in Table.4. In iteration – 1, the priority is given to the queues have waited for long duration.

Table.4. Proposed AHP (Iteration -1); priority given to queue waited from long duration

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Q1	1	1	0.5	0.2	0.333333	0.142857	0.111111
Q2	1	1	2	0.333333	0.5	0.142857	0.111111
Q3	2	0.5	1	0.333333	0.5	0.25	0.166667
Q4	5	3	3	1	3	0.333333	0.142857
Q5	3	2	2	0.333333	1	0.333333	0.166667
Q6	7	7	4	3	3	1	0.25
Q7	9	9	6	7	6	4	1

Consistency Ratio: **0.057768526 < 0.10. Hence, Decision Matrix is consistent.**

In the iteration - 1, pairwise comparison matrix (PCM), more importance is given to Q7, Q6 which means that customers in both the queues have waited for a long duration. For the given importance in PCM, the consistency check is carried out to make sure that the considered importance whether correct or not. From AHP analysis, the measured value of Consistency Ratio is 0.057768526 which is below 0.10. As from AHP, if the consistency ratio from measured value is less than 0.10 then it is said to be the decision is consistent and also importance given to criteria in the pairwise comparison matrix is also acceptable.

Table.5. Weighted Criteria values for iteration -1 based on PCM

Queue	Criteria Weights	Criteria Weights (%)
Q1	0.032143267	3.214326671
Q2	0.046948688	4.694868811
Q3	0.047830309	4.783030902
Q4	0.126675037	12.66750374
Q5	0.076675673	7.667567309
Q6	0.215547214	21.55472144
Q7	0.454179811	45.41798113

Order of priority: Q_7- Q_6- Q_5- Q_4- Q_3- Q_2- Q_1

In further calculations, based on criteria weight calculations the order of releasing these seven queues from their waiting location to merging location is generated by AHP method. From Table.5, the order of priority likely will begin with Q7- Q6- Q5- Q4- Q3- Q2- Q1. which means in reverse chronology order that indicates the waiting time of customers standing in Q7, Q6, Q5 & Q4 will be reduced.

Iteration -1 is generic in nature, whereas it can be done by the manual process without going for scientific methods but the actual problem will begin after iteration -1. After iteration -1, in the next cycle of release, queues from the waiting location to merging locations again the order of priority is to be considered otherwise discrepancies may arise with customers standing in Q1, Q2, Q3, Q4 & Q5 queues. Whereas these people are opting shrine visit on the booking process nearly one or two months ago, by keeping these customers aside and keep on repeating iteration -1 resembles an unjustified activity which results in customer dissatisfaction. Random mixing of queues for merging location is also not advisable, Iteration -2 should be considered for these kinds of context. For this time in Iteration - 2, importance is given to Q1, Q2, Q3 in addition to Q6 &Q7. Whereas first three queues belong to senior citizens, physically handicapped and infants, so they may not wait for a long time even though maintaining a separate queue system from other people and final merging taking place at location - 7. This case is to be considered under humanity grounds based on a contextual basis.

Table.6. Proposed AHP for Iteration -2 considering importance to Q1, Q2, Q3, Q6 & Q7

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Q1	1	3	2	4	4	4	4
Q2	0.333333	1	2	8	5	4	4
Q3	0.5	0.5	1	8	3	8	8
Q4	0.25	0.125	0.125	1	2	0.5	0.5
Q5	0.25	0.2	0.333333	0.5	1	0.5	0.5
Q6	0.25	0.25	0.125	2	2	1	0.5
Q7	0.25	0.25	0.125	2	2	2	1

Consistency Ratio: 0.097308723 < 0.10, Hence, Decision Matrix is consistent

In the iteration - 2, pairwise comparison matrix (PCM), more importance is given to Q1, Q2, Q3, Q6 & Q7 as shown in Table.6. For the given importance in PCM, the consistency check is carried out, the measured value of Consistency Ratio is 0.097308723 which is below 0.10. The decision is consistent and also importance given to criteria in the pairwise comparison matrix is also acceptable.

Table.7. Calculated Weighted Criteria values for iteration -2 based on PCM

Queue	Criteria Weights	Criteria Weights (%)
Q1	0.292898814	29.28988
Q2	0.235557864	23.55579
Q3	0.249943206	24.99432
Q4	0.047159022	4.715902
Q5	0.044064941	4.406494
Q6	0.059686146	5.968615
Q7	0.070690007	7.069001

Order of priority: Q_1- Q_2- Q_3- Q_7- Q_6- Q_4- Q_5

Based on criteria weight calculations, the order of releasing these seven queues from their waiting location to the merging location is generated by AHP method. From Table.7, the order of priority likely will begin with Q1-Q2-Q3-Q7-Q6-Q4-Q5. which means, the order that indicates the customers like senior citizens, physically handicapped, infants will be sent first then subsequently people have waited for longer duration can sent in remaining order from waiting location, the waiting time of customers standing in Q1, Q2, Q3, Q7 &Q6 will be reduced. In iteration -1 & 2, the order of priority is given to the customers waited for a long time and for senior citizens, infants, physically handicapped. But while coming to Q4 & Q5 are given with last preference because of their moderate waiting period. In Iteration -3, the importance is given for these two queues in addition to Q6, Q7 and finally for Q1, Q2 & Q3. Whereas in all the three iterations, queues Q6 & Q7 is given with either primary or secondary priority due to their long waiting time compared to other queues. The pairwise comparison matrix for iteration -3 is shown in Table.8.

Table.8. Proposed AHP for Iteration -3 considering importance to Q_1, Q_2, Q_3, Q_6 & Q_7

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Q1	1	1	0.5	0.333333	0.333333	0.333333	0.25
Q2	1	1	1	0.5	0.5	0.166667	0.166667
Q3	2	1	1	0.333333	1	0.166667	0.2
Q4	3	2	3	1	1	0.25	0.142857
Q5	3	2	1	1	1	0.2	0.125
Q6	3	6	6	4	5	1	0.2
Q7	4	6	5	7	8	5	1

Consistency Ratio: 0.09906701 <0.10, Hence, Decision Matrix is consistent.

For the given importance in PCM for iteration -3, the consistency check is carried out. The measured value of Consistency Ratio is 0.09906701 which is below 0.10. The decision is consistent and also importance given to criteria in the pairwise comparison matrix is also acceptable. From the criteria weight calculations, the order of releasing these seven queues from their waiting location to the merging location is generated by AHP method. From Table.9, the order of priority likely will begin with Q7- Q6- Q4- Q5- Q3- Q1- Q2.

Table.9. Calculated Weighted Criteria values based on PCM for iteration -3

Queue	Criteria Weights	Criteria Weights (%)
Q1	0.050018258	5.001825773
Q2	0.048138367	4.8138367
Q3	0.061388746	6.138874646
Q4	0.098116795	9.811679519
Q5	0.079562794	7.956279393
Q6	0.235851464	23.58514637
Q7	0.426923576	42.6923576

Order of priority: Q_7- Q_6- Q_4- Q_5- Q_3- Q_1- Q_2

AHP analysis is carried out for effective management of the queue system for an existing process as shown figure.2. In addition to the AHP method, a lot of upgrades are highly recommended to meet the challenges in terms of effectiveness, safety and reliability. For instance, the advanced full-body scanning process is proposed to replace the existing method of ongoing inspection processes like Metal detectors and physical scanning systems. These advanced systems will provide qualitative, quantitative results, increases safety systems and reliability. These systems are more effective, helpful in reducing waiting time by minimizing gaps in current process. By comparing figure.2 & 3, the safety system-1 is made common for all the customers in proposed layout irrespective of their type of visit which is located at location -2. In the proposed system; Entry, report and identity check are brought to one place called location -1 but in the existing process these are placed at three different locations causing an increase in waiting time. The two safety systems are proposed at two locations - 2 & 6, every customer shall undergo these two stages before getting shrine visit without fail.

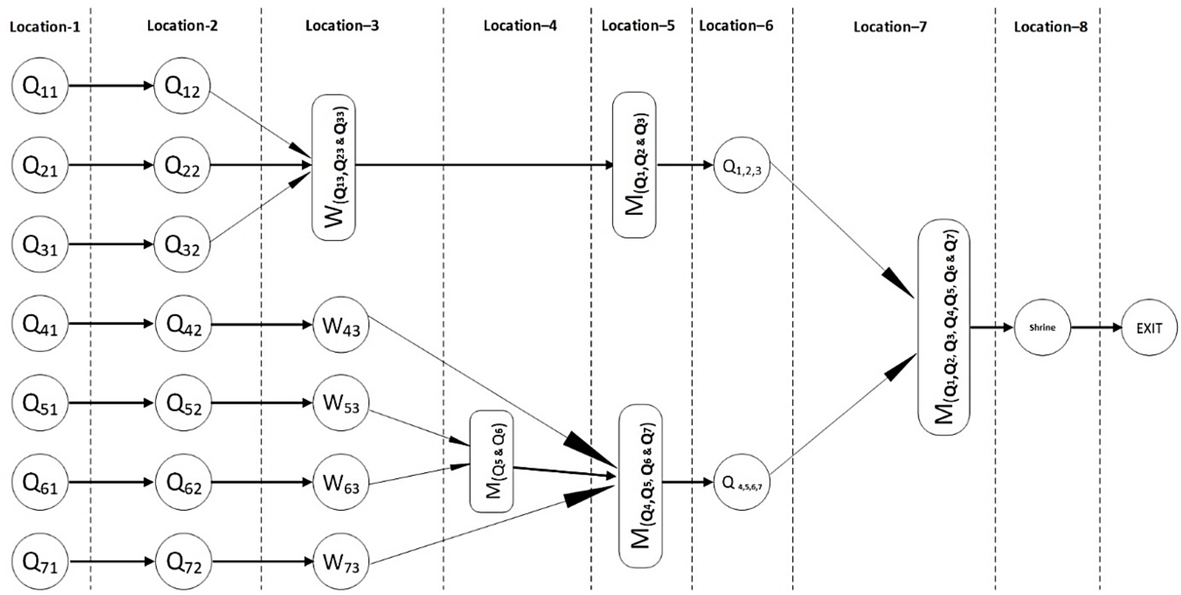

Figure.3. The proposed process flow of queues at various locations

The fifth queue (Q5) belong to ritual, customers enter at location -1 to complete their preliminary process like entry registration, dress code and identity checking then only they are allowed to complete their rituals. Later, customers are allowed to waiting location through checking point (location -2). In the proposed layout, location – 1, 2, 3, 4, 5, 6, 7 & 8 represents Entry + Reporting point + Identity verification, Scanning system, Waiting location, Merge point (Q_5+Q_6), pre - merge process to form as two different merged queues, scanning system, final merge takes place then forms as the unified queue and shrine visit location respectively. On comparing the proposed layout and the existing layout few locations are combined due to their similar type of activities to optimize the queue processing time. In the simplified process, locations are minimized to the maximum extent to reduce the waiting time and to make the flow process very smooth manner. Later, AHP process is to be implemented for better results.

The proposed process flow of queues at various locations is shown in figure.3. By using table.2 lead time of the existing process flow, lead time of proposed process flow in between entry and exit points are estimated and tabulated as shown in Table.10.

Table.10. Lead time of proposed process flow in between entry and exit points

Queue No	Location 1 (min)	Location 2 (min)	Location 3 (min)	Location 4 (min)	Location 5 (min)	Location 6 (min)	Location 7 (min)	Location 8 (min)	Lead Time (min)
Q_1	5	10	20	-	10	10	30	5	**90**
Q_2	10	15	30	-	10	10	30	5	**110**
Q_3	15	25	40	-	10	10	30	5	**135**
Q_4	150	15	20	-	15	10	30	5	**245**
Q_5	20	20	60	10	20	15	30	5	**180**
Q_6	25	25	120	20	20	25	30	5	**270**
Q_7	40	40	300	-	60	35	30	5	**510**

Comparison of lead time between the existing system and the proposed system is shown in Table.11. Whereas in figure.4, the graph drawn for waiting time of existing and proposed process. From these, the lead time is reduced in proposed system. Particularly at Q_7 lead time reduced by 29.17%, when compared to existing process.

Table.11. Percentage reduction in lead time from the existing system to proposed system

Queue No	Existing flow Process (min)	Proposed flow Process (min)	Lead time reduction (%)
Q_1	120	90	25.00
Q_2	120	110	8.33
Q_3	180	135	25.00
Q_4	300	245	18.33
Q_5	240	180	25.00
Q_6	300	270	10.00
Q_7	720	510	29.17

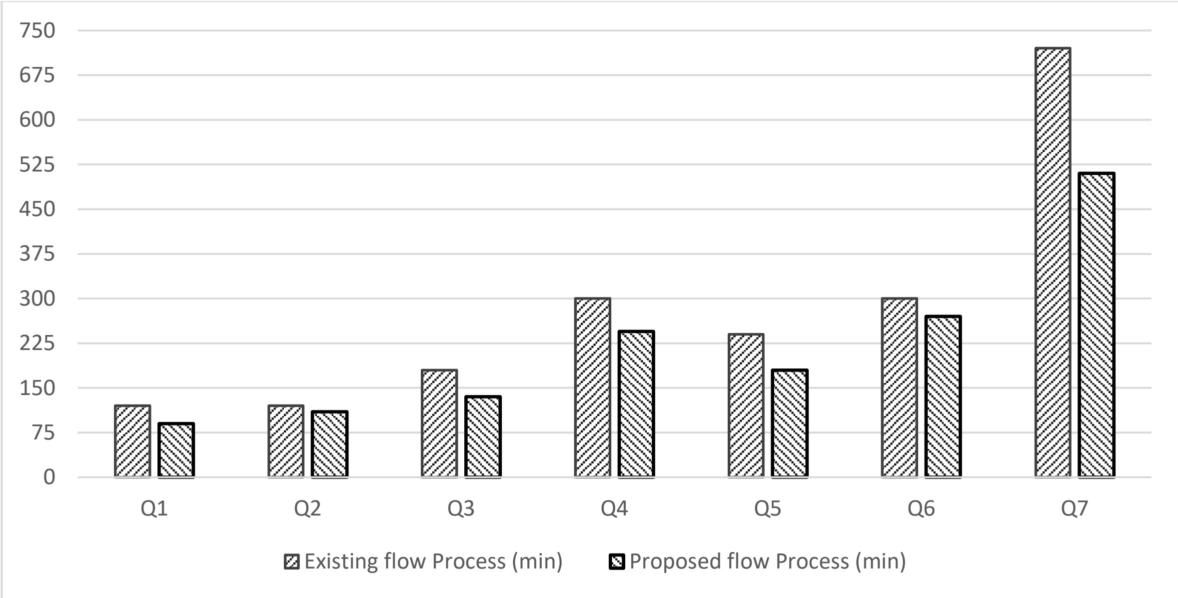

Figure.4. Graph plotted for waiting time of existing and proposed process

6. Conclusion

By using the Analytic Hierarchy Process, in iteration-1 process, the order of priority is given to customers in the queues who have waited for a long duration. In iteration -2, the order of priority is given to senior citizens, physically handicapped, infant customers. In addition to that priority is continued for customers waited for long-duration say Q7 & Q6. Whereas in the iteration -3, order of priority is given for ritual & paid shrine visit customers again priority is continued for customers waited for long-duration say Q7 & Q6. In all the three-iteration process, Q6 & Q7 queues considered high priority due to their more waiting time. More than two-thirds of customers belong to Q6 & Q7. To maintain minimized waiting time and to ensure satisfaction by all the customers, decision-making process like priority order plays a key role in the existing process. But even though scientific approaches are being developed for the existing system there may be gaps in process flow due to habituated to the traditional process and lack of upgrade to advanced process etc. Proposed AHP method for the existing system helps in developing and maintaining the current system. But it is observed from iteration-1, 2 & 3 few queues are given with priority simultaneously low priority is given for other queues vice versa. By this process, the lead time will be minimized but not the extent mark.

The AHP method will work efficiently as shown in proposed layout figure.3 as for as the selected location is concerned. From Table.11, the percentage of reduction of lead time in the proposed system is more compared to the existing process. Particularly, in Q7 there is a lot of difference is to be noticed, nearly 29.17% of lead time is reduced from existing to the proposed system as shown in figure.4. Q7 has the major contribution of the entire system, almost 80,000 customers visit temples every day in that nearly 60,000 customers come under Q7 category. The proposed system in addition to the AHP process, the count may be increased more than existing those will make shrine visit in less time. It is advisable to adopt new technologies like automated scanning system, Radio Frequency Identification (RFID) technology for assigning customers to the waiting locations through their bar code at the entry point itself then customers have to wait in desired locations, so they may not have access to other locations which results in smooth and continuous flow. The temples with the high flow of customers every day may be considered with high mix high volume mass customized industries. In this work, it is observed that temples have huge number of customers visit considered as high volume and services rendered by the temple to serve the customers through various ways like free shrine visit, paid shrine visit, ritual, senior citizens, physically handicapped, infants etc. All these may be considered as high mix process. To maintain constant or reduced lead time, the temples have to upgrade to new technology like all high productivity industries upgrading to Industry 4.O. In global context, it is suggested that with the introduction of such methodologies, customer satisfaction will improve since there has been quite reduced waiting time for the service to be delivered as proved from the work.

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Investigation of Social Sustainability Factors in the Public Market during the Pandemic; The Case of Al Ain Market, UAE

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Abstract: Public markets have always been essential elements of city dynamics. This remains crucial even during the recent COVID19 pandemic, where public markets continue to socioeconomically sustain cities. While the COVID19 crisis caused additional uncertainties to city public spaces in general, public markets were resilient and continued to offer some sort of social interactions that requires in-depth investigation. Following a pilot study analysis, this paper aims to evaluate the impact and relevance of social sustainability factors, and resilience of public market in Al Ain city, in the United Arab Emirates, mainly during the COVID 19 pandemic. The research adopted a mixed-method approach to evaluate social sustainability's physical and non-physical factors in the Al Ain public market. To investigate the correlation between public space and people perception, a conceptual framework has been developed based on theories of social sustainability, urban resilience, human behavior, and public space. Accordingly, multiple research tools have been applied to assess social sustainability factors, such as field observations, interviews, and surveys. The study results indicate that although Al Ain public market maybe physically not fully utilized as a public space, it offers high adaptability and multiple social conditions for multiple users. This includes social cohesion and a source of place attachment where people connect with memories, they collected over years of visiting the market. The research concludes that Al Ain public market has partially achieved social sustainability factors retrieved from previous literature. The preliminary findings revealed yet more about the market adaptability and social sustainability factors, thus further research is ongoing to support generalization of outcomes in the context of UAE.

Keywords: COVID 19; pandemic; Social sustainability; Public markets; Urban resilience; Al Ain, UAE.

1. Introduction

Coronavirus pandemic (COVID19) is caused by an infectious virus of a new strain of coronavirus family SARS-CoV2 [1]. The virus exhibits extremely high transmissibility from person to person, which allows it to circulate between people at an unpredictable pace. Although there is no yet proven data that public space has caused the emergence of COVID 19, it's believed to have started at a wet public market in Wuhan, China, in December of 2019 [2]. Ever since, public markets have globally been a significant concern to many authorities regarding COVID19 transmissibility between people. Nevertheless, people continued to be resilient to shopping and socializing at public markets regardless of the risks and advanced available shopping alternatives. This research aims to explore public markets' urban resilience strategies beyond food supply to shed light on its crucial role in people's social life recovery.

Likewise, public markets in the United Arab Emirates (UAE) went through total lockdowns for two months. Therefore, the UAE offered an optimal "experimental ground" for this study to test the developed conceptual framework. Based on mixed-method case study in UAE, particularly in Al

Ain public market, pilot research was initiated to examine the impact of social sustainability of public space. The framework aims to evaluate the impact and relevance of five physical and non-physical social sustainability factors on urban resiliency in cities during the COVID19 pandemic. More specifically, this research has two questions:

1. What is the correlation between public market and social sustainability in cities, mainly under uncertainties?
2. How social sustainability is perceived in Al-Ain public market?

1.1 Urban Social Sustainability as a Component of Urban Resilience in Public Spaces

Urban resilience is defined by Vale & Campanella (2005) as "the capacity of a city to rebound from destruction" [3], (p.141). While achieving urban resilience is a dynamic concept that hosts many components, this study focuses on social sustainability component to achieve resilience [4]. The focus of resilience here is to maintain critical goals of functionality (e.g., performance, safety, and profit) during and after crisis[4]. Although all sustainability pillars are equally crucial to urban resilience achievement in public markets, the scope of this study focuses on the evaluation of social sustainability.

Urban social sustainability has diverse definitions depending on different contexts and local perspectives [5]. In an attempt to define social sustainability, the city of Vancouver explained it as "… a socially sustainable community must have the ability to maintain and build on its resources and have the resiliency to prevent and address problems in the future" [6] (p-12). This definition appoints social sustainability as a part of achieving resilience in communities. Urban social sustainability is a dynamic concept with different physical and non-physical factors that might negatively or positively affect its function in cities and within communities [7]. Accordingly, Social sustainability's factors should be investigated using a framework that this study attempts to establish.

Poles & Stren (2002) argue that urban policies conducive to social sustainability must aim to bring people together, make urban areas cohesive and increase access to services and employment within a framework ideally produced by local governments and capable of standing the test of time [8]. Academics and policymakers have developed several frameworks of social sustainability to employ physical and non-physical factors evaluation. However, among different scales of urban distracts, social sustainability of public spaces is still an understudied topic with only limited developed conceptual frameworks [9].

Public space is a major urban design element of cities where unpredictability often happens. The definition of public space adopted for this study is drafted by Abu Dhabi's government, which states that public spaces include all open spaces within the community of the built and natural environments or spaces for public gathering [10]. Accordingly, public markets are one of the oldest forms of public space in the city. They are also the earliest and most iconic public spaces feature of Islamic cities, typically located in the city center as a landmark beside the mosque building [11]. In general, open public spaces in many Arab cities, including the UAE, haven't received much attention from academics and city planning strategies [11]. Given this context, it is not surprising there is a lack of public space typologies and projects in the UAE. However, traditional public markets continue to contribute to the urban imagery of many cities in the UAE, in which people use as landmarks to orient and navigate themselves.

According to Kevin Lynch (1960), the space that people could easily and mentally navigate through to understand patterns that visually organize the environment into an image is referred to as the legibility of space [12]. Legibility is not necessarily only related to the non-physical aesthetic of a place but also, to its urban scale of time, size, and complexity that form physical dimension of space [12]. Lynch believed that the best way to understand legibility in an urban environment is to produce different mental images of different spaces through people's perceptions [12]. The amount of legibility of a space depends on the spatial psychological that could vary between observers of the space.

Lynch also argued that there is a single physical sense ordinated dimension of the space that further assesses spaces beyond the non-physical dimension and is equally important to study, which he called imageability [13]. Lynch defined imageability as "… [the] quality in a physical object which gives it a high probability of evoking a strong image in any given observer" [12] (p.9). Hence, imageability is objective and suggests that the physical factors of spaces could be identified for different people in the same manner. Public space's physical (legibility) and Non-physical (imageability) factors contribute to the overall image of the city and are factors that aided this study to develop a framework to achieve social sustainability.

1.2 Factors of social sustainability: establishment of the framework.

Social sustainability is a dynamic concept that relates to collective factors of everyday social life. To further explore aspects of social life in public space, five interrelated factors of social sustainability which are: social cohesion, place attachment, accessibility, adaptability and security, considered for the purpose of this research [6, 7]. These factors relate to multiple aspects of everyday life and are essential factors at the scale of public markets.

1. Social cohesion is the constant integration of diverse people's behavior in a social place. Social inclusion is an essential part of social cohesion, which emphasizes the diversity of social and cultural groups in societies while all social activities are included to provide spaces for social interaction [5, 8]. For this to occur within a space, individuals need to actively participate in the community activities [14]. Daily ritual, trust and respect between people will further enhance social cohesion of the community [14]. Also, integrating multiple facilities within spaces allow people to participate in more than one activity [14].
2. Place attachment depends on people's perception of a place. According to Lynch, the visual features are the greatest inspiration for reflecting an understanding of a space in which we start the construction of place identity [12]. Dempsey et al. (2011) argue that place attachment relates to the physical environment preserved quality and socio-spatial interpretation. People create attachment through long-term memories with other people such as family and friends [7]. Therefore, place attachment has strong ties with the idea of belonging to a space with shared users to form unique order, which makes it different from other places, and spaces [14].
3. Accessibility indicates how easily the services, such as public transportation, cycling, and walking, are reached and used by everyone within a reasonable cost and time [15]. Lynch argues that access to services is assessed by reaching diverse and multiple activities, elements, facilities, information, and people in the same place [13]. Accessibility of public spaces should also include safe and obstacle-free entrances for the elderly, children, and wheelchair users. The spatial organization in urban areas may produce obstacles to pedestrians' mobility (such as highways or lack of crossing zones) [8].
4. Adaptability is the amount of resiliency for people and societies to creatively act upon change [6]. The process of adaptability in built environment is simply a space with high fixability [13]. As much as flexible to change is important in space, human adaptation is a key to social recovery. Adapting humans' systems to change includes the right to be protected from any current, or future, danger by adopting measures that help in achieving safety [16].
5. Security is fundamental factor for social sustainability and it refers to public space free of crime and disorder to allow users to feel safe and increase their trust within the community [7]. Security is also important in the built environment, which includes surveillance, i.e., active lighting during the night, which increases safety and enhances social interactions. However, built environments with poor conditions and lack of maintenance are believed to cause phycological effects on people's sense of security which may likely bring more unlawful behaviors [7]

1.1.1 Conceptual Framework

During the last decade, the UAE local government has suggested several sustainability frameworks that were inclusive of environmental and economic pillars of sustainability. However, social sustainability factors have never locally been developed into any framework. This research suggests a framework that was developed based on revised literature. Nevertheless, the conducted pilot fieldwork was insightful in offering additional emerging factors to consider for more in-depth conceptualization of the suggested framework.

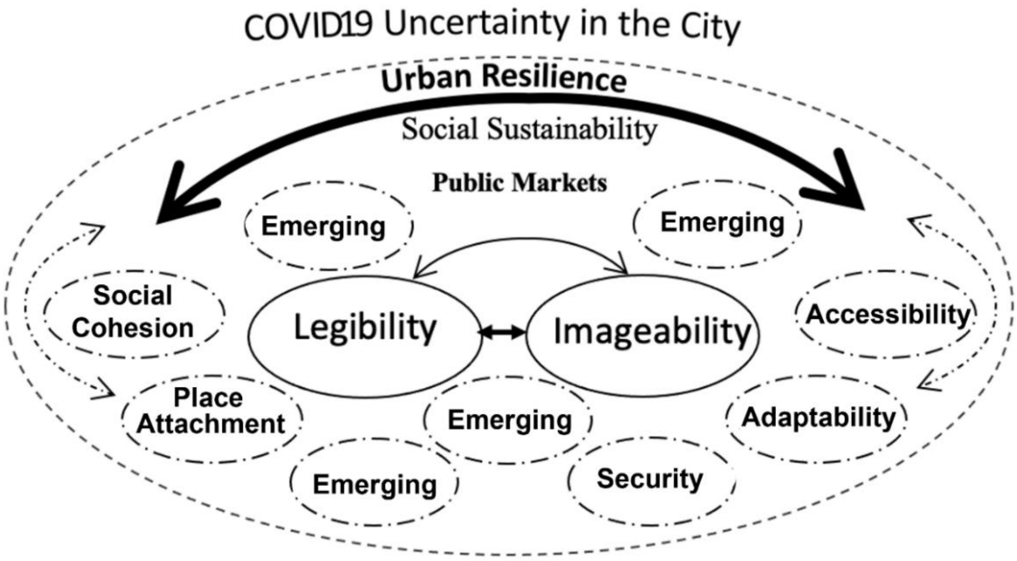

Figure 1: A pilot framework of social sustainability in the public market by authors

2. Methodology and Research design

2.1 Research design

This research employs an exploratory sequential mixed-method case study approach using qualitative and quantitative research methodology. The research design was based on Jhon Creswell and David Creswell's (2018) mixed methodology approach [17]. The investigation first began by reviewing the literature on social sustainability factors and its indicators. Second, factors were measured in the market using qualitative tools such as observations and interviews on a randomly selected sample of the market users. Afterward, a survey was shared with the community of Al Ain city that was designed based on the reviewed literature and identified factors. The survey included questions to collect people's input on the market space and activities. It also included a section on demographic data of the participants to connect the qualitative analysis with the quantitative features of the study. Undoubtfully, the quantitative sample is bigger than that of a qualitative sample. This goes hand-in-hand with the intent of the data collection for the quantitative method is meant to support the qualitative analysis with statical details to validate the research construct.

2.1.1 Observation

The observation tool was selected to provide detailed view of the natural pattern of people behavior in the market during the pandemic. First, the market was observed on ad hoc basis and on random times for the researcher to get more familiar with market site and its everyday dynamics. In so doing, activities and behavioral patterns were recorded using field notes. Second, the market was extensively visited based on scheduled time, photographed were collected, and short videos were recorded (thirty seconds – two minutes) to document the social dynamics in the market.

The data was collected on days when temperature ranged between 28 °C and 38 °C from late October 2020 through early December 2021. Observations were conducted between 8:00 a.m. and 10:00 p.m. over weekends and weekdays. Simultaneously, random observations were used to track people's non-stationary and stationary activity at different times of the day/week.

2.1.2 Interviews

Face-to-face semi-structured interviews were used to understand people's perceptions and attitude towards the market's physical and non-physical characteristics and infrastructure. The interviews were conducted in parallel with the observation period. Interviews were conducted with 21 active users of the market within a period of five to ten minutes. While the questions started with the demographic section to classify participant groups (i.e., visitors, vendors, and workers), most of the questions were opened-ended to allow the users to freely share their perception and spatial Experience. Thus, each participant was asked three questions, as follows:

1. How does the market's changing conditions affect their overall spatial/social experience?
2. What does the market mean to them, and how/what makes them attached to it?
3. How do they perceive the overall physical condition of the market?

2.1.3 Survey

The online survey was designed to gather larger sample of the community's input to reflect on the social market experience. This tool was also used to compare with and verify against the collected data from interviews. The aim here is to find out to what extent the selected social sustainability factors contribute to the overall social sustainability of the city using Quantified data. The online survey was constructed using 15 questions and was sent to Al Ain residents during one week using multiple social media platforms resulting in a total of 218 participants.

First, the survey included five demographic questions to learn on the research participants background in terms of nationality, age, level of education, gender, and marital status. Second, to assess which key subgroups (i.e., a community member of different ages) respond differently to social sustainability measures. Third, the remaining majority of the 15 questions were asked to participants to rate the five selected factors and how they affected their choice of visiting the market.

2.2 The pilot study: Al Ain Central Public Market

Al Ain Central Market has been functioning since the early forties and still sells various daily goodies until today [18]. The market building was one of the first economic buildings to be constructed in the city. It contains multiple shopping options, including indoor, outdoor, and drive-through services. The name "Central" market refers to its location since it's in the heart of Al Ain city. It's also located next to the first and only central bus transit station in Al Ain. Figure 2, shows the map of the market with the identified land use. The study focused on the outdoor market since it has direct access to the public, it includes a mosque and empty shaded space, while the indoor market was excluded from the analysis.

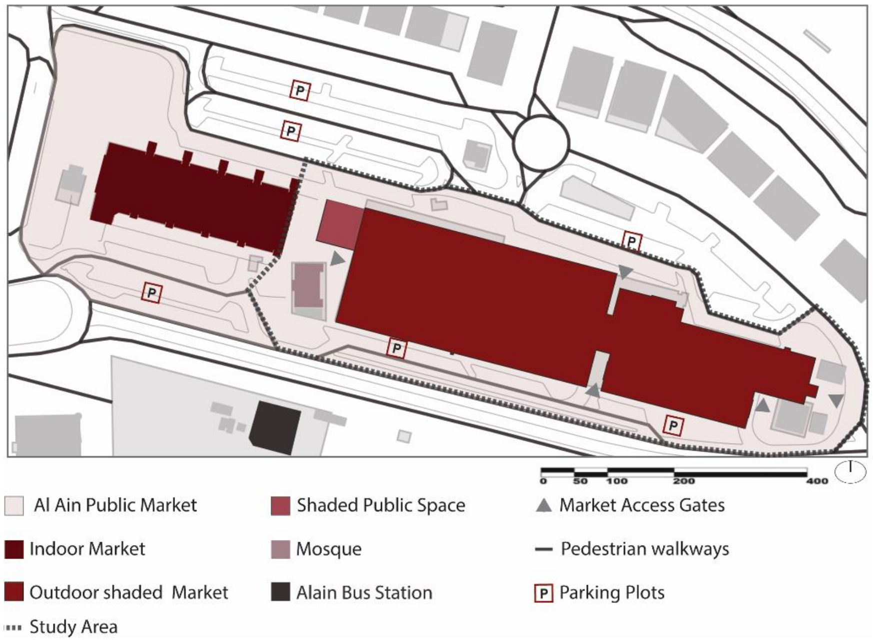

Figure 2: Al Ain Public Mark, source: Abu Dhabi Spatial Data Infrastructure Agency (ADSDI), 2015, retrieved, 21/10/2020

Since the emergence of the COVID-19 pandemic, the market has encountered many physical, economic, and social changes. After a total lockdown of two months, the COVID-19 complete closure was lifted, and the recovery management phase was launched in the UAE [19]. On May 5th, 2020, the announcement of the market's reopening came with strict implementations of health restrictions set by the health authority following World Health Organization (WHO) safety rules. The restriction included all vendors conducting a COVID-19 test every two weeks and obligatory wearing of masks and gloves [19]. Also, the authority enforces all visitors to wear masks, gloves and temperature was measured at each of the market gates.[19] Furthermore, visitors must do their shopping within 15 minutes while keeping a physical distance of at least 1.5 meters. Finally, informative signs on physical distancing and precaution measures were hanged on the market walls, furniture, and utilities.

3. Data Analysis and Integration

3.1 Participants' demographic data

Based on the collected survey and interviews, Table 1 shows the research participants demographic data and descriptions. The results show that 157 (72.02%) of the survey participants were females, while the interviews were mainly with 16 (76.19%) male respondents. Through different observation rounds, men were more regularly present in the market than women, especially during the evenings and on weekends. On the other hand, women were observed to shop more often in the morning.

The age group that was mostly dominant in the market is 45-53-year-old people. Likewise, the interviews also had the highest number of participants, 8 (38.1%), from the same age group. Thus, both observations and interviews had almost equivalent age participants, which seems the representative age of the daily users of the market. At the same time, the survey's highest participant age group was 25-44-year-old, with almost half of the participants 106 (48.6%) under this age group. This age group was not mostly in the market during weekdays; however, during weekends they were observed especially accompanied by either their parents, siblings, or children.

The survey also hosted a small number of daily users as only 60 (28.2 %) participants were daily shoppers. Most of the survey participants were not active market users, which shed light on what is missing in the market. While the interviews were mostly with daily shoppers 10 (47.61%). It was also important to interview vendors and inspectors as they spend all their time at the market, 8 (38.09%) vendors and 2 (9.52%) inspectors. The participants inputs were insightful to understanding the daily changes of the market.

Table 1. Participants' demographic data

Tool	**Age**						**Gender**		**User Category**		
	13-17	18-24	25-44	45-53	55+	**T**[1]	**F**[1]	**M**[1]	**V**[1]	**S**[1]	**I**[1]
Survey	12	42	106	27	31	**218**	157	61	0	60	0
	5.5%	19.3%	48.6%	12.4%	14.2%	**100%**	72.02%	27.98%		28.2%	
Interviews	-	2	4	8	5	**21**	5	16	8	10	2
		9.52%	19.05%	38.1%	23.81%	**100%**	23.81%	76.19%	38.09%	47.61%	9.52%

T: Total, F: Female, M: Meal, V: Vendors, S: shoppers, I: Inspectors

3.2 Data Evaluation

A factor-based assessment approach, distinguished as an indicator-led process Pope et al. (2004), has been applied [20], to guide the evaluation and assessment of social sustainability factors within the conceptual framework shown in Figure 1. The conducted assessments use a "direction to target" approach which is indicated as follows '(+)" (-/+)' or '(-)'positively, partially or negatively archived towards sustainability factors described as follows:

1. Social cohesion was partially achieved (-/+) in two indicators: First, social inclusion (+); second participation (-).
2. Place attachment was achieved positively (+) using long-term memory as an indicator (+).
3. Accessibility was positively achieved (+), in two indicators: First, ease of access using multiple transportation modes (+) and the ability to reach diverse shops at once (+).
4. Adaptability was positively achieved in two indicators: First the change by the flexibility of built environment (+); Second human behavior flexibility (+).
5. Security: was partially achieved (-/+) in two indictors: First the of availability of surveillance and good lighting (+) second lack of maintenance (-)

As explained in the above, not all the investigated factors were achieved, therefore, the social sustainability of the Al Ain public market is only partially achieved here (-/+).

4. Discussions and Interpretation

4.1 Factor 1 : Social Cohesion

The study results implies that the market is socially inclusive to diverse people and age groups. Figure 3a. shows the diversity of users within the market. Similarly, the interviews and surveys were conducted with people from diverse backgrounds and ages. Although social inclusion's indicator of social cohesion is "positively achieved" (**+**), it is not enough to achieve social cohesion.

Participation in activities contributes to the successfulness of social cohesion as people will "hang together" more [14]. Due to the COVID 19 restrictions, all the activities were suspended, including daily prayers, cultural events, and national day celebrations. During the interviews, multiple participants claimed that the mosque closure made them leave the market to pray at home. Thus, COVID19 caused the participation to be "negatively achieved" (**-**). Dempsey et al. (2011) argue that lack of community activity might not necessarily lower social sustainability; however, it may weaken the social cohesion that integrates the community. Thus, this factor is partially achieved (-/+) only.

(**a**)

(**b**)

Figure 3. (**a**) People diversity in Alain public market **(b)** Father showing his son how to shop at the market. Source: photos taken by the authors 13/11/2020

4.2 Factor 2: Place attachment

The market offers high levels of place attachment to Al Ain community members. Based on the conducted survey, 89 (41.1%) of the participants feel strongly attached to the market, while 45 (21%) respondents said they nostalgically recall their memories in the market. However, only 61 (28.2%) of the survey participant are shoppers of the markets. This is because many survey participants visit the market with shoppers they care about. 132 (64.4%) of the survey participants visit the market with their parents or spouses. Also, Figure 3b shows many visitors who came with a companion, especially with parents or children. Such social interactions result in long-term memory that relates to space. Dempsey et al. (2011) argue that long-term memories of special place motivate people to form a mental image that helps in achieving place attachment [7]. Thus, place attachment is positively achieved (+).

4.3 Factor 3: Accessibility

The central location of the market plays an important role in the success of its accessibility. Figure 2 shows five entrances to the markets connected to multiple pedestrian walkways that enhance walkability and connectivity. The market also offers six parking plots for car users around the market. The bus transit station is next to the market, as shown in figure 1, thus there is only one bus stop next to the market. Additionally, while interviewing vendors of the market, most of them use cycling as a means of transportation, especially that they live around the market. Ramps are provided for all the five entrances to make the market inclusively accessible for all users. The successful achievement of accessibility measures not only improves social sustainability but also enhances the use of the public market as a public space.

4.4 Factor 4: Adaptability

Adaptability to change is a major step in any attempt of recovery. The flexibility of the market supported its rapid recovery process before many public spaces during the pandemic. For example, before the pandemic, the outdoor market shown in figure 4a was chaotic with stalls vendors randomly distributed in 2018. However, in 2020 the same area was completely replaced with benches and seats, as shown in figure 4b. The market recovered from disruptions (losing businesses spaces) to improvement as a public space with urban furniture. During an interview with the chief of inspectors regarding the urban seating, he claimed that people were coming to the market more often as it's the only space open to the public. To reduce contact between people, urban furniture was added. Reorganizing spaces based on the socio-spatial settings of risk is important for faster recovery, especially for vulnerable people [16]. Added to the flexibility of space, people were observed adapting to new measures of COVID19 that included wearing masks all the time at the market. The success of adaptability is "positively achieved (+)" along with the adaption of the physical environment of the space and adaptation of new human behaviors.

(**a**) (**b**)

Figure 4. (**a**) Outdoor stacks vendors September 2018 (**b**) Stacks replaced with seating October 2020. Source: photos taken by the authors.

4.5 Factor 5:Security

The fieldwork outcomes showed that the market "positively achieved" (+) urban surveillance because it includes CCTV mentoring camera, seven security officers and good overall lighting. However, the survey showed that 86 (39.2%) of research participants stated that if there more advanced security measures were installed, they would have visited the market more often. Also, one of the participants interviewees claimed that they come alone because their family and friends don't feel the market is safe enough. This may be due to the lack of maintenance of the market which makes people feel the authorities don't have control on the market space. This finding corelates with Wilson & Kellin (1982) in their "broken window" theory argue that visible signs of disorder in public spaces from low service such as broken windows provoke the feeling of crime and cause fear of space [21]. Also, 125 (57.2%) survey participants stated that if the image of the market improved, they would have visited the market more often. Thus, the security factor is only partially achieved (-/+).

5. Conclusion

This paper provides an initial exploratory stage of understanding public markets urban resilience strategies. It also tests the claim that micro public spaces social sustainability contributes positively to the social sustainability of the city. The findings show that several factors positively influence social sustainability, particularly place attachment, accessibility, and adaptability. On the other hand, the security factor needs to be enhanced by improving the overall physical infrastructure and appearance of the market.

The social cohesion factor of the market community was restricted with the recent emergence of COVID 19; therefore, only limited number of people were in the market to participate in the research survey. However, with the recent government intention to gradually bring life to normal, we expect more people to be in the market during the upcoming in-depth fieldwork. The conducted pilot fieldwork and analysis were meant to shed light on how the public market managed to absorb the rupture caused by the pandemic and the unfolding uncertainty. The research findings yet have exhibited emerging factors that contribute to enhancing social sustainability in public markets. These emerging factors are considered in refining the pilot to proceed with additional fieldwork, which the researchers are currently working on.

Notes:

1. All the names of the interviewees have been kept confidential to protect their anonymity.
2. Interviews and surveys were conducted in Arabic and translated to English by the researchers.
3. All photos are used with permission, and credit is given to owners.

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The Principles of Healthy Arab Cities and their Resilience for Pandemics

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Abstract: Cities will not become sustainable and resilient if it is not to take the measures to confront of epidemics, not only by taking the measures, but by achieving healthy cities which applied principles and standards of public health in its plans and urban design of its neighborhoods, some of healthy city's principles may be agreed upon by all cities of different types, but others may be different according to the characteristics of the city and its location. The research problem is that although there are general principles for healthy cities, but there are no appropriate principles for regional cities like Arab ones, also there is a conflict between the concepts of healthy cities and resilience cities for a pandemic, what is the difference?, The research aims to determine the appropriate healthy cities principles for Arab cities, and also it focuses on the difference between healthy and resilient cities, and it develops a method for implementing the healthy cities strategy within the urban plans of the Arab cities, the research method will depend on the inductive approach on discriminate between healthy and resilience cities and deductive approach to determine healthy and resilience principles on Arab cities.

Keywords: - healthy cities, resilient, sustainable, cities strategies, Arab cities

1. Introduction

Many countries have taken it upon themselves to realize the concept of healthy cities; those cities have principles and the opportunities for achieving a healthy life for their residents, However, these principles may differ from those in cities that are resistant to epidemics, the latter is prepared to face these epidemics so that their design and planning are qualified to face epidemics, its performance in terms of services, administration, communications, methods that are in times of crisis different from its performance in the normal days.

The importance of healthy cities has increased after the exacerbation of public health problems because of urbanization and random growth, so the healthy city concern on improving the physical, mental and social condition of people, and aims to achieve healthy justice and increase the capacity of the population to face the various requirements of life, improving health leads to resistance to various epidemics.

The main development goal relates to the advancement of human beings and the improvement of their lives and their ability to produce, think and create, and it is mainly achieved by upgrading the urban environment surrounding them, sustainable and resilient of urbanization means the ability of a city to survive and thrive in the face of various disasters which pandemics are one of them, healthy cities are related to sustainable and resilience and if we applied healthy cities principles, we can achieve sustainably and resilience for cities.

1.1 Methods

In the first we will study successful examples in Europe and USA and using the inductive method to determine important urban variables which improve and preserve public health for cities inhabitants, then we study the different criteria between (Europe, USA) and Arab (Egypt), which effect on urban healthy elements and to determine which variable suitable to achieve health Arab cities, We depend on an inductive approach to select healthy city variables by reviewing urban variable which affect on public healthy, we select the variables which have a reliability effect on human health.

We also study spatial variable effects on public health by classifying them sectorial (economic, environmental, social, urban) and by level (city region, local, urban) using the inductive method, to determine healthy city elements and criteria, And we use the deductive method to determine which of this variable is suitable for the Arab environment depending on the criteria which we have discussed in the beginning, for each variable we try to determine in the first its effect on health of inhabitants, Second, we determine suitable standards for those variables to achieve healthy cities. Finally, we classify the city healthy variables: - global city health variables, city's health variables appropriate for Arab and Egyptian communities.

1.2 Different of health city variables between Europe and USA Vs Arab (Egypt) communities (initial determination)

The research aims to determine the appropriate healthy cities principles for Arab cities, we have mentioned before that some of healthy city's principles may be agreed upon by all cities of different types, but others may be different according to the characteristics of the city and its location, we have studied examples of Europe and USA which agree with Arab cities on most principles, but they are different in some another specially in the environment and some potential, Egypt environment as example is (hot, dry summer, warm, rainy winter) and Europe is (Moderate summer cold winter), The temperature difference of them is between 10-15 degrees Celsius.

The difference of Environment (as the main difference between Northwest cities Vs Arab cities) can affect on (percentage of green, area and open spaces, building heights, width of the roads, trees and plantation), for potential (as the main difference between northwest cities and gulf cities Vs other Arab cities) variable like (density, open space facilities, public transportation, safety systems, road crossings), we will discuss all these variables in detailed later.

1.3 Public Health important

The term public health aims to protect people in cities from contracting various diseases, and maintaining them in good health, by providing a safe, healthy environment, and providing the health services, in order to limit the spread of diseases, and provide the treatments for them, also to improve health behaviors and environmental conditions, which include mental, psychological or physical aspects, in addition, the social aspect To enable residents to perform all their work, rational thinking and build healthy social Relationships. WHO define Public Health as "the art and science of preventing disease, prolonging life and promoting health through the organized efforts of society" (Acheson, 1988; WHO, 2021). [1]

1.4 The importance of healthy cities

The major goal of development is to achieve a quality of life, and improve people's ability to produce, think and create, which is mainly achieved by upgrading the urban environment. Cities will not become sustainable and resilient, except through taking the measures to confront various pandemics, besides planning and designing them according to public health standards. Urban resilience is considered a city's ability to survive and thrive in the face of various disasters. The policies emanating from it are also considered one of the most important policies that urban communities need to face various epidemics.

WHO know Healthy cities as cities that provide a healthy environment for residents to benefit from their energy and potential, by setting extra dimensions in urban development strategies that enable the city to provide a healthy environment for them. Also, it depends on a set of standards and principles applied to city plans, urban designs, to ensure achieving safe public health for its residents [2].

In addition, it is one that is continually creating and improving those physical and social environments and expanding those community resources, which enable people to support each other in performing all the functions of life, and in developing to their maximum potential [3]. Also, healthy cities are constantly working to make use of the resources to achieve a healthy and sporty life for their residents, and it depends on practical experience.

2-International experiences to achieve healthy cities

We will review two examples for achieving healthy cities in Europe and America.

2.1 Glasgow experience

Glasgow is a member of the WHO's European Healthy Cities Project since 1988, In its experience, the city of Glasgow focused on how to achieve the principles of public health on all elements of the urban system, as well as how to enhance participation in decision-making through a set of measures that support this process, and these measures include [4]: -

1. Determining the criteria that would verify the positive impact of the elements of the urban system on public health.
2. Determining the most important terms of cooperation with partners to promote the inclusion of health and well-being principles in urban development strategies.
3. Monitor and follow up implementing health measures related to urbanization through local authorities, and the Health Impact Assessment (HIA) to determine the health impacts and potential well-being of urban plans and strategies. Figure (1)

Figure 1. Developing Glasgow's city center in line with healthy city standards[ii]

2.2 Morristown Experience, NJ, USA[iii]

The city has adopted the following principles to achieve healthy cities: -

1. Providing open and green areas for practicing sports
    A. The central public park in the city center, from which all residents benefit.
    B. Providing trees on both sides of the sidewalks along the roads
    C. Providing places to practice sports and yoga in all open areas

2. Transportation
    A. Achievement of pedestrian cities, Morristown score of (71) walk score
    B. Providing most of the major services within 500-800 meters
    C. Providing public transportation to serve the near and far areas.
    D. Providing cycling paths along the roads.

3. Easy access to health services. Figure (2)

Figure 2. Imagine of movement and afforestation in the city of Moriston[iv]

4. Social communication.

2.2 Factors which affect on the healthy cities

We can elicit factors affecting healthy cities from previous examples as the following chart:-

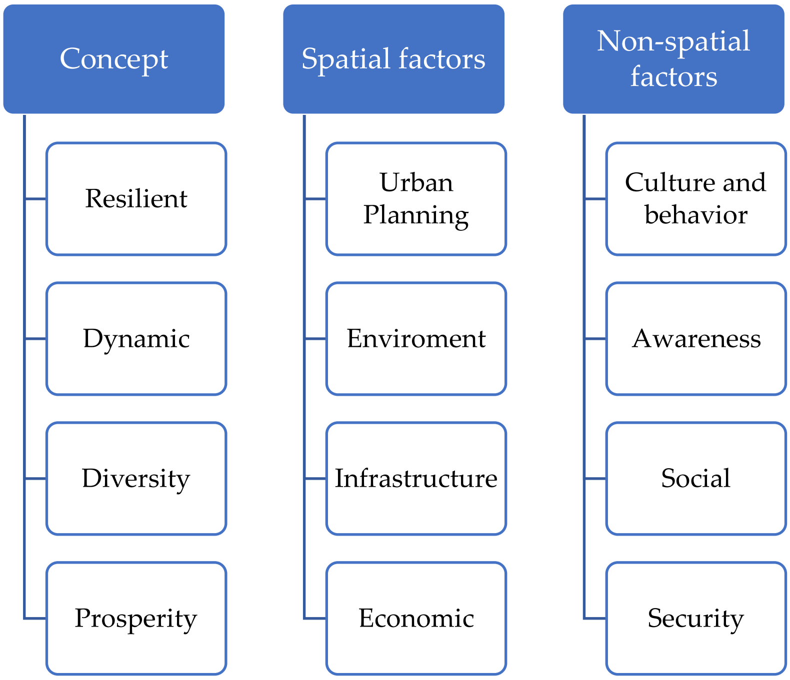

Figure 3. Classification healthy cities factor

3. Levels of planning healthy cities.

Healthy cities can be achieved through a combination of factors and at many levels, Therefore, the classification of levels and factors for achieving healthy cities helps to clarify the idea and facilitate its realization, with the possibility of evaluating each factor and each level separately, the research try to classify healthy cities into three levels, according to the field of variables which we will review: Figure (4).

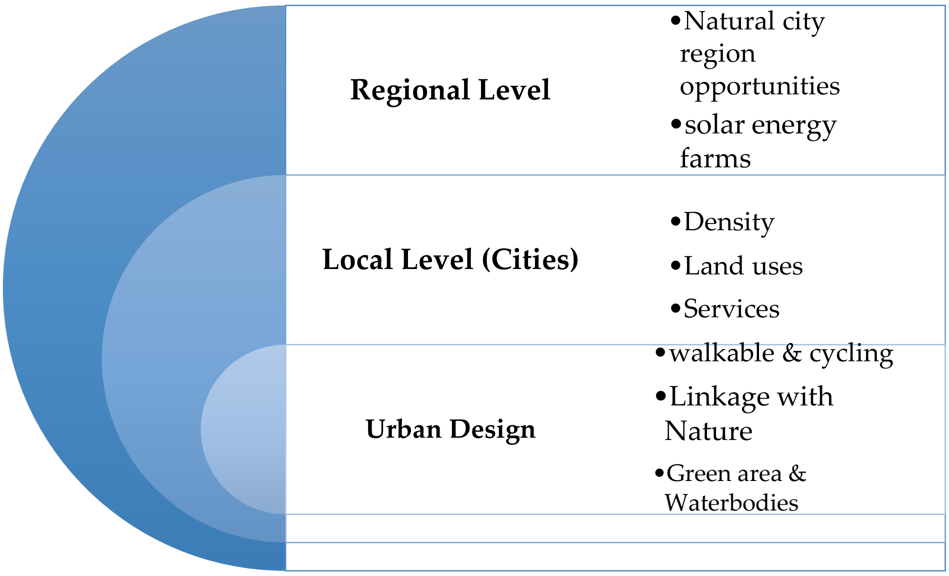

Figure 4. Levels of Achieving Healthy Cities

3.1 Spatial factors affecting the achievement of healthy cities

We can classify the factors which support cities to be healthier in two dimensions first non-spatial factors, and second spatial factors, the tow dimension are Including many development sectors in cities, such as economic, environmental, social, urban, infrastructure, and others, and each of these sectors has an important role in achieving public health.

3.1.1 The Regional Level:

We can also classify Urban communities into four classifications according to their location and the distinctiveness of their natural environment and their effect on public health 1-urban communities that have a desert region, 2-urban communities with an agricultural region, 3- oases 4-areas located on water bodies (seas, lakes, rivers), It is important to benefiting from the region of urban communities, whether this is an agricultural or desert, which can be used to improve the health of the residents of these communities.

1. Take advantage of the city region

Take advantage of the green fields surrounding urban areas by achieving a full panoramic view of green, taking advantage of the distinctive view and hiking, and preventing the blocking of vision on it, as well as taking advantage of opening the vision in front of the landscapes in oases and coastal cities and taking advantage of the desert areas through safari and camping.

Desert areas have a positive effect on human health, just as the purity of the atmosphere Low levels of sulfur oxide and carbon pollutants, in addition, the integration with nature improves human performance. Also, the more people move away from devices that cause radiation or electromagnetic field, the more positively this will have on the health.

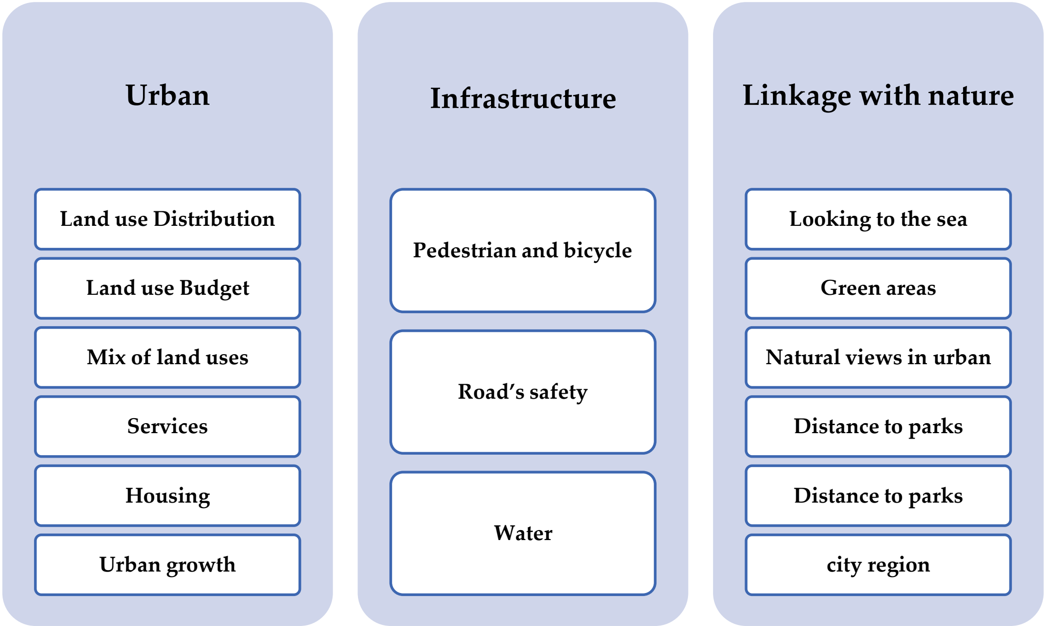

Figure 5. Healthy city urban factor

2. Providing solar energy farms in the city region

Renewable energy is clean energy that does not cause pollution like fossil fuel energy and does not produce noise or emissions, so it has not affected negatively on the health. Therefore, it is important to provide suitable land for solar energy farms. As, cities depend on a percentage of them to meet their energy needs.

3.1.2 Urban factors for healthy cities

It is possible to classify the spatial factors affecting healthy cities to: - first regional factors, secondly local factors (cities), thirdly factors at the level of urban design. We will discuss spatial factor of healthy cities:

1. Adequate density to achieve healthy city

Many studies confirm that high population density achieves a healthy life for its residents, as high density provides activity and dynamic for the city, interaction and social relations between its inhabitants, and achieves cities fit for pedestrians. We can do it by (availability services, economic feasibility of public transport, commercial activities), in a British study of 400 thousand people in twenty-two cities, it was found that the population density to achieve a healthy city in which the possibilities of living and pedestrian paths are available in a good way. And, with green spaces and parks should not be less the density is about 65 persons/acre [8]. The same density that other studies indicated to achieve feasibility to provide public transport in these cities. Which differs from Arab cities that suitable density for it may be reached 100 persons/acre, there is

Another study applied to 36 cities showed that there is no direct relationship between the high density and the spread of Corona disease [9]. Where there are high-density cities such as Tokyo, Seoul and Hong Kong have succeeded in their prevention measures despite the high density of these cities[v], Figure (5).

With considering taking into account the areas with high density, to take strict measures with them on social distancing because of their great impact on increasing the speed of spread [11].

This is because people in high-density societies are more physically active. And their cities are more "walkable", which means there is a possibility of walking to shops, schools and other services nearby, As for the Egyptian cities, many of which are within the agricultural areas and the others are within the hot, dry desert areas, the medium and high density is the nature of Egyptian cities, therefore the density of healthy cities for them can range between (80-120) people per acre, which is the highest slightly than the average intensity showed by some previous studies.

2. Land use and healthy cities

Land use is one of the most important studies that reflects the nature of the city, its function, its history, and other aspects that express the city, and it is one studies through which we can achieve healthy cities. Below we present the most important points that must be considered in the use of lands to achieve healthy cities: -

A. Land use distribution and healthy cities

Many non-residential uses can cause significant risks to human health when combined with residential uses, including polluting uses such as industrial uses, heaters and other noisy activities such as workshops, nightclubs. All these conflicting activities negatively affect the general health of the population, so there must be controls to achieve complete separation from residential areas. Table 1 clarifies the relationship between the different uses.

Table 1. Relation between land uses (Researcher)

Land use	Industrial area	Commercial area	Services	Mixed use	Residencia
Residential	×	O	√	√	√
Commercial	O	√	O	√	O
Religion	√	√	√	√	√
Hospital	×	O	√	√	√
Education	×	O	√	√	√
cultural	×	O	√	√	√
and Entertainment Tourism	×	√	O	×	×
sport	×	√	√	√	√
Administrative	√	√	√	√	O
Industrial	√	×	×	×	×
Social	×	O	√	√	√
Areas Green	√	√	√	√	√

B. Land use budget and healthy cities

The successive developments in the fields of transportation and communications have affected the land use budget in urban communities, especially after Corona virus, after so businesses and educational materials became through the Internet and from a distance, and thus it was possible to reduce some land use ratios with a land use budget in future cities and healthy cities such as work, education and services, and increasing the percentage of other uses such as green and open areas and clubs, Sports, social, and other cultural and social activities, as well as the use of pedestrian and cycling paths will lead to greater proportions of roads within land use, which will be determined in other points in the study. Figure (6)

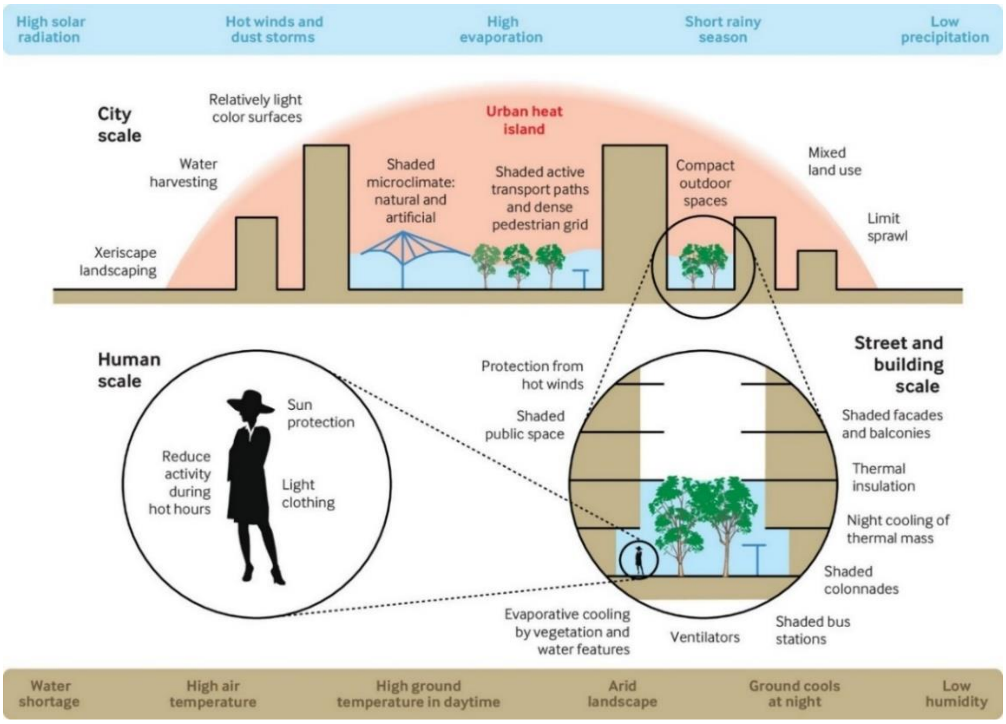

Figure 6. Arab cities' characters and healthy standards [12]

C. Variety and mix of land uses

Recent studies have shown that the multiplicity and diversity of activities within residential neighborhoods like sport, social convergence, etc., which provide a friendly community for residents, are very important for their health. The diversity of uses is linked to the population density that makes the city more dynamic and more suitable for living, and the diversity of socio-economic levels and the diversity of activities creates healthier communities.

D. Availability of areas for exercising

One of the important characteristics of healthy cities is the provision of yards for all residents to practice different sports and yoga, especially sports that require open areas. The provision of these squares in public and central parks, makes the percentage of open area in healthy cities not less than 15% [13] of the city's land use budget. In the otherwise it cannot be over 10% in Arab cities as environmental effects.

3. Urban growth and its impact on public health

According to studies conducted in western, Gulf and Egyptian cities, most cities tend to sprawl, which is inconsistent with the densities of healthy cities, as well as the principles of the dynamic of the city and the mixing of uses and other modern urban concepts, which requires a different thought for urban growth in terms of Densities, Which should be no less than 80 people on an acre, and the main street widths of not less than 30 meters to accommodate the movement of pedestrians and bicycles to the main roads, as well as the linkage of new extensions to the existing city, and the creation of a mechanism to support services and commercial activities with these extensions in order to provide dynamic, activity and safety of these cities.

4. Providing suitable housing units for all residents

The importance of providing housing units for all residents according to their characteristics and capabilities, work to stabilize the real estate market, governorate care for residents who are cannot own a house while providing subsidized housing units, land prices have not scalable by determine suitable policies, emphasize the stability of rental laws and all laws related to housing.

5. Providing services

All educational, health, social and sports services for neighborhood must be provided within a 20-minute walk of homes, and the services provided must be highly efficient and meet the needs of the residents. Walk Score of at least 70 [14]. Cairo walkable score Is 96 but there are some problems, encounter pedestrian in Cairo. We have achieved 80% of services can be got by walking, importance of equitable distribution of services.

3.1.3 Healthy cities (urban design level)

1. Pedestrian and bicycle cities

Cities in developed countries are distinguished because walking in them is enjoyable and safe, which leads to reduced driving rates in cars that cause pollution, our fuel consumption, and it also helps to improve the level of public health. As walking is one of the most important sports that are suitable for all ages. Also, walking for a period ranging between 20 and 30 minutes a day in the midst of nature reduces the stress hormone "cortisol" by 10%, according to the British newspaper " science daily” [15]. It can also be considered the most important way to meet daily needs, and it strengthens social relations within the residential neighborhood, besides that it invites people to meditate, contemplate and enjoy nature, as well as it is related to standards of happiness, quality of life, and improving the person's mood, and it is suitable for inhabitants. Who hasn’t capability (health or financial). it is recommended to daily walk of 15-30 minutes, i.e. (2-4) km, which is important for the health of people, as it burns (150-200) calories. Walking also affects (stimulating blood circulation, lungs, strengthening the respiratory system, the heart, strengthening the muscles of the feet, legs, arms and shoulders. Reducing blood pressure and reducing cholesterol). The provision of a safe environment for pedestrians by using the integrated planning and design standards of the movement network (vehicle - pedestrian) will have a great impact on improving the quality of life and achieving the sustainability of urban areas. These standards can be identified: -

i. Comfort in walking by providing (shading: - small blocks, priority for pedestrians, dividing the space, appropriate sidewalk height, lack of occupancy on the sidewalk), Figure (7)
ii. Providing safe passage for pedestrian traffic.
iii. The availability of basic services within a 2 km or twenty-minute walk.
iv. Achieving safety for pedestrians (safe crossing, sidewalk lighting, security surveillance.
v. Compact land uses and density [16].
vi. That the streets are lively and sociable through the diversity of activities, high density, lighting and services.
vii. Stronger walking connections [17}

Figure 7. Streets standards for healthy cities [18]

viii. Passage (restricting crossing except at designated crossings, achieving priority for pedestrians, providing comfortable bridges and tunnels for pedestrians, traffic discipline and drivers 'behavior).

ix. Vancouver strategy achieves 50% (Public transport, bicycles, walking) [19]. we suggest 60% (45% Public transport 5% bicycles 10% walking) for Egypt. But it differs from gulf countries as the climate differs from Egypt.

2. The linkage with nature environment

The link between urbanization and nature is one of the elements that directly affects public health. Looking at nature in a daily green area and bodies of water, the mountains and the sky will improve their general health. Therefore, residents should spend from 20 to 30 minutes sitting in natural areas [20] as well as the green and open areas, providing suitable places for walking and sports, which positively affects the health of city residents.

A. Looking at the sea

Many studies have proven the importance of looking for green and blue areas for their direct impact on improving public health, looking to the sea ten minutes a week eliminates the need for visiting the psychiatrist [21]. All residents of the city can enjoy looking to the sea in the coastal cities through a gradient of building heights and being of a Corniche along the beach.

B. Green areas and nature open for all

Green areas purify the air of carbon dioxide during the day, which provides a healthy environment for the population. Reduce the ratio of the cholesterol hormone, because an increase in the normal range negatively affects human health, as mentioned previously.

Urban green space can be regarded as a preventive public health measure [22]. For individuals who have access, parks, gardens [23]. Green space can also affect on health by reducing mortality ratio, many studies testings the correlation between green space exposure, and mortality have been done in the USA, this research will look over one of them. :- Wilker and colleagues [24] calculated the correlation between residential green space exposure and risk of death for 1645 people [25] who had a stroke between 1999 and 2008. For individuals living in the greenest areas, compared with the least green areas, risk of death was reduced (hazard ratio [HR] 0・78, 95% CI 0・63–0・97) (CI (confidence interval). [26]

Rojas-Rueda, and colleagues [27] have studied the green space exposure−mortality effect, including 8324652 adults from seven countries [28]. The authors found significantly lower risk of all-cause mortality with increased residential green space exposure within 500 m (per 0・1 unit increase in the Normalized Difference Vegetation Index [NDVI]; HR 0・96, 95% CI 0・94–0・97) [29]. (NDVI is a measure of vegetation density based on the difference between visible red and near-infrared, based on how the plant reflects light at certain frequencies [30]) Evidence suggests that trees in particular, compared with other forms of urban vegetation, affect human health and wellbeing [31].

C. Trees and their importance in achieving healthy cities

According to the FAO, the percentage of trees in Egypt does not exceed 1% of the total area, which is a tiny percentage in comparison with many countries of the world, and trees are one of the most important factors that affect the improvement of the environment of the region. On average, one tree absorbs 1.7 kg of carbon dioxide (CO_2) per day. Harmful to health annually, and produces about 140 liters of oxygen per day, the average car produces about 12 kg of carbon dioxide per day, and therefore it is necessary to plant about 7 trees to remove pollutants for each car.

Rojas-Rueda, consider that increment in greenness around homes is significantly associated with reduced premature mortality [32]. Another study found out the equation determines the relation between percent of tree canopies and $NDVI = -0{\cdot}03 + (0{\cdot}51 \times UTC^{1/2})$, and R^2 was 0·85. Where [UTC] refers to present of tree canopy, and the study finds out that a 5% increase in tree canopy (from 10% to 15%) translates into a 0·04 increase in mean NDVI [34]. This is mean that almost, 0,1 of NDVI refer to change in 0.125 of tree canopies as you refer before 0.1 of NDVI affects on mortality risk of .96% that is also meant 1% increase in tree canopy or green area can reduce almost 0.0075 of mortality. So green areas are very important for healthy and other study suggested that green areas have not less than 15%[8] [34] of land use, and park have not far from all houses more than 500 m.

D. Natural views in urban areas

Looking to nature, whether it is the mountains, waterfalls and valleys or the clear sky, all of them positively affect human health directly, As mountains within residential areas such as Taif, Abha, Al-Muqtam and Muscat, as well as lower building heights in some cities, Such as Baghdad and Sur in Amman, people can see the sky and integrate with nature, as well as waterfalls and lakes in some Canadian cities and major parks such as the New Administrative Capital, taking advantage of the natural potential within cities is outrageous to improve the health of its inhabitants. Building heights have not over 6 floors for seeing sky, Figure (8).

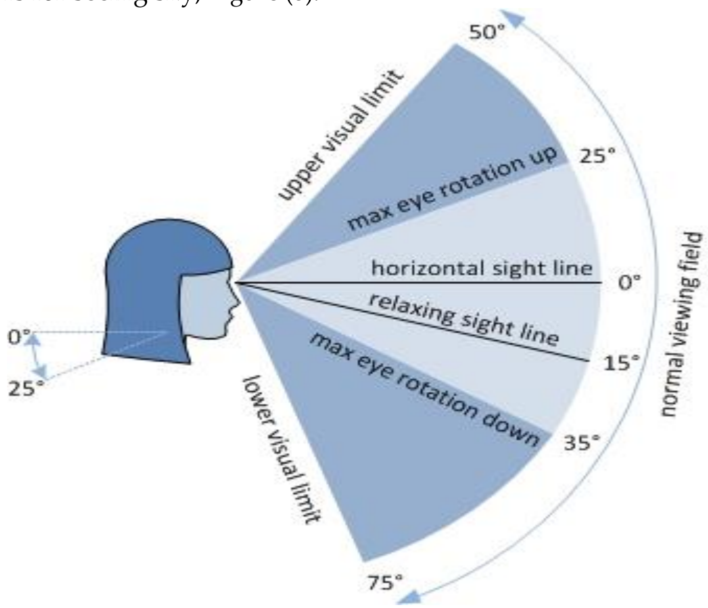

Figure 8. Vertical Viewing Field of the Eye can determine buildings heights [35]

E. Distance to parks

The more parks are closer to the population for the usual walking distance of 500-1000 (in which the inhabitant dispenses with other means), the more positive is the health for its inhabitants. For example, Minneapolis city USA number of residents who live within a distance of no over 1000 meters from the parks reaches 99% [36].

F. Colors and their effect on public health

Colors affect a person's mood, behavior, and even their diet, sleep system, and biological clock, It may affect heart rate, temperature and blood pressure And the energy of colors can be used, especially in urban design and landscape elements, by using the color allocated in the right place, as well as in the use of harmonious color combinations, which benefit from the energies of different colors, under the standards and determinants of public health, Some studies have showed that the green color motivates the population to think positively and hopefully, In England, when Black friars

Bridge was painted green, suicide rates on the bridge dropped by 34% [37]. Another study shows that the use of particular colors can increase motivation concentration, learning retention and recall by 55% to 78% [38]. The blue color calls for calm and hope. Yellow is associated with optimism, cheerfulness and energy. **Figure** (9).

Figure 9. Color of building white and blue is side Abu Said Tunis

3.1.4 The role of infrastructure in achieving healthy cities

A. Reliable solid waste and drainage management

Reliable management of solid waste is very important to keep good health of inhabitant of the cities, the Healthy City emphasis on improving urban processes to achieve a better quality of life and general well-being [39]. The city must provide reliable waste management at city level and use high technology on it.

B. Water

Most human survival depends on consistent supplies of sufficient safe water [40]. There are many Diseases related to polluted water, like Intestinal catarrh, dysentery, typhoid [41]. Chronic water-related illnesses may result in reduced work capacity or school absenteeism [42]. Often with long-term effects on wealth, education and quality of life, Further, water management is an integral element of urban safety, for example, in fire-fighting, flood control and management of sea-level rise. Increasing access and supply of safe and clean water support inhabitants to get healthier and well-being and physical activity. in addition, water influences mood and self-esteem, and mental health [43], therefor healthy city has to preserve safe water for its inhabitants.

C. Road's safety

The year 2019 alone witnessed about 9,900 accidents in Egypt, and 9 people out of every 100,000 people died due to them [44], the second in the world index. What are the reasons for the increase in road accidents in Egypt? There are many precautionary measures that prevent and reduce road accidents and reduce their risk, including the provision of safe pedestrian crossings and a modern system for traffic lights with the possibility of manually stopping them in emergency cases, bridges and pedestrian tunnels, secure bicycle lanes, The strict application of traffic rules and instructions, reducing the crash risk which involves applying the road-design standards and guidelines (such as from AASHTO), improving driver behavior and enforcement [45].

3.2 Non-Spatial factors affecting the achievement of healthy cities

3.2.1 Equity and healthy cities

The relationship between (equity, urban and public health) can be clarified in two main axes. The first is to achieve equity in providing a healthy environment for all, which is what the European Program for the Achievement of Healthy Cities has relied on, and the second axis is to achieve benefit from all Distinguish urban and natural areas for all city's inhabitants, so that the largest numbers of the city's inhabitants' benefits. Which reflects positively on their health, and examples of these distinct areas are the Corniche, sea vision, major parks, distinct areas of rivers, lakes, seas, mountains, islands, and other places, and all these places. If equity is achieved in the greater number of residents benefiting from seeing and enjoying them, this will be reflected positively on their health.

3.2.3 Social and political participation

Participation in social and political life, such as voting in elections, freedom of expression and participation, civil society are all activities that contribute to an active, positive and healthy life for the population. All those activities are important to healthy cities.

3.2.3 Reliable urban development management

Good management of urban development is important to preserve the health of its inhabitants, as, through good urban management, the necessary services and green areas will be provided, irregularities are prevented, order is maintained, pollution and noise are prevented.

3.2.4 looking to animals and its effect on public health

Recent studies have shown that looking to some animals gives a sense of happiness and improves the general mood, which positively affects their health, as animals such as cats and birds, and on the contrary, some other animals may have a negative effect, Therefore, many natural areas and open forests affect the population positively, In Egypt, green areas and trees congregate with birds, Also, places can be provided in public parks to raise some animals that have a positive effect, such as cats birds, fish, and others.

4. Problems affecting the achievement of healthy cities

4.1 Pollution

Urbanization and industrialization, along with economic development, have led to an increase in energy consumption and waste discharges. The global environmental pollution, including greenhouse gas emissions and acid deposition [46], as well as water pollution and waste management is considered as international public health problems in cities, pollution is a major concern of the new civilized world, which has a serious toxicological impact on human health and the environment. It has several different emission sources, but motor vehicles and industrial processes contribute to the major part of air pollution, which is the main environmental pollution. According to the World Health Organization (WHO), six major air pollutants include particle pollution, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. Long- and short-term exposure to air suspended toxicants has a different toxicological impact on human, including respiratory and cardiovascular diseases, neuropsychiatric complications, so we have to select an industrial area in the right site to the urban areas [47]. The necessity for the polluted land uses to be far from the city, especially the industrial areas, which must be placed in a suitable and thoughtful place for the city as workshops, noisy shops, massacres.

4.2 Noise

Sound has a public health effect. Urban noise has serious and negative public health impacts, the noise considers the second most prominent urban environmental stressor affecting people's health in Europe (WHO 2018). Recent studies reported by the EEA (2020) show that at least one in five European people are exposed to levels considered harmful to health [48]. The WHO (2018) alerts us that long-term exposure to noise can cause cardiovascular diseases, cognitive impairment, sleep disturbance, hypertension and annoyance, the noise in the streets is represented by annoying uses, such as workshops and cafes in residential areas, car and motorcycle cabs, congestion and traffic knots. Table (2)

Long-term average exposure to levels above 55 dB (for residential area) similar to the noise from a busy street, can trigger elevated blood pressure and heart attacks [49] continued exposure to noise above 70 dB over time will cause hearing loss [50]. According to (WHO) guidelines, annual average night exposure should not exceed 40 decibels, corresponding to the sound of a quiet street in a residential area [51]. Table (2) explains noise for each land use. The research suggests redistributing uses according to the noise emitted from them and separate annoying uses from residential areas.

Table 2. Land uses and its noise dB [52,53]

land uses	Noise DB	Urban Site	land uses	Noise DB	Urban Site
Farm land	40	Residential	Core commercial	75	Special sites within cities
Nursery	40		Construction / Workshops	75	
Low-density housing	45		Secondary school	80	
Medium-density housing	50		Heavier industry	75	Special sites on the outskirts of cities
Public institution	55		Mining	80	
Townhouse/mixed uses	55		HW9 100- 120kmh Heavy Traffic	85	
HW1 (Highway) 40 kmh	60	Residential commercial	Heavy Traffic, Noisy Restaurant	85	
Lighter Industry	60		Truck	90	
Shopping Center	65		Motorcycle	110	On the outskirts of cities, according to the requirements
Intensive recreation	65		Music Club, Disco	110	
Shopping center	65		Symphony Concert	110	
Strip commercial	70		Car Horn	110	
Freeway Traffic	70		Football Game Stadium	117	
HW3 65 kmh	70		Band Concert	120	
Elementary school	74		Motorcycle Horn	120	

5. The principles of Healthy Arab cities

The research will represent a case study from Egyptian cities as Arab cities

5.1 Characteristics of Egyptian cities

The Egyptian cities environmentally Characterize hot in summer, moderate most of the year with little rain, which minimize the green area percentage, the importance of the streets being wide enough that does not affect the shadows of buildings, Egyptian cites are Suffering from primacy and characterize with an agricultural background, which makes most of those cities, dense that is supporting them to be walkable and dynamics, but encounter other problems like mis controlling, high traffic, noise and services maldistribution. Figure (10)

Figure 10. Good sidewalk in Egypt

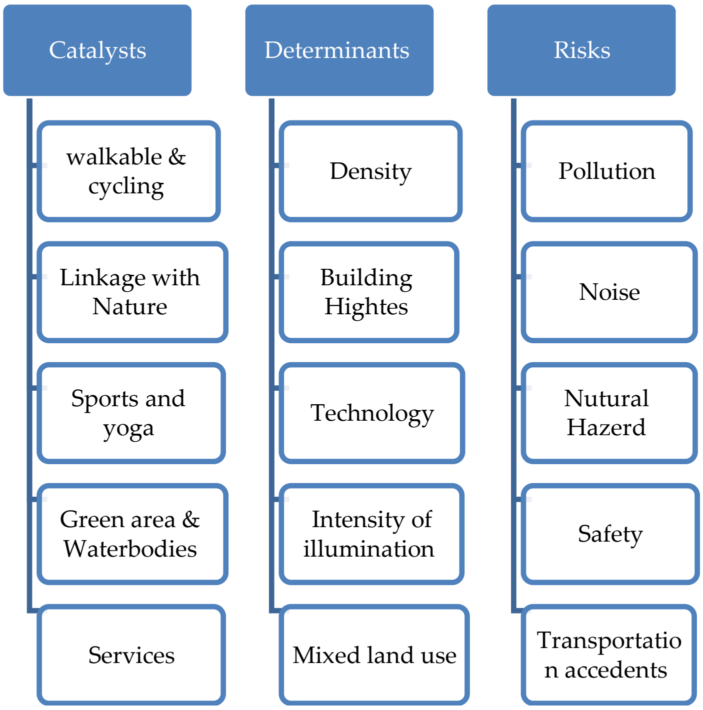

Figure 11. Healthy cities Dimensions

5.2 Problem of Arab cities (Egyptian cities)

Most of Egyptian cities encounter the same problems as crowded, road accidents, noise, sidewalk not exist or occupied, safe pedestrian crossings, Instability of housing rental laws. Lack of suitable bike paths, lack of green areas and tree canopy, blocking the view of the beaches and special areas, pollution, etc. so we can determine suitable Principles for Egyptian cities:

1. Reduce traffic accidents by creating safe pedestrian crossings (max 100m).
2. Avoid polluted land use near of residential area.
3. Brighter, lighter streets with clear Sight line.
4. Avoid occupation of the sidewalks, with providing efficient width of them for pedestrians.
5. Separating the disturbing and polluting land uses from the residential areas, and redistributing the land uses according to the noise they cause.
6. Manage noise of cars and motorcycle by enforcing laws.
7. Distribute services equitably to all residents
8. Providing housing units that suit the capabilities of all residents.
9. Reducing high density in overcrowded cities to reduce the risk of various epidemics.
10. Achieve 70 % of residents use sustainable transportation mode share.

Conclusion of Healthy cities Dimensions Figure (11).

Table 3. Healthy standards according to location

Hhealthy cities variables	Europe and America	Egypt Cities	Gulf Cities
Density	60-A 80-E	100-120	60-80
Green Area	15%	10%	10%
Public Transportation	50%	60%	40%
Walking-Cycling	10-15%	10-15%	5-10%
Building Hightes	3-4	5-7	3-4
Solar Energy	20%	35%	30%
Distance to parks	500	800-1000	800-1000

6. Conclusions

We can achieve healthy cities and reduce mortality risk significantly by many factors which we can classify in two categories, the first one is common factors that we are known from recent studies like, dynamic, diversity, participation, resilience, etc. second category, we can classify in two dimensions first non-spatial factors, and second spatial factors which also can classify them by level of study to regional factors, local factors, and urban design factors. The paper also found that there are fundamental differences between the values of variables of healthy cities between Europe, the Gulf and Egypt. We can determine important healthy city variables: -

We emphasize the spatial factors affecting the achievement of health for all cities: -

1. Healthy cities have to take advantage of the natural potential within its region to improve the health of its inhabitants.
2. Healthy cities have to provide places to practice sports and yoga in all open areas.

3. Healthy cities have parks within 500 m from its houses.
4. Healthy cities have green areas 15% of land use of Western cities and (10% for Arab cites).
5. Healthy cities have to provide trees on both sides of the sidewalks along the roads, walkable score not less than 70.
6. Healthy cities have to provide cycling paths along the roads.
7. Healthy cities have to provide 80% of services within 500-800 meters or within 20 mints walking.
8. A proper color of building in different urban spaces and land uses is very important to achieve healthy cities.
9. Most healthy city's inhabitants have to see the sea through a gradient of building heights and the being of a Corniche along the beach.
10. Healthy cities have to take advantage of the desert areas through safari and camping
11. Healthy cities have to provide different social activities.
12. Healthy cities have to density between (80-100) for European and American cities and (100-120) for Egyptian cities. We can determine the difference in table (3)

We emphasize the spatial factors affecting the achievement of healthy for Egyptian cities:

1. Healthy cities have to reduce noise, especially in residential areas, they have not to exceed 50 dB at night by redistributing uses and enforcing the law.
2. Healthy cities have to reduce traffic accidents by creating safe pedestrian crossings (max 100m).
3. Healthy cities have to achieve stability of laws related to housing and health care.
4. Healthy cities have to avoid occupation of the sidewalks, with providing efficient width of them for pedestrians.

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Session 12:

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Sustainable Energy Policies, Cities, and Buildings in Gulf Cooperation Council (GCC)

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Abstract: The scarcity of resources and growing dependency on the contemporary industrial world on the non-renewable energy sources has rendered the need for sustainable practice and enhanced dependency on renewable energy sources. Sustainable energy management is emphasized not just by certain business- but nations as a whole aim to create a balance between economic, social, and environmental sustainability. In general, people become more aware of the downside of using non-sustainable energy resources on health and environment in general, they have left nations with no choice but to develop a systematic approach to containing quantity, cost, and effect of energy resources. This paper will give a very brief study to some sustainable energy policies and projects within major cities in some countries in GCC. It was found that many GCC countries are moving towards green energy with reforms in policies and environmental projects.

Keywords: GCC sustainable energy; Environmental policies of GCC; Sustainable projects; Future renewable energy plans

1. Introduction (GCC Sustainability & Sustenance)

For a long time, Gulf States' economic diversification depended on non-sustainable tactics which showed their reluctance towards sustainability agenda. The GCC now focuses on environmental resilience and adopting policies that mediate economic diversification with environmental sustainability because of domestic pressure.

With the global threat environmentally, which is facing our world, countries around the world stepped up their effort to try to overcome this challenge. Thus, many significant agreements were made such as 'The Paris Agreement and 'Kyoto Protocol' which were made to help slow the negative environmental effects. The success of sustainable development goals is however questionable. Nonetheless considering these development goals the countries are becoming active and the activism is not limited to the government but extends to non-government actors and businesses. Their agenda not only encompasses the use of renewable energy sources but also covers pollution, flora and fauna, climate change, water preservation, greenhouse effect, etc. Dire issues such as climate change are a subject of attention in world politics and are the basis for deriving new diplomatic relations [1].

2. Government rules and regulations

The term environmental diplomacy was casually used for negotiations on environmental disputes, but it has gained more importance ever since it was used in UN Conference on Environment and Development (Earth Summit) and it was since then there has been an expansion of key players involved in forming environmental policies.

The social and economic fabric of Gulf countries changed drastically with the dominance of oil in the late 90s. The oil industry not only changed the physical environment but also the social, economic, and geographical setting. Rapid urbanization and growth were inversely related to the exploitation of resources. This massive change brought by foreign investments and changing economies overshadowed the importance of the environment [2].

In the past few years, GCC countries as main producers of fossil fuel seem not interested in pushing for sustainable development goals. Nevertheless, recent negotiations related to climate and their aim to reduce carbon production marks a clear shift in the gulf countries' approach to sustainability. The GCC developed a block of developing countries (G77) while the more developed countries are now engaging and restructuring national action and are empowered in the decision-making process.

3. GCC resistance to Environment Sustainability Goals

The Arab States' reluctance to environmental goals as previously mentioned was due to the economic boom that occurred because of the increase in oil prices during the 1970s. GCC states became more in control of the oil output specifically after the nationalization policies of the Iranian revolution. GCC countries remain a central resource of fossil fuel during most of the latter half of the 20th century the early 2000s and saved as the basis for their indifferent attitude towards sustainability concerns. The GCC countries saw sustainability goals as an arrangement to hinder their development which can be understood considering the U.S's negative response to the Kyoto protocol even though it is one of the biggest contributors to carbon emission. The need of such change it started to become obvious especially looking at the data of emitted CO_2 in the GCC countries environment, Figure1 [3].

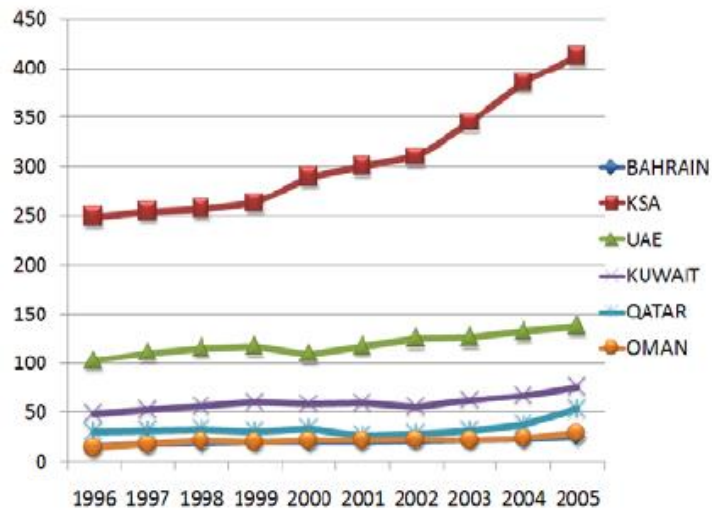

Figure 1. CO2 Emissions from different GCC countries

3.1 Potential for new dynamic economy renewable energy driven

The GCC countries may have earned a lot of revenue from fossil fuels but they have a lot of potential in renewable energy generation. For instance, the opportunities for conserving winds to generate electricity are high in countries like Oman, Qatar, Bahrain, and Kuwait with the wind speed of 5-7 m/s. The conditions for solar energy conservation are even more favorable since most of the GCC countries are sunny all over the year. For example, Saudi Arabia alone benefits from 2200 kWh per square meter. Taking advantage of natural resources will not only reduce carbon emissions but also provide GCC countries with an alternate economic market as the non-renewable energy resources run scarce [4].

4. GCC Policies and contributions

4.1 At international level

GCC countries have agreed on the to Kyoto protocol as a non-annex 1 part which renders them unaccountable for greenhouse gas emissions reduction. Saudi Arabia is a key regional player and because of its funding holds a dominating position in alliances or organizations such as the GCC, G77, and the organization of Arab Petroleum Exporting Countries (OAPEC).

Another major policy established by 'The League of Arab States' and was followed since the agreement of Kyoto protocol states that oil-producing countries be provided with compensation to sustain the damage to the petroleum industry as a result of climate change.

One of the initiatives included hosting International Renewable Energy Agency headquarters in carbon neutral Masdar City was previously mentioned. It was to serve as the first of its kind agency in the Middle East. To convince the foreign community a fund of USD 50million has been allocated to sustain the agency. It not only introduced Abu Dhabi as one of the contemporary countries in the post-oil world but also set the tone for dynamic economies that the GCC countries needed to embrace later if not sooner. Despite being a Non-Annex member GCC countries have the potential to sustain renewable energy projects. The development mechanism is still questionable as only one project has been proposed by Qatar which aims at reducing tons of CO_2 emission from the Al-Shaheen oil field-transporting it to a processing plant for local utilization [5].

4.2 At Regional Level

The GCC cooperation at the international level might be progressing at a steady pace but it is also taking initiative to further enhance support at the regional level as well. The GCC Supreme Council serves this reason and has laid down a joint action plan which addresses the following:

- Preservation of Natural resources
- Creating awareness to enhance local participation.
- Training workforce to prepare for the latest technology.
- Introducing a clean mechanism

The cooperation has a fully functional administrative force, a key player among which is the Secretariat General who is tasked with preparing annual reports and a coordinated plan according to the stats. He is further assisted by 5 assistant secretaries under him.

The secretary of human and environmental affairs is responsible for environment-related policies and disaster control. It, therefore, assists GCC countries in coming to an appropriate conclusion. Furthermore, an environmental unit is formed which not only ensures proper coordination among national players but also provides an incentive to whoever wins the best environmental project. This grant encourages the proliferation of environmental preservation ideas and policies. Topics related to sustainability are made an essential element of the educational curriculum as well [6]. This could influence the public to strongly agree on supporting reformed national policies for renewable energy, Figure 2 [7].

A- Targets and roadmaps are already sufficient of their own to trigger investments in renewable energies.

B- Targets and roadmaps do not promote investment, because they are merely symbolic steps to promote renewable energy whereas actual policies do not change.

C- Targets and roadmaps are a necessary first step towards a country's developing a coherent national policy framework to support renewable energy.

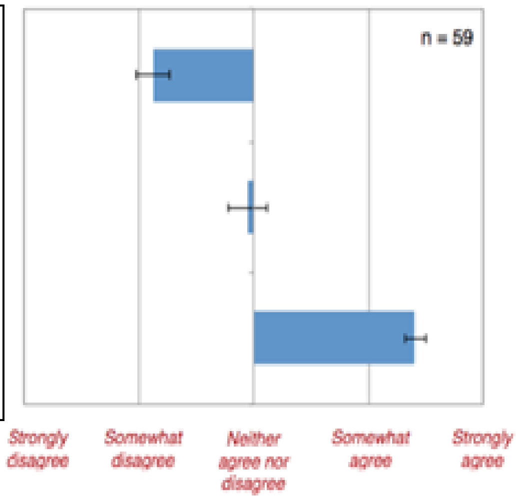

Figure 2. Public opinion on GCC energy policies

5. Major sustainability projects

Apart from regional and international participation GCC countries are running some of the sustainability projects in alliance with other countries for instance Saudi Arabia has formed SOLERAS (Solar Energy Research American Saudi) in alliance with the American government which was tasked with powering two of the Saudi villages with electricity powered by solar energy. In addition to this, the GCC states are working individually and have administrative departments such as the Supreme Council for Environment and National reserves and the ministry of Environment and climate change are in place. Furthermore, there have been individual attempts such as the installation of wind turbines in, Bahrain and the construction of sustainable sites. This site would be able to utilize recycled material and active methods are being employed such as the solar and photovoltaic cells which will generate around 12000 sqm of solar energy [5]. Another example of great project in Saudi is KAUST University which is a university for postgraduate studies and research. There are many renewable energy projects and centers at KAUST. Moreover, KAUST was built considering the suitability factor in mind, Figure 3 [8].

Figure 3. KAUST university sustainable campus, Thuwal city, Saudi Arabia

Masdar is a project city in Abu Dhabi, UAE, established in 2006 where it relies on depending on solar energy and other renewable energy sources. Also, it hosts the headquarters of the International Renewable Energy Agency. Many sustainability training workshops are given by Masdar where the theoretical knowledge meets practical real life deployment, Figure 4 [9].

Figure 4. Passive architecture planning in Masdar city, Abu Dhabi, UAE

Qatar was also working on building an Energy city that was to serve as one of the main energy hubs. Some of the major clean development mechanism (CDM) projects active under the GCC include the Al-Shaheen project. After the completion of the project, it is stated that the total gas consumption will be 5000 tpd, almost half of which will be exported to Qatar petroleum and the remaining will be utilized for on-site consumption. The objective of the project is to reduce CO2 emissions. Another active project lined under the CDM is the Gasco project which aims to reduce CO2emissions in addition to lowering the consumption of fuel gas.

Msheireb Downtown Doha is also restoring downtown by creating a space consisting of LEED-certified buildings. The energy consumption will be reduced by 32percent. The design also employs passive sustainable methods by placing buildings in a way that they create wind tunnels and provide shade. The design aims to assist pedestrian traffic by enhancing cycling and walking opportunities. There is also, Pacific Control Headquarter which employs active means by including photovoltaic cells and water management equipment -rendering it as the first LEED Platinum certification in the entire Middle East, Figure 5 [10].

Figure 5. Msheireb Downtown, Doha, Qatar

6. Conclusions

GCC is facing inconsistency in terms of the implementation of sustainability-related policies. The GCC is facing a similar problem to the west, especially the U.S which is trying to find a balance between three essentials of sustainability that is economy, ecology, and society. GCC countries are already facing energy deficiency and it will not be long before they become the importer rather than the exporters of fossil fuel energy. As already mentioned, they will not only benefit in terms of environmental protection but also the latest technology will open a new market for export thus sustaining the economy which was once solely dependent on oil.

Also, GCC has a lot to lose from environmental degradation. (Raouf) Bahrain already lost 15 kilometers of coastline and with sea levels rising at a rapid rate; it will not be long before man-made islands are completely immersed in oceans. This will also affect the marine life which serves as a livelihood for many. Furthermore, with constantly rising temperature, it will not take long before the GCC countries face water scarcity which is already a dire issue worldwide.

Saudi and Iran are among the top 50 countries for producing carbon waste. With their economy mainly dependent on oil these countries without a doubt will suffer a setback but as already discussed they can fill the gap by investing in technology and research on sustainability instead. Further, the GCC should consider the user pay principle which allows them to charge more for oil export, and the extra revenue can then be utilized to take environment protection precautions. Adding UPP can also fill the economical gap which is the major concern of the governments of the respective countries. Employing green techniques will open job opportunities for people and can contribute to unemployment since the region receives many temporary immigrants. The GCC also needs to consider the social and economic fabric of recipient countries to enhance the deployment of green technology. In short, GCC needs to structure their existing policies to change their ideal goals to actual ones [11].

Recently, many GCC countries started to realize the harmful effect of digging for oil. Also, it seems there is a shift in global depends or demand on oil. Thus, many GCC countries started to investigate and entertain renewable energy projects. Such a strategy would keep them as major suppliers of energy for years to come. Also, it would relieve their economy from fossil fuel dependency. For this to happen, many government policies and programs must be initiated by the government to educate and push the public for such a green and sustainable movement.

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EPS Construction Systems for the Building Industry 4.0

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Abstract: The construction industry has been creating a tremendous impact on the environment, so there is growing consciousness about the importance of sustainability in the construction industry. Companies are now increasingly orienting themselves towards the prefabrication market in order to minimize construction times and consequently the energy impact. To make the construction sector increasingly sustainable, it is important to make every phase of the construction process more efficient in order to allow the efficiency of the entire process, from the production of the material, to its installation up to its final disposal or recycling. It is therefore, essential to search for materials that are eco-sustainable at every stage of this process.

The paper presents the study of an expanded polystyrene foam panel (EPS) reinforced with galvanized steel, it can be used both as a load-bearing wall and as a cladding panel. The innovative manufacturing technique consists in the modularity and absence of wet materials and reduced weight allowing a faster production without the requirements of specialized manpower. With the reference to the current Italian\European rules and requirements, the study analyses 3 fundamental parameters: thermal insulation, acoustic insulation and resistance to fire. Furthermore, a comparison with the traditional construction techniques has been made, in order to highlight even more, the enormous advantages of this new technique. The paper tries also to find a solution for fulfilling the legislation requirements in terms of periodic thermal transmittance, that the use of this type of panel for cladding arises.

The results demonstrate the excellent performance in terms of structural efficiency and thermal insulation together with fast manufacturing combined with the overall lightness.

All this means high energy savings in terms of requirements during the production of the materials and construction of the buildings. At the same time, the construction system is easily recyclable.

Keywords: Reinforced EPS, Modularity, Sustainability, Innovative construction systems, Light constructions, Prefabricated curtain walls

1. Introduction

The construction industry has created a huge impact on the environment and on people, there is a growing awareness of the importance of environmental sustainability in all the processes that lead to the realization of the final product. Companies are increasingly turning to the prefabrication market to minimize construction times and consequently the energy impact.

To make the construction sector ever more sustainable, it is important to make each phase of the construction process of a structure more efficient to allow the efficiency of the entire process, from the production of the material, to its installation up to its final disposal or recycling. It is therefore essential to look for materials that are eco-sustainable at every stage of this process.

For this purpose, the following article reports the results of the study of an EPS (sintered expanded polystyrene) panel reinforced with galvanized steel, which can be used both as a load-bearing element and as a cladding panel. The innovative manufacturing technique allows modularity, the absence of wet materials and the reduced weight with the consequence of having a faster installation and without the need for specialized labor. With reference to the current Italian and

European standards and requirements, the study analyzes 3 fundamental parameters: thermal insulation, acoustic insulation and fire resistance. In addition, a comparison was made with traditional construction techniques, to further highlight the enormous advantages of this new technique. The article also tries to find a solution to meet the legislative requirements in terms of periodic thermal transmittance, which the use of this type of panel for cladding involves. The results demonstrate excellent performance in terms of structural efficiency and thermal insulation along with fast production combined with overall lightness.

2. Materials and methods

The new production processes of the construction industry 4.0 integrate new technologies to increase the productivity and production quality of the plants. The construction system of the new reinforced EPS panels moves in this direction.

The materials making up the reinforced EPS panel are two:

- the sintered expanded polystyrene matrix;
- the reinforcement material with galvanized steel nets.

The panel therefore has a three-dimensionally electro-welded galvanized steel wire structure, such as to create a multi-layered square mesh network, incorporated in the sintering of high-density EPS, self-extinguishing and chemically inert.

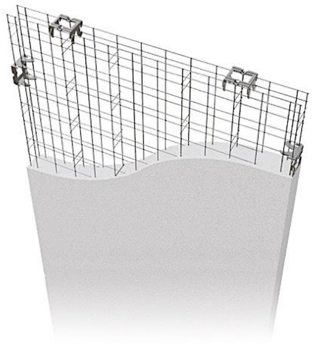

Figure 1: Reinforced EPS panel

Figure 2: Joining of the panels

A strong point of the EPS panel under study is its high level of customization. In fact, it is possible to intervene both on the dimensions of the panel according to the needs and on the density of the EPS itself.

The reinforced EPS panels are made using a fourth generation automated process, specially developed to make the management of the entire process easier but at the same time guaranteeing a high quality standard.

The production process of the reinforced EPS usually takes place in three phases, namely:

- Pre-expansion;
- Maturation;
- Printing.

The machine used for the production allows to incorporate the electro-welded steel meshes between the second and the third making of the sintered expanded polystyrene. That is, this reinforcement is incorporated into the EPS during the sintering phase.

Figure 3. Machine for the production of panels (courtesy by AC Engineering, Fano, Italy)

One of the most important aspects of this production technique is the reduction of production times. For example, the production time of a single 5.76 m2 panel is approximately 3 minutes. This means that the quantity of panels that can be made in a single day, considering a single 8-hour work shift, is approximately equal to 160 equal to approximately 921.60 m2 of panel.

As this is a completely automated production process that does not require manpower but can be controlled by the operating software, it can be assumed that the daily production can reach an average of 2500.00m2 / day.

3. Tests

3.1 Thermal insulation.

The objective of thermal insulation is to reduce the energy consumption necessary for heating or cooling buildings, in order to prevent atmospheric pollution linked to the emissions of polluting gases deriving from the combustion processes of energy sources.

The particular composition of the EPS matrix of the studied panel guarantees high performance in the thermal field, allowing it to fully satisfy the requirements imposed by legislation in terms of thermal transmittance.

With regard to energy efficiency, the European Community has indicated to all member countries the rules to be followed with Directive 2002/91 / EC "Energy performance in buildings"; also known as EPBD, effective from 9 July 2010.

The indications deriving from the European directive are introduced in Italy through the Legislative Decree. 192/05 and the Law Decree 63/13 subsequently converted into law on August 3, 2013 by Law 90/13.

According to the new rules, for opaque vertical structures that border towards non-air-conditioned environments, towards the outside or against the ground, the limit values of thermal transmittance are shown in the following table:

Table 1: Thermal transmittance of vertical opaque structures

Climatic zone	U [W / m2K]	
	2015	2019
A and B	0,45	0,43
C.	0,38	0,34
D.	0,34	0,29
IS	0,30	0,26
F.	0,28	0,24

It was decided to obtain and compare the values, by means of laboratory tests on EPS samples, for panels with a density of e and a thickness of e. $35\ kg/m^3\ 45\ kg/m^3 120\ mm 160\ mm$

All the EPS samples have two galvanized steel meshes ϕ3 with 100x100 mm mesh inside.
The samples were named with the following terms:

- HD120-1: Reinforced EPS panel, thick, intact; 120 mm
- HD120-2: Reinforced EPS panel, thickness, two joined panels; 120 mm
- HD160-1: Reinforced EPS panel, thick, intact; 160 mm
- HD160-2: Reinforced EPS panel, thick, two joined panels. 160 mm

For each thickness two different samples were considered, one intact and one containing the joint between the panels; in order to determine not only the required parameters, but also to verify the possible establishment of thermal bridges near the joints between the two panels.

The tests on the samples were performed using a LaserComp FOX1000 heat flow meter

To simulate the most severe situations that the panel could work on, on each sample, two tests were carried out with temperature ranges that vary for the first test from to and for the second test from to.$-10°C 15°C 20°C 40°C$

The tests carried out have a duration ranging from four to six hours and the results give us the values of higher thermal conductivity, lower thermal conductivity and average thermal conductivity.

Once the thermal conductivity has been determined by means of the tests, it is possible to obtain the other parameters and make a comparison with the theoretically obtained values:

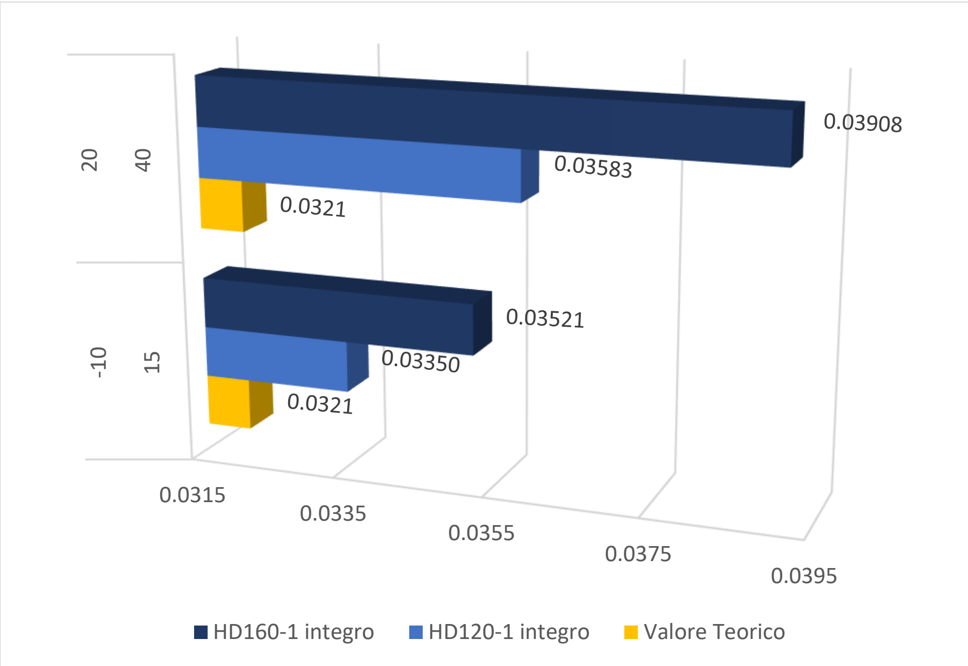

Figure 4. Comparison of Thermal Conductivity (λ) Integri Panels

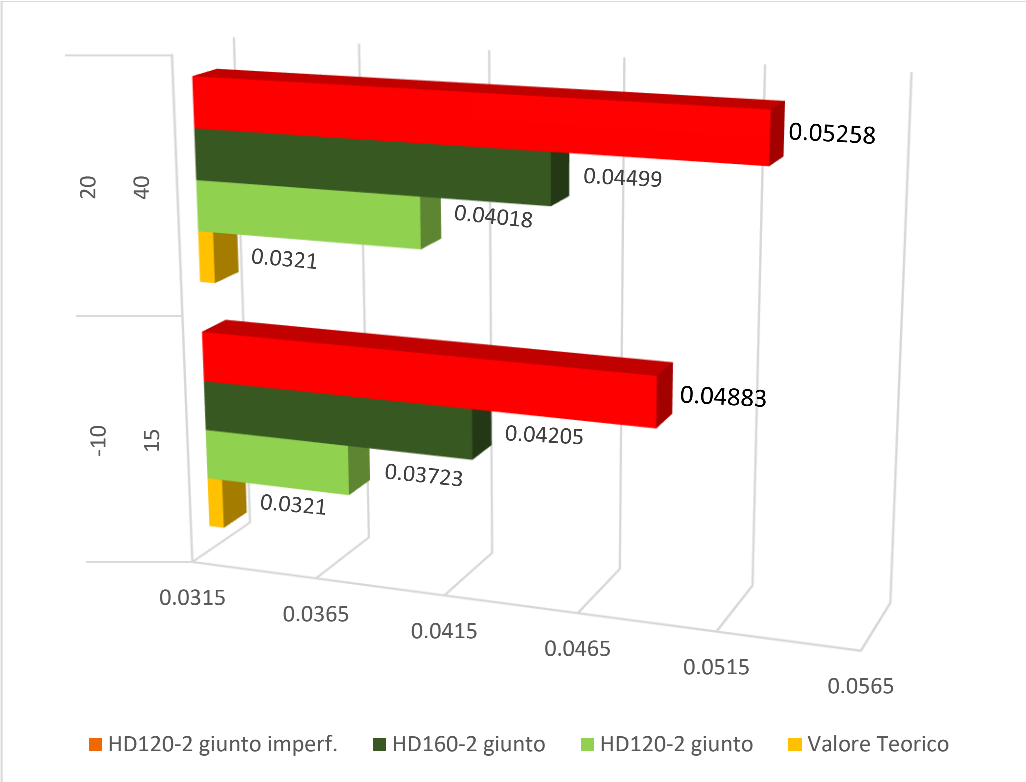

Figure 5. Comparison of Thermal Conductivity (λ) Panels with Joint

The graphs highlight a clear difference, in terms of thermal conductivity, between the theoretically acquired values relating to the EPS matrix alone and the values instead obtained through experimental tests on the reinforced EPS panel.

An important aspect, when the reinforced EPS panels will be installed, is the creation of the joint, in order to avoid the possible formation of thermal bridges on the completed wall.

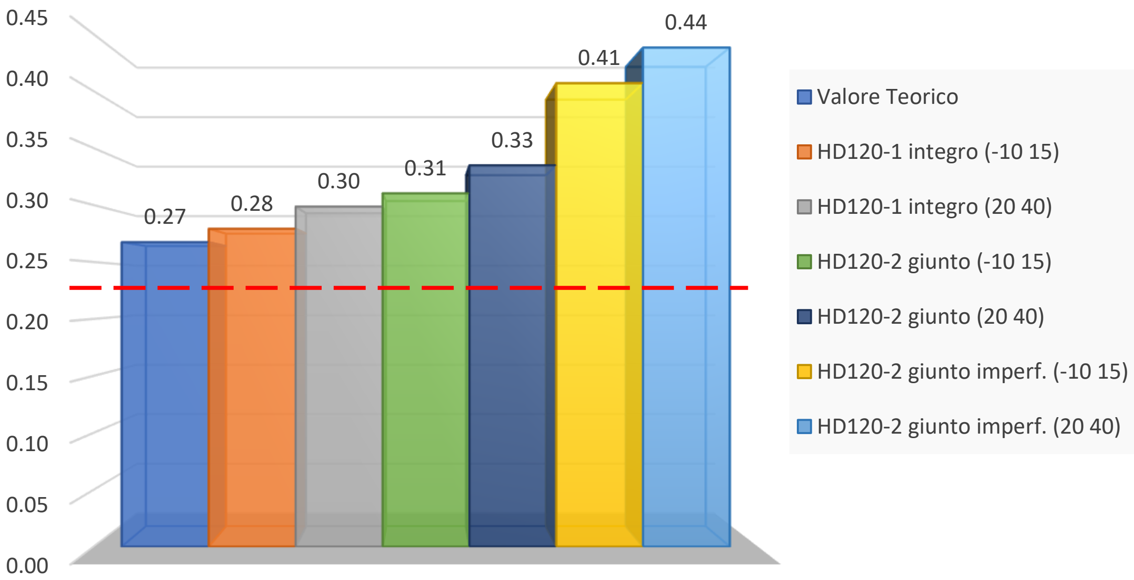

Figure 6. Comparison of Thermal Transmittance "U" HD120

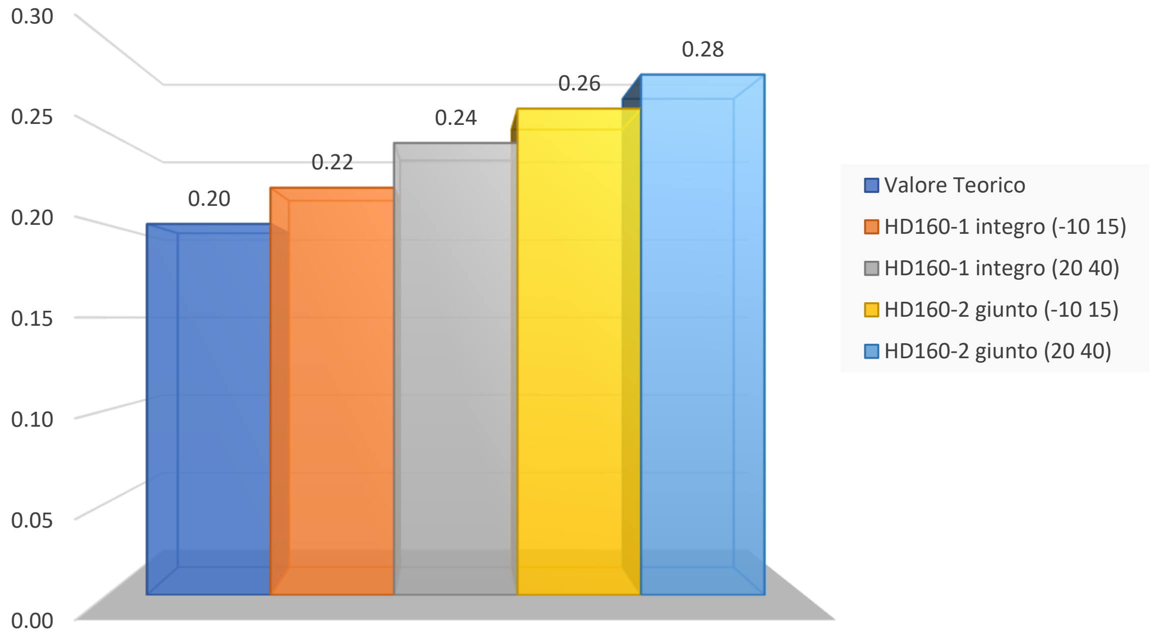

Figure 7. Comparison of Thermal Transmittance "U" HD160

Once the thermal conductivity values have been determined, the other characteristics of the panel are evaluated, the results obtained are shown below:

The graphs obtained highlight how the values of the thermal transmittance U acquired through experimental analysis tend to be different from those obtained theoretically.

In conclusion, the high capacities in terms of thermal transmittance of the panel can be noted, especially if related to the thickness of the same.

In addition to the thermal transmittance U, the standard takes into consideration two other very important aspects.

Or:

- the periodic thermal transmittance YIE;
- the frontal mass or surface mass Ms.

To verify these limits, regardless of the climatic zone to which reference is made, we proceed with the determination and study of different stratigraphies, aimed at identifying one of them capable of respecting all the limits imposed by legislation. Furthermore, these stratigraphies are also studied and verified in the acoustic and fire resistance fields.

To increase the properties of the reinforced EPS panel, 29 combinations have been studied which provide, in addition to the reinforced EPS panel, the use of:

- Gypsum plates in calcium sulphate dihydrate, with specific additives and incorporated between two sheets of special high-strength cardboard such as Gypsotech STD type A produced by Fassa Bortolo $CaSO_4 2H_2O$
- Gypsum plates in calcium sulphate dihydrate, with special additives in the core, such as fiberglass, vermiculite, water repellents and natural wood flour with different granulometry, incorporated between two sheets of special high-strength cardboard such as Gypsotech GypsoLIGNUM type DEFH1IR produced by Fassa Bortolo $CaSO_4 2H_2O$
- Glass wool, obtained by melting a mixture of glass and sand, subsequently converted into fibers and cut into rolls or panels having a thermal conductivity between, a density

that varies between and a specific thermal capacity between. $0{,}032 - 0{,}053\ W/mK 10 - 70\ kg/m^3 840 - 1030\ J/kgK$

- Rock wool, obtained from diabasic, basaltic and dolomite eruptive rocks with adhesives. Which, in addition to its excellent thermal insulation capacity, is also equipped with sound-absorbing properties and has excellent fire behavior (fire resistance class A1) as it does not contribute to the development or propagation of fires. It has a thermal resistance between, a density that varies from and a specific heat capacity equal to.$0{,}75 - 1{,}25\ m^2\ K/W$ $30 - 140\ kg/m^3$ $1030\ J/kgK$
- Celenit N, thermal and acoustic insulation panel, in mineralized spruce wood wool bound with gray Portland cement.
- Fermacell, or rather sheets made up of gypsum and cellulose fibers for the remainder obtained from selected and shredded recycled paper. The production process involves mixing these two components in water, so that the gypsum reacts and envelops the cellulose fibers. By subjecting the mixture obtained to compression, Fermacell gypsum fiber plates are obtained.80%20%

It was therefore decided to study the possible stratigraphies proposed also by means of the software provided by Logical Soft and called Termolog [9].

Specifically, after having entered the different layers of each stratigraphy, the software not only returns the thermal properties of the loaded stratigraphy, but also allows you to immediately check the limits imposed by the legislation in terms of thermal transmittance U, surface condensation, frontal mass Ms and periodic thermal transmittance YIE.
The most performing stratigraphy from a thermal point of view is the one composed of:

- Reinforced EPS panel 120 mm thick and 45 kg / m3 density;
- n ° 1 CELENIT N type slabs, 35 mm thick;
- Insulation: Rock wool, thickness of 50 mm and density of 40 kg / m3;
- n ° 2 Gypsotech STD 13 (Type A) gypsum plates, 12.5 mm thick.

In fact, this stratigraphy not only allows to respect the limits imposed by legislation in terms of thermal transmittance, but at the same time also allows to respect one of the limits relating to the periodic thermal transmittance or to the frontal mass [13-14].

***3.2** Fire resistant*

In the field of fire prevention, there are numerous legislative provisions and technical standards of reference. Of particular importance is the Ministerial Decree dated 03/08/2015, "Technical regulations for fire prevention", pursuant to art. 15 of the legislative decree of 8 March 2006.
The materials can be classified as:

Italian class	Definition
0	Non-combustible materials
1	Non-flammable combustible materials
2	Hardly flammable combustible materials
3	Flammable combustible materials
4	Easily flammable combustible materials
5	Extremely flammable combustible materials

The EPS material consists of hydrogen and carbon, therefore of combustible elements. At temperatures above 100 ° C it undergoes a thermal collapse, begins to become soft and if the temperature remains constant, it transforms into a viscous liquid. The decomposition of EPS begins from about with the emission of flammable vapors, but only when higher temperatures are reached (equal to about), there is an effective ignition with flame propagation if there is sufficient oxygen supply. . The above highlights how a certain amount of energy is required for ignition. This means that, for example, simple electrostatic sparks or lit tobacco particles are not enough for the EPS to burn. In addition, the cellular structure of the material, it causes it to contract due to the collapse of the cells under the action of heat, effectively moving away from the heat source even before it begins to decompose. The legislation on fire resistance distinguishes the behavior of combustible materials by means of an appropriate classification, within which the self-extinguishing EPS is placed in class E, D or higher depending on whether the latter is suitably protected or not (EN 13501-1). From the point of view of the toxic gases produced by the combustion of EPS, similarly to wood materials, we can basically find carbon monoxide but no trace of dioxin. What has just been described highlights how the contribution of EPS in terms of energy balance in a fire, it is actually modest in relation to its low density. In fact, the calorific value of of EPS with density of is approximately; against i of a cube of the same volume but made with fir wood.$230-260°C400-500°C1\ dm^3 15\ \ kg/m^3 590\ J 9200\ J$[15-16].

3.3 *Soundproofing*

As far as acoustic insulation is concerned, law no. 447, "Framework Law on noise pollution" is considered, which establishes the rules that protect the living environment from noise pollution and from the external environment. Law establishes the passive acoustic requirements of buildings, their components and their internal sources [10].

In Italy, specifically, the UNI 11367 standard "Acoustics in building - Acoustic classification of real estate units - Evaluation procedure on site", provides for an acoustic classification of buildings into four different classes, in which the degree of acoustic insulation decreases as you go down from the first class to the fourth.

Regarding the acoustic insulation, this is still regulated today by the framework law n ° 447 of 24/10/95. Which determines the acoustic requirements of the sound sources inside buildings and the passive acoustic requirements. The particular cellular structure of the EPS, composed for the air, allows to have a high soundproofing power; able to reach acoustic insulation values equal to.98%45 dB

Law No. 447, "Framework Law on Noise Pollution", establishes the rules that protect the living environment against noise and external environment pollution. The expected soundproofing power of this reinforced EPS wall is comparable to that of other traditional solutions.

Among the various stratigraphic solutions determined and analyzed by means of software, it was possible to identify one that theoretically allows to obtain excellent performances in both the thermal and acoustic fields, but also good fire resistance capabilities. Specifically, the solution identified involves the creation of a counter-wall, in addition to the reinforced EPS panel, composed of different layers of materials such as: gypsum sheets, rock wool and a spruce wood wool slab bound with gray Portland cement type CELENIT N [15].

The stratigraphic solution thus identified, capable of theoretically respecting the various limits imposed by the Regulations, is the one chosen for physical tests in certified laboratories, in order to certify their real capabilities and obtain certification at European level. The tests that are in progress anticipate characteristic values compatible with REI 120[16]. The expected soundproofing power of this reinforced EPS wall is comparable to that of other traditional solutions [17-18].

4. Conclusions

The studies carried out on the reinforced EPS panel have highlighted the high thermal capacities of the panel, which would allow, in themselves, to satisfy the limits imposed by the Regulations and relating to different climatic zones in terms of thermal transmittance U.

Among the other advantages of this innovative technique, which look to industry 4.0, we note the speed of mass production of the panel, the modularity, the rapidity and simplicity of assembly, the high maneuverability and the possibility of creating completely dry elements. . Furthermore, the panel represents a valid and more performing alternative to traditional techniques that involve the use of insulated panels in the building of emergency response.

The main problem encountered, relating to the use of the panel as infill, concerns the satisfaction of the additional limits imposed by the legislation in terms of Periodic Thermal Transmittance "YIE" and Frontal Mass "Ms", which led to a research and theoretical study of different stratigraphic solutions, such as to allow the satisfaction of all the limits set by the legislation, not only in terms of thermal insulation, but also of acoustic insulation and fire resistance.

The comparison with the same properties of traditional infill, made with artificial brick elements, has highlighted how the innovative infill in reinforced EPS has thermal and acoustic performance comparable or significantly better than traditional infill but with much lower thickness; this observation, however, does not apply to fire resistance. Traditional infill panels are in fact characterized by a better fire behavior than the analyzed technique.

5. Discussion

The reinforced EPS panels are composite elements characterized by the presence of a sintered expanded polystyrene matrix and reinforced by three-dimensional galvanized steel meshes. As demonstrated, the thermal and acoustic insulation capacities of the panel are attributed to the EPS matrix, while the bearing capacities are assigned exclusively to the steel meshes. A study in the structural field of these panels is proposed for future developments, for the implementation of a calculation model of the dry load-bearing elements.

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Opportunities and Challenges for Adopting Modularity in Commercial Projects

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Abstract: In recent years, modularity has stood out as a promising concept for the improvement of the building industry, especially in the delivery of engineer-to-order prefabricated building systems. Although it is a well-established concept in other industries, modularity is still poorly disseminated in the construction industry, and it needs to be adapted to the peculiarities of the sector. Previous research has investigated how construction companies apply modularity in the product, process and supply chain, indicating there are different levels of modularity for each dimension. This paper discusses opportunities and challenges for modularity adoption in commercial projects. It is based on the empirical study of a company that designs and delivers commercial buildings by using a combination of traditional and industrialised building systems. This study illustrates the different levels of modularity involved in a construction project, indicating opportunities and challenges to modularity adoption in each dimension. The conceptualisation derived from a systematic literature review, and a set of modularity-related concepts were adapted to the construction context. The main contribution of this investigation is the understanding of opportunities to achieve strategic goals by adopting modularity in the three dimensions. It also explores how to assess the degree of modularity of each dimension.

Keywords: Modularity; Construction; Opportunities; Challenges

1. Introduction

The adoption of prefabricated building systems has been increasing due to the need to reduce the duration and cost of construction projects and to improve quality and working conditions [1][2]. There is a growing interest in the application of the modularity concept in those systems, especially in engineer-to-order (ETO) production systems [3]. ETO production systems are used in a large number of construction projects [4] and can be defined as production systems driven by clients' orders, which often involve a high degree of customisation [5].

Several studies describe modularity as a strategy to deliver customised products to clients [6][7], [8]. Construction companies that do not practice mass production, such as ETO companies, can benefit from different levels of product modularity [9]. In fact, the benefits of modularity increase when related to industrialised construction concepts such as standardisation [10]. Standardisation can be defined as the extensive and repetitive use of a solution [11], while a modular product implies the idea of dividing a product into modules with standardised interfaces [12]. Hence, modularity is seen as a key enabler of mass customisation [13], as a trade-off can be achieved between high product variety and high volume [14]. Regarding the process perspective, a modular process involves the adoption of standardised operations with shared interfaces [15].

While in other industries, modularity has contributed substantially to achieve efficiency in the offer of customised products, in the construction industry it remains an under-explored area, despite the fact that buildings require specific solutions [16] and are usually designed or produced as unique products [17].

The peculiarities of the construction industry make it difficult to simply adopt the concept of modularity used in manufacturing [18]. In fact, previous research related the nature of construction projects to difficulties in the adoption of modularity, especially the high degree of complexity due the large number of components and interdependences [19], the immobility of buildings [20], the project-based nature of this industry, the uniqueness of site conditions [21] and the high levels of uncertainty involved [20].

Although the issue of modularity in construction has been explored since the 1980s (e.g. [22], [12], [23],[18], [7], [24], [25]), there still remain important gaps in the knowledge. Emphasis is often on product modularity, while other types of modularity, such as process and supply chain (SC), still lack in-depth investigation [26]. The lack of consensus on the meaning of modularity has also been pointed out by Salvador [27] as a major barrier to the adoption of this concept by the manufacturing industry. A widely adopted method or clear measure of modularity would help designers to increase the degree of modularity of different products [12]. Devising suitable measures, conceptual models and clear definitions of terms is necessary for creating a theoretical framework that can be used as a reference in empirical studies [27], [28].

Moreover, there are differences in the definitions and terminology used in manufacturing and construction due to the different nature of those industries [29]. That is due to certain peculiarities of the construction industry which require some adaptation of the concepts and methods that emerged in the manufacturing industry. Therefore, the challenge is to establish a set of constructs related to modularity in the construction industry, that can be connected to modularity-related core concepts.

Even though the concepts of industrialisation and modularity are closely related, off-site prefabrication is not necessarily needed to achieve modularity [7]. Two questions arise from the previous discussion: (i) How to adapt the concept of modularity can be adapted to construction projects, considering that there is often a mixture of industrialized and traditional technologies? And (ii) how can the different types of modularity in product, process and supply chain be implemented?

This investigation was developed in the commercial building sector, in which industrialized technologies tend to be more used, compared to other sectors. An empirical study was carried out in a company that develops retail commercial buildings, which adopts a combination of industrialized and traditional building technologies. The aim of this research study is to identify the challenges and opportunities in adopting the concept of modularity in construction projects. This investigation is part of a broader research project on modularity whose main outcome is a conceptual model for defining modularity degrees and constructs in the construction industry, focused on ETO building companies.

2. Core concepts related to modularity

Modularity can be defined as the degree to which a system can be divided into subunits (modules) that can be joined and recombined in different ways [30], [31]. A module is understood as an independent unit which has its own functionality and standardised interfaces that interact according to the system's definition [6]. Fine [32] pointed out there are three dimensions of modularity: product, process and supply chain.

2.1. Product modularity

Ulrich [11] proposed a theory of modular product architecture, which is explained by three elements: the arrangement of functional elements, the mapping from functional elements to physical components, and the specification of the interfaces between interacting physical components. Three product modularity-related terms are discussed in this section due to their importance in the construction industry: interface standardisation, interdependency and separability.

Fine [33] states that modular products have standardised interfaces and interchangeable components, while Salvador [27] argues that the standardisation of interfaces is crucial to allow combinability, a fundamental requirement for any modular product. Ulrich [11] establishes three types of modular architecture according to the interaction between modules: (a) slot, where all interfaces are different and the modules are not interchangeable, (b) bus, which has a common bus to which all the modules connect through the same type of interface, (c) sectional, where interfaces are all the same and can connect with any other module; the modules are interchangeable. It is understood that a product architecture with standardised interfaces between the modules is more modular, while an architecture with different or multiple interfaces is less modular.

Interdependency, related to the 1:1 function and component mapping (each component has one function) by Ulrich [11], classifies the degree of dependency between the product's modules, i.e., to what degree the function of one product depends on another product.

In the construction industry, a component can be analysed at levels of aggregation, depending on the construction system, such as building, component, subcomponent, or element, each one containing a different function package, rather than a single function [27]

Pimmler and Eppinger [34] describe different types of interactions between physical elements and functions: (1) spatial, when interactions need adjacency or contact; (2) energy, when energy is transferred; (3) information, when there is a need to exchange signals or information and (4) material, when there is exchange of materials between the elements. A component may need more than one type of interaction and have different levels of need [34]. Some interactions entail more physical proximity and higher interdependency. Spatial and information interactions require less integration, while material and energy interactions require transfers of material/energy between components.

Separability is based on the characteristics of the connections between modules (coupled/cohesive or decoupled /loose) and autonomy. Modular products are characterised by their modules being loosely coupled [33] or de-coupled [11]. Salvador [27] proposed the concept of cohesion, which is the connection strength between the components of a product. In a cohesive connection there is more interdependency between the modules, while in a loose connection there is more independency. One of the properties of modular architecture products is independency and the possibility of individual updating, i.e., a product's capacity to change a specific function (performed by a specific component) without affecting or altering the remaining components. [11, 33].

Modular systems have high internal cohesion in the module and low cohesion between modules [27]. Therefore, products that are more modular have weaker connections between its components, while less modular products present stronger cohesion between its components.

2.2 Process modularity

Process modularity is defined as the modularity of production or manufacturing [23] or the processes that are necessary for installing a set of components [35]. A modular building construction process usually involves the off-site production of elements (volumetric or smaller sized modules), transportation and assembling [35, 36].

The process aspect can be analysed at different phases of the production process: planning and design, pre-construction, construction and post-construction [37]. Fine [38] divides the process dimension into technology and planning, which can also be related to the stages in the project process (planning) and the production process (technology).

Two dimensions determine the modularity of the process: time (fast or slow) and space (centralised or dispersed) [23], [33]. More modular production occurs in a more spatially distant way, and less modular production occurs in spatial proximity. More modular production is more rapid/concentrated in time, while less modular production is slower/more dispersed in time. The manufacturing processes of prefabricated products take place more rapidly in factories (rapid/tight in time) and can be performed at any location and by different factories (dispersed in space).

2.3. Suply Chain modularity

Modular supply chains leads to suppliers' independency [39], where suppliers have a flexible and interchangeable relationship [18] that allows supplier substitution and SC variations when different performance or functionalities are intended [23].

The modularity of SCs can be determined based on the degree of proximity regarding geographic location, organisation, communication and language [32]. All stakeholders, from customers to manufacturers, are considered participants of the SC [3]. The relationship between the modularity of a product and that of the SC is divided into three main combinations: (i) modular products with loosely coupled SCs; (ii) non-modular (traditional) products with integrated SC, and (iii) prefabricated products with modular SCs [3].

3. Modularity in prefabricated building systems

There is some confusion between different concepts used to describe industrialised construction systems, such as off-site prefabrication, preassembly and modularisation [37]. However, although the concepts of industrialisation and modularity are closely related, industrial preassembly is not necessarily needed to achieve modularity [7]. Industrialisation involves production, process and supply chain issues [24]. In the construction industry, modularity is often associated with prefabricated components in a manufacturing environment [18]. Preassembly in the construction industry means that buildings or parts of buildings are assembled off-site before on-site installation [40].

Building production can be classified into four types of production systems with varying degrees of off-site production, from component manufacturing and sub-assembly (traditional construction) to modular construction, where the production is carried out off-site with high levels of completion [40]. Within the modular construction perspective, Doran and Gianakis [41] proposed a classification that divides modular buildings into three categories, pure modular, hybrid and on-site modular, ranging from more standardised buildings to those with a high level of customisation.

The concept of industrialisation involves several sub-areas, including standardisation [24], which is an essential element of industrialisation. Standardisation is the repetitive use of a solution [11] not only in products, but also in processes. Platform refers to a collection of products that share a set of common components and parts to produce different products [42]. The adoption of the concept of platform can potentially contribute for the adoption of modularity in the construction industry.

Figure 1 shows a mind map based on the literature review, which connects modularity related terms and the attributes of a modular product, process and supply chain. From a product architecture perspective, a module is generically defined as a physical part of a building or system [43]. This definition is adapted from the manufacturing industry, but caution must be taken: (i) a building is provided by spatial voids [35] i.e., a module can be the space of a room [44]; (ii) the word architecture acquires an inappropriate double meaning in the construction industry [45].

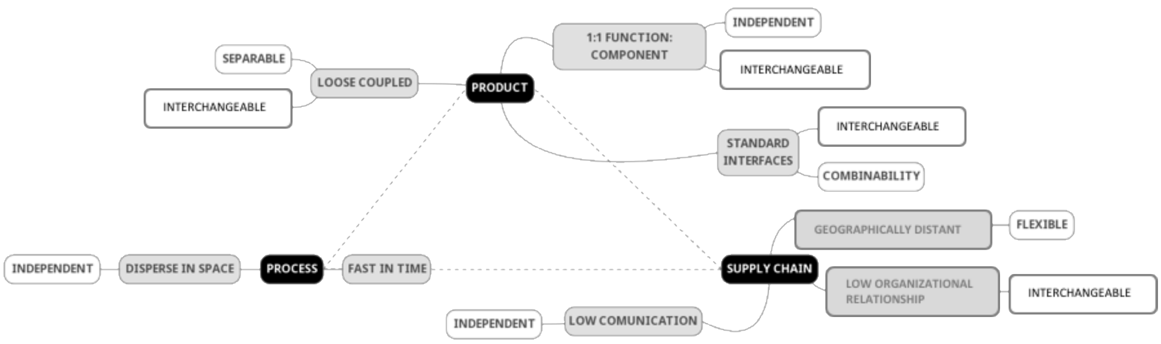

Figure 1. Concept map showing the relationships between modular product, modular process and modular supply chain, related terms (in grey nodes) and attributes (in white nodes).

5. Research method

The research strategy adopted in this investigation is case study. The case study method is recommended when "how" or "why" questions are posed and the investigation is focused on a contemporary phenomenon [46]. A single descriptive case study on a retail company was conducted. Company A was chosen for this case study due to the fact that this company was interested in improving the degree of industrialisation of the building system adopted in its project portfolio. From one hand the company wanted to increase the degree of project standardization in order to make it simple the management of facilities, and, on the other hand some degree of flexibility was necessary to adapt the design to the location and scope of the project. Moreover, project delivery involved a several stakeholders: the company itself (as client and owner), the design team, the construction team and suppliers. Some were involved in most projects, while others varied according to location. Hence, the study in this company allowed the consideration of three types of modularities (product, process and supply chain), starting from the interest of the different stakeholders.

The data for the case study was collected from multiple sources of evidence, with the aim of improving data reliability [46]. The sources of evidence adopted were: (i) one semi-structured interview with the company's director of expansion, (ii) one semi-structured interview with the head of engineering; (iii) one semi-structured interview with two design and project management team members; (iv) one visit to a construction site; (v) a document analysis of 16 building designs. The study was carried out over a ten-month period in 2019. Table 1 presents details about the sources of evidence, including the purpose of each one.

Table 1. Source of evidence of the case study and purpose

Source	Purpose
(i) one semi-structured interview with the company's director of expansion,	To get a general understanding of the company's goals and the building solution.
(ii) one semi-structured interview with the head of engineering;	To understand the main engineering topics, such as choice of building technology; supply chain relationships, development goals, main barriers.
(iii) one semi-structured interview with two design and management team members;	To understand the production steps and the design process, to capture the design challenges.
(iv) one visit to the construction site (along with the engineer in charge);	To observe the building construction process and collect building information;
(v) document analysis of 16 building plans.	To get design information, including standard elements, areas, construction process.

An important limitation of this investigation is the fact that visits to construction sites for analysing production processes had to be interrupted in March 2020, due to the COVID-19 pandemic.

6. Results

Company A develops commercial projects for company`s two types of business, wholesale and retail. It has been in operation for 63 years. It has developed ten retail stores and thirteen wholesale stores. Currently, it is working on the expansion of the wholesale segment. Two sectors of the company are involved in construction projects: expansion and engineering. The expansion sector is in charge of the strategic planning of new units and the engineering sector manages the design, planning and construction of the new units. Both design and construction services are outsourced.

The main goals pursued by Company A are: (i) design process: reduce design time, standardise building units; (ii) project management: improve communication among supply chain members; standardise processes ; (iii) building production: increase off-site production, reduce construction time; eliminate bottlenecks by foreseeing production, estimate reliably industrialised off-site concrete structure production, and decouple production from the approvals by regulatory bodies ; (iv) product: standardise products, adopt three product families for different size demands; improve building performance and maintainability; simplify commercial management operations through layout standardisation (this goal was highlighted by the expansion director, stating that similarity between the stores makes it easy to transfer managers between units); make buildings flexible, considering a 50-year life span; (v) cost: reduce construction costs.

Table 2 summarises key characteristics of the company in relation to product, process and supply chain.

Table 2. Current product, process and supply chain characteristics of Company A.

Category	Description
Product	Off-site prefabricated concrete column-beam structure, prefabricated concrete panels for external walls, light-weight internal partitions, steel roof structure, metal roofing, on-site produced industrial concrete floor.
Process	Internal architecture design team, outsourced structural and building service designs, internal production management team. Although each design is unique, the construction process follows the same steps.
Supply Chain	Outsourced production crews, long term relationship with some suppliers. much information exchange is necessary between SC members.

6.1. Product modularity

Sixteen units built or designed between 2018 and 2019 were analysed. The analysis was carried out based on architectural and structural design documents and project specifications. All designs adopted standards for building components and functional areas.

The projects were categorised by the company into three families, according to the sales area. For the purpose of product analysis, the following parameters were proposed: type-A unit (store area between 1,000 and 4,099,99 square meters), type-B unit (store area between 4,100.00 square meters and 6,099.99 square meters) and type-C unit (store area larger than 6,100 square meters). The units are customised according to the desired sales area, lot area, parking positions, access locations and docks position. The units can be single-story or two-story with a parking floor.

The aim of the expansion sector was to develop a standard product with customisations according to the sales area, docks and accesses. The remaining rooms, such as bathrooms, administrative area, staff area, warehouse, bakery, cold storage and freezer had the same requirements in for each category of store. Figure 2 shows schematic representation of the customisation decision-making process.

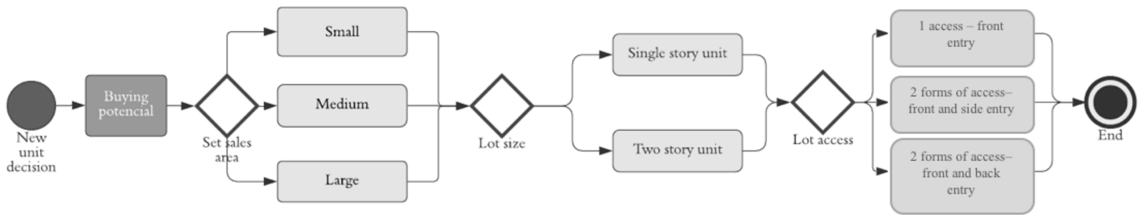

Figure 2. Customisation process diagram showing three decisions that define product configuration.

6.1.1. Standardisation

The strategic requirements of commercial demand determine the product family (A, B or C) and the location. The unit's area determines the lot area, although the choice of lot depends also on the financial and legal feasibility, which usually prevails over area requirements. Hence, the lot area depends firstly on strategic requirements, and secondly on design requirements.

The analysis of the designs confirmed that bathrooms, administrative area, staff area, warehouse, bakery, cold storage and freezer had similar dimensions, due to the same requirements, regardless of store size, i.e. do not vary proportionately to the sales areas. This represent an opportunity to standardise rooms or components for each product family.

6.1.2 Prefabrication

The analysis of the product regarding prefabrication begins with the definition of the physical unit of the evaluated product module. The physical unit was established according to the degree of industrialisation. The company's construction system is non-volumetric prefabricated panels, and the type of unit to be evaluated is components (doors, windows, vertical fence panels, horizontal fences, etc.).

6.1.3 Interface

A building is formed by multiple components. For example, the external envelope element is made up of vertical and horizontal external closures. The external vertical facade is made of concrete panels, concrete columns, metal gates, automatic aluminium doors and glass. The vertical panels are in standardised prefabricated concrete. However, the interface with other components is not standardised, making it necessary to adjust other components to the prefabricated panels. The external horizontal closure consists of metal roofing and a steel structure. In this case, the interface between the roofing and the structure is standardised.

6.1.3 Interdependency ß

The interdependency analysis consisted of analysing function and component binding. The external sealing function is performed by several components, such as concrete panels, doors and tiles. The access function is performed by doors and gates. One component, such a door, performs the function of external sealing and access, 1: 2 ratio (component: function binding) and several components perform the function of external sealing, ratio 1: 1 (physical component to functional element). As to the type of interaction, most of the external facade components have a highly independent spatial relationship, while the doors and gates components are less independent.

6.1.4 Separability

In the external vertical facade, some components, such as the concrete panels are interchangeable. However, if their positions are switched, other components require adjustments in the components with which they share an interface. As to the autonomy aspect, changing one component requires changes in the adjacent components' interfaces, but not in all components. For example, if the thickness of a prefabricated concrete panel is changed, then the concrete columns and the frames of the doors and gates also need to be changed. However, no changes are required in the metal structure of the roof, for example.

6.2. Process

The design process starts with a commercial demand, when the size of the building is defined, based on a sales area demand analysis. The expansion sector requests the engineering sector to make an architectural feasibility study on prospected areas (average duration of 10 days). When the architectural feasibility study has been approved by the director, the strategic feasibility study starts, which includes the commercial feasibility of the business, lot negotiation and raising financial resources (60 – 90 days average duration). Thereafter, an internal design team draws up the building plans for approval by the official regulatory body. While the legal approval process is under way, structural, and building service designs are performed by outsourced companies. Some parts of the project are pre-engineered, such as the concrete structure and prefabricated facade, with adaptations made to fit design requirements. The internal design team is also in charge of several cycles of clash detection between designs.

Construction begins as soon as the legal approvals and construction permit have been obtained, which takes between three and six months. The average duration of the construction process is 8 months. The production process is relatively slow mostly due to the limited degree of prefabrication. Regarding location of the suppliers, the production of most prefabricated components takes place nearby, and several elements are manufactured *in loco*.

6.3 Supply Chain

Finally, regarding SC modularity, the analysis considered the relationship between customers and company, and suppliers and company. There was a high level of client's interference in the project, since the projects arise from the client's demand. The suppliers also have a strong influence in the design and construction of the units. The internal managerial staff of the company is in charge of monitoring the entire production process, with a high level of information exchange with suppliers.

7. Improvement opportunities

Several opportunities and challenges regarding modularity were identified for company A. These are presented for each category: product, process and supply chain.

7.1 Product modularity

Figure 3 presents a schematic representation of common areas, allowing a visualisation of the combinability between the typologies. This representation is based on the form proposed by Salvador [27] to identify separable components. The analysis considered empty spaces, in other words, rooms as store area, bathrooms, employees' area, administration, bakery, etc.

The process was divided into 4 steps: (1) subdivision of products into families (A, B and C), according to the sales area requirements, (2) variations of the families to meet lot area and lot access requirements, (3) analysis of common areas between family variations, or simply identifying which areas are shares by different families; and (4) identifying separable components, which are the rooms shared by the different units.

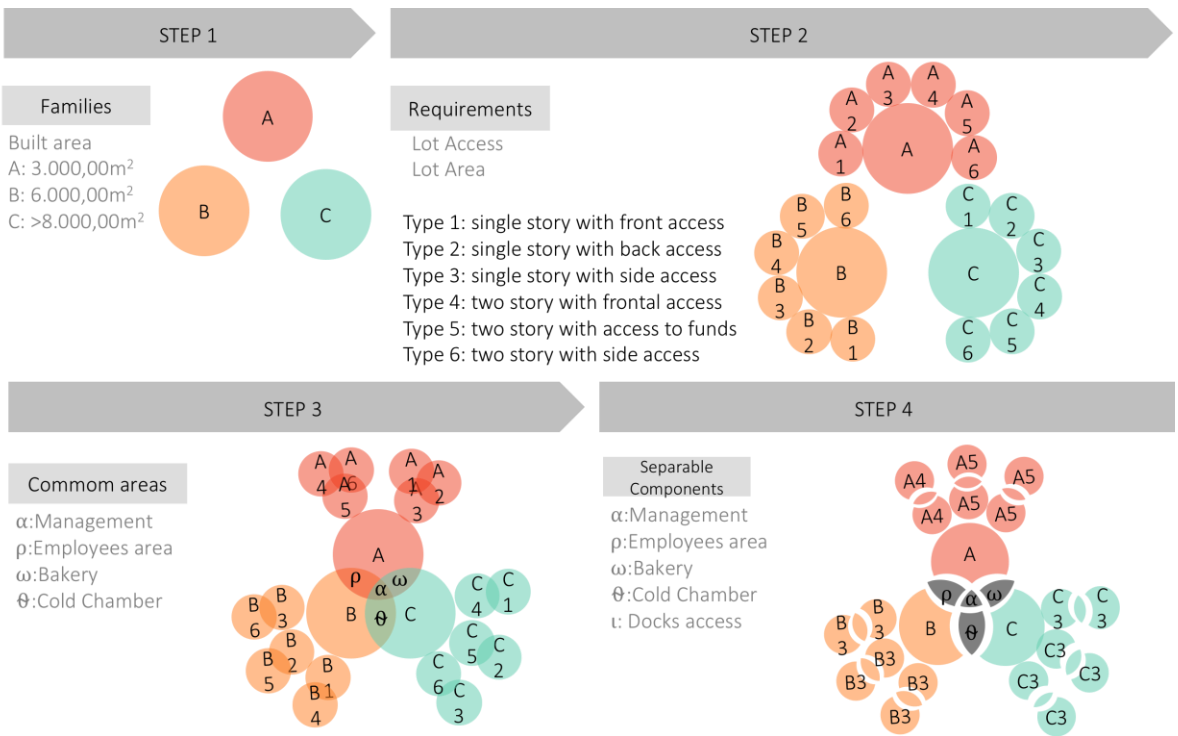

Figure 3. Four-step process showing the steps to identify product families with separable components, based on Salvador (2007).

7.2. Process modularity

Regarding the design process, company A aims to standardise their product and speed up the design process. As an alternative, the company could replace its ETO project strategy by an ATO strategy, where the project can be pre-engineered. When a demand for a new floor is presented, the design team must adapt the solution to the unit's requirements.

With a higher level of product standardisation, it is possible to prefabricate standardised spaces, increasing the rate of prefabrication and hence meet the company's goal of speeding up the construction stage.

7.3. Supply Chain modularity

Company A has been operating in a limited region in the south of Brazil. The supply chain is the same in several projects, involving mostly local suppliers, enabling intense information exchange and easy communication. These are characteristics of an integral SC. With the expansion project, Company A started to extend the geographic location of new projects. This made it too costly to keep the same suppliers, since they may be located far away from the project. Another problem caused by the integral SC is that design solutions are heavily influenced by suppliers, forcing the company to keep the same technology, thus reducing the possibility of innovations.

A modular SC allied with a certain level of product standardisation could offer an opportunity to expand the possibilities of using different technology solutions, as well as to increase the offer of suppliers and possibly enable better price negotiations, reducing costs. Costs can be reduced by using local suppliers when logistics have a substantial impact on costs.

8. Discussion and conclusions

Company A's building projects have a relatively low level of prefabrication, mixing prefabricated solutions (such as concrete columns-beam structural systems, concrete external panels, and light weight panels for internal partitions), and traditional on-site work (e.g. electric and plumbing systems, cast in place concrete floor, steel roof structure assembly and metal roof tiles, glass façade and painting). In this case, the focus of prefabrication is mostly structural, i.e. on a single discipline. It is worth noting that even with these characteristics it was possible to apply some modularity-related concepts in this context and to point out improvement opportunities. Some level of modularisation can support improvements aligned with the company's five main goals, as presented previously. **Table 3** presents the company's goals and how modularity can support these goals.

Table 3. Company A's goals and modularity opportunities

Company goals	How modularity can support
(i) design process: reduce design time, standardise units;	Product standardisation, such as a platform solution, and pre-engineered solutions could shift the design process from ETO to ATO (adapt-to-order), which results in a faster design process.
(ii) building process: improve communication among outsourced supply chain members; standardise steps;	The building process can be divided into modules or small lots, reducing interdependency in each module or lot. This contributes to process standardisation, besides generating a learning curve along the execution of modules.
(iii) building production: increase off-site production, reduce project duration; foresee production to avoid bottlenecks, anticipate industrialised off-site prefabricated concrete structure production and decouple production from legal design approvals;	Product standardisation may allow the beginning of production before legal approvals, and the adoption of large prefabricated components (e.g. fully serviced panels in complex areas, such as bakery, cold chamber and bathrooms.
(iv) product: standardise products, specify three product families according to project size; improve building performance and maintainability; simplify commercial management operation by layout standardisation;	Product standardisation, and adoption of a platform solution with specification of families with standardised and customisable areas.

(v) cost: construction cost reduction.	With a standardised (but customisable) product and process, the company could benefit from a modular supply chain, which can make it possible to have a large number of suppliers, enhancing price competition, reducing stakeholders' dominance and improving negotiations.

Standardisation could help Company A to achieve some of its goals relating to product, process and supply chain management. Regarding the product, in this type of building, which have large areas, long external wall spans and few small internal rooms, it is impracticable to use 3D modules. Moreover, the low volume of building production by the company also contribute to make ineffective the adoption of 3D modules. Nevertheless, it is possible to adopt other modular solutions, such as full serviced panels, for example, especially in complex areas, such as bakery and cold chamber.

It is worth mentioning that Company A has established a standardisation goal, although they did not have a clear mapping of the common areas between different units. As an example, the company stated that some areas need to be extended as the sales area increased. However, an analysis of the units showed the opposite, as support areas has approximately the same size in different size units. The division into families, with standard and customisable areas, can potentially allow the company to achieve product standardisation goals and reduce design time without reducing its customisation requirements.

In terms of process, dividing the construction process into modules, or small lots, could be an opportunity to reduce interdependence between construction sectors, particularly in areas with high design complexity, such as cold chambers and bakery areas, which involve many design and production specialties.

Finally, the supply chain can benefit from product and process standardisation. With a standard product and more independence between modules (or components) the company would be able to adopt different construction technologies, which would be better suited to each location or time, price or unit requirements. Tolerance plays a key role in the communication between product and process design and can be described as a method to accommodate variability in the product or production process by establishing the acceptable variations in one or more parameters [48].

Further work is necessary on the application of the modularity concept in other construction companies with higher off-site production levels or in other industrialised building systems. Considering that many companies mix industrialised building systems and traditional construction technologies [35], a broader investigation would give a better understanding of the opportunities for modularity adoption. Additionally, supply chain and process modularity issues need more in-depth studies to better understand the application of modularity application in this sector.

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Low Carbon Recycled Aggregate Concrete: Roles of Slag and Silica Fume

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Abstract: Recycled coarse aggregate from construction demolition waste offers a promising and sustainable solution to overcome challenges facing the construction industry, in relation to the increasing landfill areas, decreasing natural aggregate reserves, and increasing environmental impact of concrete production. Previous studies have shown that recycled aggregate concretes (RAC) are, however, more susceptible to deterioration. This paper presents an experimental investigation to improve the performance of concretes manufactured with locally produced recycled coarse aggregate in the UAE. More specifically, it aims to investigate the potential of incorporating ground granulated blast-furnace slag (GGBS) and silica fume (SF) in RACs, and their influence on key engineering properties of concrete. It is shown that partial replacement of Portland cement with GGBS and SF is effective to reduce the resistance of RAC to chloride ion penetration (hence durability), and lower the drying shrinkage and CO_2 emissions, with minimal influence on the long-term mechanical properties. A reduction of approximately 40% in CO_2 emissions was found in a concrete mix with combined replacement of recycled and waste materials.

Keywords: Recycled coarse aggregate; GGBS, Silica fume; Durability; CO_2 emission.

1. Introduction

Over the past 15 years, much of the research in sustainable construction has focused on three main topics: reducing, reusing and recycling, commonly known as the '3Rs' principle [1]. Construction and demolition waste form the largest component of the waste stream that account for 25-30% of the total waste generation [2]. Of these, concrete constitutes a major share of the amount of construction waste produced globally. This is due to the fact that concrete is the most used construction material worldwide due to its versatility [3]. The production of concrete has, however, a negative impact on the environment, and the increasing pace of construction has even made the situation worse. According to Environment and Climate Change Canada [4], for example, in 2016 alone, cement and concrete product manufacturing contributed 13% (10 Mt CO_2 eq.) of the total CO_2 emission generated by the manufacturing sector in Canada. This problem is not exclusive to Canada, and is of major concern in many countries around the world, including the UAE. In 2018, the UAE was even identified as one of the world's largest per capita CO_2 emitters because of its relatively low population [5]. To address this issue, the UAE Government has introduced several environmental policies over the past few years. As an example, Estidama in Abu Dhabi has published a green building code with a rating system known as the Pearl Building rating system (PBRS). Under this new regulation, a new building must meet, at least, one sustainable level (out of five) to obtain construction approval.

The use of recycled aggregates has attracted increasing interest from the construction industry since the past few decades as a result of rapidly depleting natural aggregate resources. With almost 20 billion tons of concrete being produced worldwide every year [7], this has put an enormous amount of pressure on the production of raw natural aggregates, provided that aggregate accounts for 70% of the concrete volume. The situation is exacerbated by the over-burdened landfill sites as a result of increasing amount of demolition of buildings, bridges and other types of reinforced concrete structures [7]. It is not surprising, therefore, that the use of recycled aggregates has recently received widespread interest, as it offers favorable and promising means of reducing landfills, saving natural resources and reducing environmental impact [8]. Over the past few decades, many research studies have focused on investigating the properties and performance of recycled aggregate concretes (RAC). According to Xie *et al*. [8], the main parameter that influences the performance of RAC is the water-to-binder ratio. They found that the compressive strength of RAC generally decreases with increasing w/c ratio and replacement level of recycled aggregate. They also found that the Interfacial Transition Zone (ITZ) of the residual mortar which are present on the surface of RCA plays an important role on the short- and long-term properties of RAC [9]. Other key influencing factors include the amount of residual mortar lumps, the grading of recycled aggregates, and various aspects related to the production of RCA such as the crushing and treatment methods, which may discredit the potential and benefits of reusing aggregates in concrete [7].

Apart from aggregate replacement, there are also some potentials of replacing Portland cement with supplementary cementitious materials (SCM), using the by-products of traditional industrial processes such as ground granulated blast-furnace slag (GGBS) and silica fume (SF). Improvements in mechanical and durability properties have been well documented and are attributed to the pozzolanic reaction with the products of hydration, which leads to long-term pore refinement [10]. Kou and Poon [11] reported that the use of SCM has the potential to improve various properties of RAC such as drying shrinkage, creep, chloride penetration resistance and carbonation, which is in agreement with Saini and Goel findings [12].

It is worth noting that greenhouse gases (GHG) caused by human activities increase the risk of global warming. This includes various activities related to the manufacturing of Portland cement and transport of raw materials involved in the production of concrete. Currently, the worldwide cement production accounts for 7% of the global CO_2 emission with transportation of materials contributing as the second main source of CO_2 emission [14]. Furthermore, the global cement production is estimated to reach around 4.4 billion by 2050, which poses significant challenges to environmental governance to find ways of "decarbonizing" the concrete production (including reducing cement consumption) in the construction industry [14].

In this study, an experimental program was undertaken to investigate the performance of concretes produced with a locally produced RCA in the UAE, along with the use of GGBS and SF. For this purpose, the three concrete mixtures were tested and discussed in terms of their mechanical and durability properties, and CO_2 emission.

2. Experimental program

2.1. Materials

The majority of the materials used within the experimental program was sourced locally from different parts of the UAE (see Figure 1). This includes CEM I 42.5N Portland cement to BS EN 197-1:2000 [15], coarse aggregate (<20 mm and <10 mm), fine aggregate (<5 mm) and dune sand; all of which were supplied from Ras Al-Khaimah (RAK) region. Two other materials, GGBS to BS EN 15167-1 2006 [16] and SF to BS EN 13263-1 [17], were supplied from outside the UAE (imported from China). A polycarboxylate superplasticizer (PC400) was added in all concrete mixes at an amount of 0.8 liters per 100 kg of cementitious materials to ensure adequate workability.

Figure 1. Concrete mix components.

2.2. Recycled coarse aggregate

The recycled coarse aggregate (RCA) used in this work was generated from construction demolition and had a relatively uniform size, generally in the range 10-14 mm (see Figure 2). The RCA was supplied by a recycling company in Sharjah Bee'ah, which was established to promote sustainable construction in the UAE, through the utilization of renewable energy resources. Every year, the company contributes up to 500,000 tons of recycled aggregate to the local market, with the aggregate produced primarily from concrete construction waste [18]. The physical and mechanical properties of all aggregates used in the test program are presented in Table 1, together with recommended values from various codes of practice. It can be observed that the measured values satisfy the specified minimum requirements indicating that the locally produced RCA can be used in concrete as normal aggregate.

Figure 2. Photograph of recycled coarse aggregates used in the project.

Table 1. Physical and mechanical properties of normal and recycled coarse aggregates.

Test descriptions			20 mm NCA	10 mm NCA	10-14 mm RCA	RCA Limits	Standard
Specific Gravity-oven dry			2.67	2.67	2.36	≥ 2.1	RILEM [19]
Specific Gravity-SSD			2.68	2.68	2.48		
Apparent Specific Gravity			2.70	2.71	2.69		
Water absorption		%	0.5	0.5	5.1	≤ 7%	RILEM [19]
Bulk density	Compacted	kg/m³	1,500	1,490	1,350	≥ 2,000	JIS A 5021 [20]
	Uncompacted	kg/m³	1,400	1,380	1,250		
Flakiness index		%	9	22	19	35%	EHE-08 [21]
Elongation index		%	24	23	15	35%	EHE-08 [21]
Acid soluble sulphate		%	0.03	0.04	0.21	0.80%	RILEM [19]
Acid soluble chloride		%	0.01	0.01	0.02	0.05%	CUR 1994 [22]
LA abrasion value		%	28	24	28	40	RILEM [19]

Aggregate crushing Value	%	26	23	23	45	WBTC [23]
Ten percent fines value	kN	160	180	190	≥80	RILEM [19]
Moisture content	%	0.1	0.1	1.5	-	
Soundness by $MgSo_4$	%	1.1	2	6	10	RILEM [19]

2.3. Concrete mix design

Three concrete mixes designed to ACI 211[26] were tested: (i) M1 mix incorporating normal aggregate, serving as the control mix (labelled as CON); (ii) M2 mix incorporating recycled aggregate (labelled as 100% RCA); and (iii) M3 mix incorporating recycled aggregate and supplementary cementitious materials (ground granulated blast-furnace slag (GGBS) and silica fume (SF); labelled as 100% RCA+50%GGBS+10%SF). The replacement level followed the optimum range in previous studies [12,24,25]. A summary of the concrete mixes used within the experimental program is presented in Table 2. In all mixes, the water-to-cement ratio was taken as 0.33. The water content in each mix was adjusted to account for water absorption of the RCA.

Table 2. Summary of concrete mixes.

Mix ID	Mass of Constituents (kg/m³)									Super-plasticiser (% by mass of OPC)
	OPC	Water	SCM		NCA	NCA	RCA	Sand	Dune	
			GGBS	SF	10 mm	20 mm	10-14 mm	5 mm	sand	
M1	400	132	-	-	553	368	-	718	308	0.8
M2	400	132	-	-	-	-	735	846	362	0.8
M3	160	132	200	40	-	-	735	846	362	0.8

3. Tests on hardened concrete

In this study, various tests were performed to obtain the fundamental mechanical and durability properties of the ordinary and recycled aggregate concretes (see Figure 3). This includes:

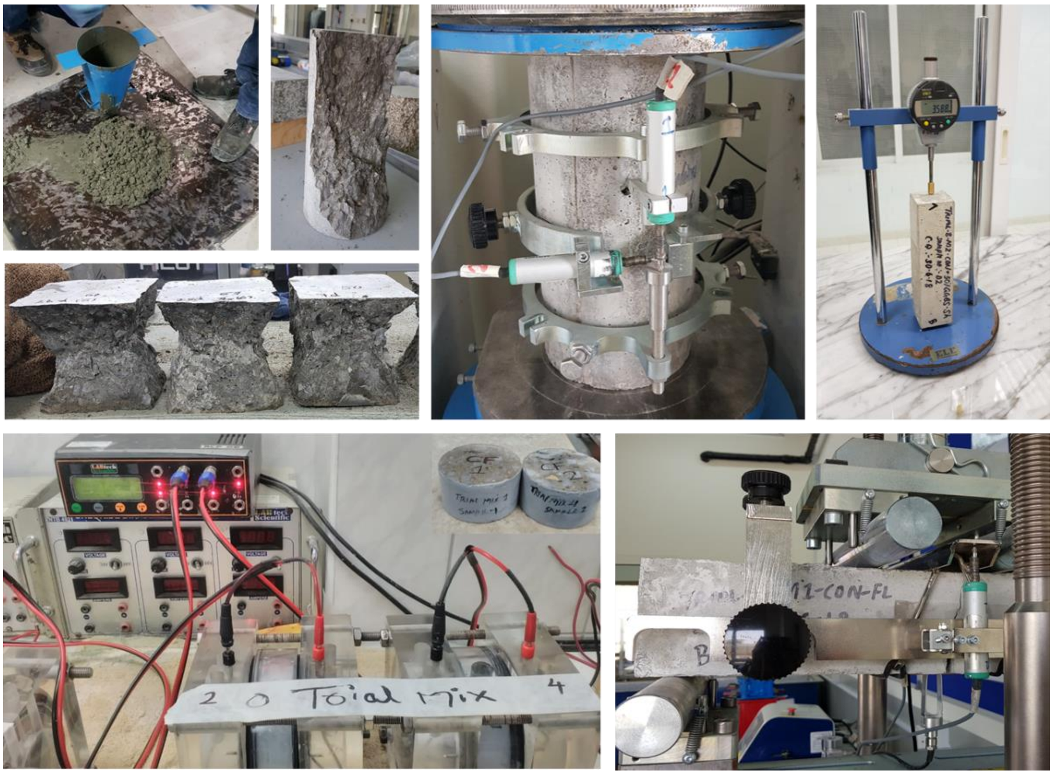

Figure 3. A collection of photos displaying the various tests undertaken on hardened concrete.

- Water absorption tests in accordance with BS 1881-122: 2011 [27] at 28 days of age;
- Compressive strength tests in accordance with BS 1881 Part 116 [28], performed on 150 mm cubes at 90 days of age. On the same day, concrete strengths and elastic moduli were also measured from 150 × 300 mm cylinders, in accordance with ASTM C39 [29] and ASTM C469 [30];
- Flexural tests in accordance with ASTM C78 [31] and 4-point load method on prism samples with dimensions of 100 × 100 × 500 mm;
- Rapid chloride penetration test (RCPT) in accordance with ASTM C1202-17a [32], on concrete disc specimens with a diameter of 100 mm and a thickness of 50 mm; and
- Drying shrinkage tests in accordance with ASTM C157 [33], on prismatic samples with dimensions of 50 × 50 × 200 mm. The samples were placed in an outdoor environment with ambient temperatures of 35±10°C and relative humidity of 60±10%, which represents common curing practice in the UAE. Readings were taken at 7, 14, 21, 28, 90 and 180 days.

4. Results and discussion

4.1. Mechanical properties

Table 3 presents the results of all tests described in Section 3. Regarding the 90-day cube compressive strength, it is evident that the addition of RCA results in a reduction in compressive strength, with Mix M2 displaying 13% lower strength than the regular concrete mix (Mix M1). The lower strength was expected, and this could be attributed to the presence of old mortars which had adhered to the surface of RCA. This 'old' mortar could be quite porous and might have pre-existing cracks due to the crushing process involved in the production of the recycled aggregate. Accordingly, RCA tends to have a weaker bond with the surrounding cement matrix than normal aggregate. This could be associated with the more porous nature of interfacial transition zone (ITZ) in concrete incorporating RCA [35], when compared to the ITZ in concrete produced with normal aggregate. No significant improvement in strength was observed for Mix M3 and this could be due to the fact that although the long-term pozzolanic reaction of GGBS and SF was found beneficial to improve the ITZ [10], this was limited to the new ITZ between the cement matrix and RCA surface only [36] (i.e., it did not influence the pre-existing ITZ between the old mortar and natural aggregates). The results of the cylinder tests follow the same trend as those for the cubes, with Mixes M2 and M3 displaying a 13% and 25% reduction in compressive strength, respectively. Similarly, the incorporation of RCA was found to decrease the flexural tensile strength, although to a less extent [37]. Mix M2 displayed an 8% lower (tensile) strength than Mix M1, while Mix M3 exhibited a 15% reduction. No improvement in flexural strength was observed through the incorporation of GGBS and SF in Mix M3, as this could be masked by the lower matrix strength. The same trends were observed in other studies [38, 39].

Table 3. Properties of concrete measured at 90 days of age (# tests were undertaken at 28 days of age).

Mix ID	Density	Cube Compressive Strength	Cylinder Compressive Strength	Flexural Tensile Strength	Elastic Modulus	Water Absorption#
	kg/m³	MPa	MPa	MPa	MPa	%
M1	2,480	72	67	4.30	43,260	1.5
M2	2,410	63	58	3.96	28,849	2.2
M3	2,294	60	50	3.66	28,041	2.2

Regarding the results of elastic modulus tests, it was found that the incorporation of RCA decreases the elastic modulus of the concrete by 33%, from approximately 43 GPa to 29 GPa. This is higher than the average reduction of 16% reported for 100% RCA replacement in [10], but within the range 6-45% reported by Batikha *et al*. [37].

With regard to the results of water absorption tests, an increase in water absorption by 46% was found in the concrete with 100% RCA (Mix M2), when compared to the regular concrete with normal aggregate (Mix M1). The use of GGBS and SF in the RCA concrete (Mix M3) did not improve the water absorption properties, possibly being masked by the high-water absorption of the RCA (5.1%, which is ten times higher than that of the normal coarse aggregate). This finding is in general agreement with Çakır [34] who found higher water absorptions in RAC with 10% SF, and in another RAC mix with 60% GGBS.

4.2. Durability properties

The results of the Rapid Chloride penetration tests (RCPT), which were undertaken at 7, 28 and 90 days, are presented in Figure 4. It is evident over the first 90 days of curing, Mix M2 displays higher charge passed values than Mix M1, which is in agreement with previous studies [40]. Furthermore, in all three mixes, chloride ion penetrability is noticed to decrease with curing time, as would be expected [41]. By comparing the results of Mixes M2 and M3, it is interesting to note that when GGBS (50%) and SF (10%) are added into the mix, the chloride ion penetrability of the concrete at 90 days of curing decreases significantly, from being classified as "Moderate" (as per ASTM C1202) to "Very Low". This clearly highlights the benefits of the supplementary cementitious materials in improving the resistance of concrete to chloride ingress (hence durability of the concrete in chloride-rich environments).

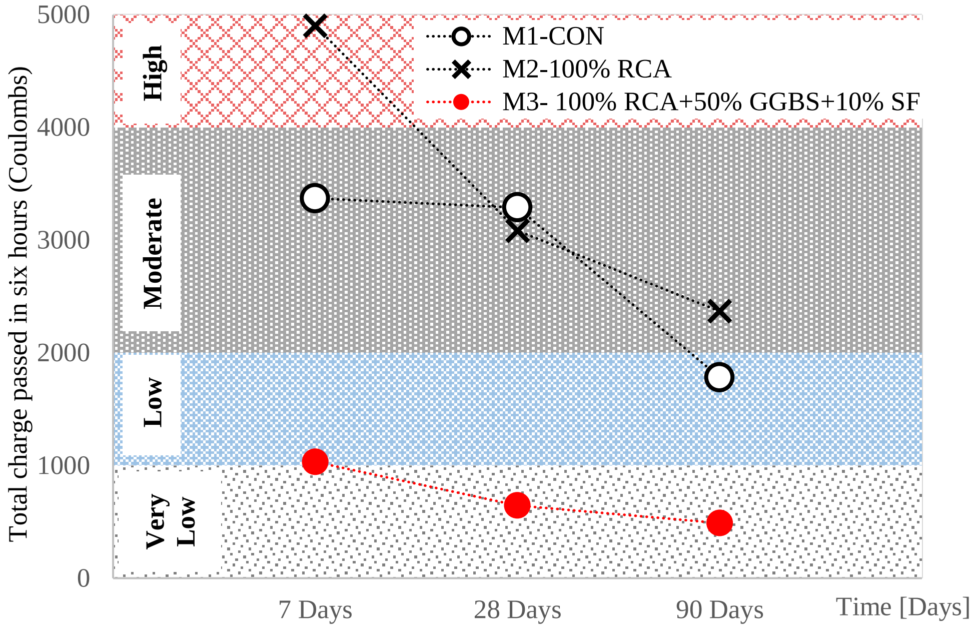

Figure 4. RCPT results for all concrete mixes.

The results of the drying shrinkage measurements at different stages of curing (up to 180 days) are presented in Figure 5. It is apparent that at 90 days, the drying shrinkage of Mix M2 is about 34% higher than that of Mix M1, which is in general agreement with previous study [42]. According to [10], 100% RCA replacement generally increases the shrinkage of concrete by 20-50%. It is interesting to note that the drying shrinkage of Mix M3 with 50%GGBS+10%SF is only half that of Mix M1 at 28 days; the difference between the two values, however, decreases with increasing curing time.

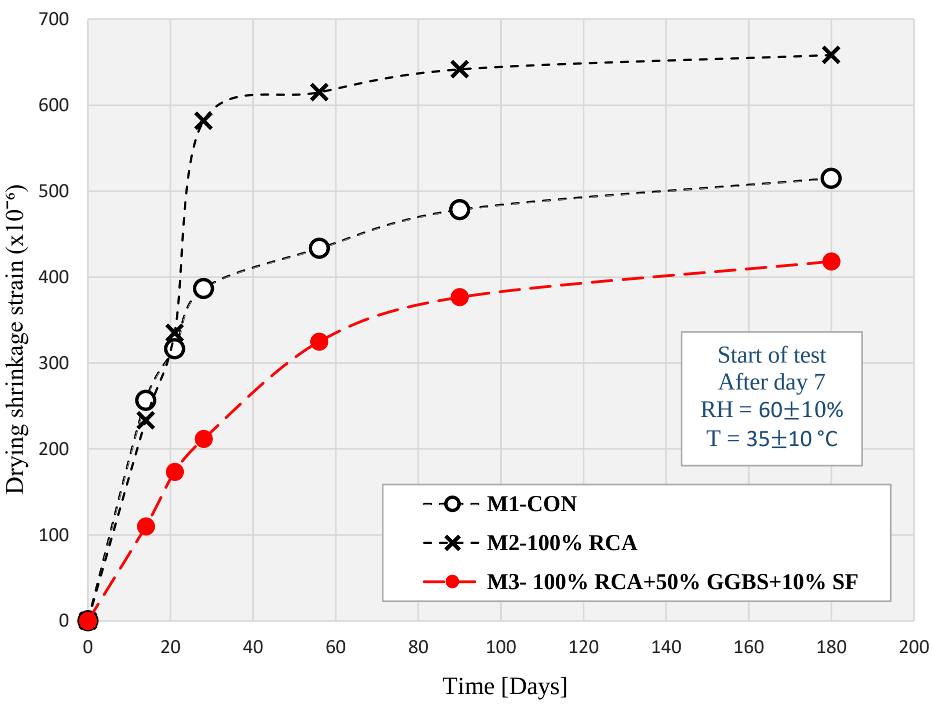

Figure 5. Drying shrinkage measured from all concrete mixes.

4.2. CO_2 Emission

The Green House Gas (GHG) emission was calculated for the three concrete mixtures using the methodology proposed in [43]. In this method, the total GHG emission is expressed as the carbon dioxide equivalent (CO_{2eq}) per ton of materials, considering not only CO_2 but also other unfavorable gases such as CH_4, NO_x, SO_x, which are normally emitted during the excavation and transportation activities. In this study, the GHG estimation has been done based on the total greenhouse gas emission ($kgCO_{2eq}$) per ton of concrete materials used in this study. As illustrated in Table 4, a number of assumptions were taken into account in estimating the CO_{2eq} emission, including the phases in cement production and the production of both coarse and fine aggregates. Moreover, transportation distance in the GHG calculation was taken as 400 km, considering the greatest possible distance in the UAE as a worst-case scenario. It is worth noting that the construction recycling in Bee'ah Tadweer follows the least energy consumption for processing recycled aggregate. It implements the common method of mechanical separation between the primary and secondary phases along with the primary and secondary crushing and washing activities. This mechanical treatment (without any heating treatment by furnace or kiln) is estimated to lie in the region of 21.7 kg CO_{2eq} / t_{RCA} [37].

Table 4 presents the total emission (in kg CO_{2eq} / t) for each concrete constituent, considering the distance required for transporting the materials across the UAE (based on the above assumptions). By mapping Table 4 onto Table 2, the calculated kg CO_{2eq} per 1 m^3 for each concrete mixture could be determined and the results of which are presented in Figure 6.

Table 4. Calculated total emission kg CO_{2eq} per 1 tonne of concrete considering transportation of materials across the UAE.

Material	Emission factor kg CO_{2eq} per 1 tonne of material		References
	without transportation	with transportation in UAE	
OPC	709	745	[44]
GGBS	25	120.8	[45]
SF	0.007	95.8	[46]
Coarse aggregate	45.9	81.9	[47]
Fine aggregate	13.9	49.9	[47]
RCA	21.7	57.7	[48]

With reference to Figure 6, it is evident that CO_{2eq} emission for Mix M2 is only 6% lower than that of Mix M1 which would indicate that the use of RCA would result in a marginal reduction in carbon emission. The addition of GGBS (50%) and SF (10%) into the binder of Mix M3 results in a concrete mix with 41% less CO_{2eq} emission than the control mix (M1), which is promising.

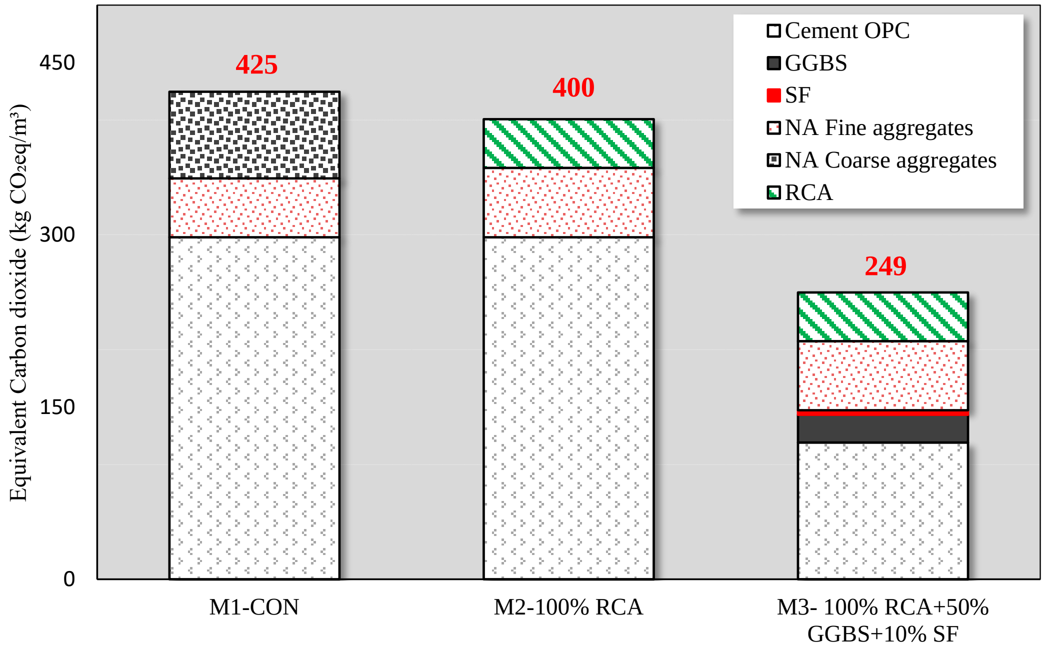

Figure 6. Equivalent Carbon dioxide (kg CO_{2eq}/m^3) for concrete mixtures.

Figure 7 provides a summary of all properties obtained from the tests undertaken as part of this research study for the three concrete mixes (conventional concrete, 100% RCA concrete, and 100% RCA concrete with 50%GGBS and 10% SF as a cement replacement). It can be seen that the addition of GGBS and SF in RCA concrete has the potential not only to improve the durability properties of concrete (as indicated by the lower RCPT and drying shrinkage values) but also to reduce CO_2 emission, with a 41% reduction observed from the mix presented in this paper. Comparable long-term mechanical properties to the ordinary concrete were obtained.

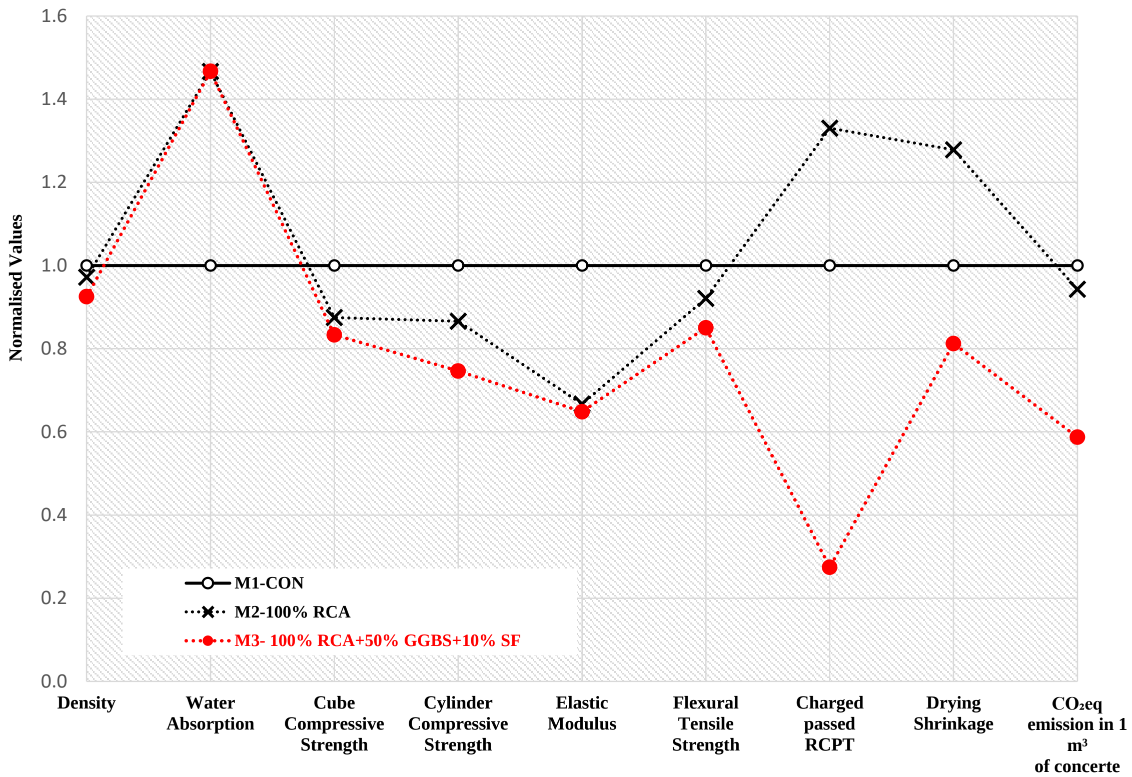

Figure 7. Properties comparison for all concrete mixtures.

5. Conclusions

Recycled aggregate and supplementary cementitious materials are untapped potentials in the UAE and their utilization can promote sustainable development in the Middle East. It is shown that the properties of concrete produced using the recycled aggregate in the UAE (produced by Bee'ah) exhibit comparable performance to those reported in previous studies, and satisfy minimum requirements specified in various international standards. The inclusion of GGBS and SF along with 100% RCA is shown to result in a 41% reduction in CO_2 emission, along with some improvements in durability aspects such as higher resistance to chloride ingress and lower drying shrinkage.

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A Systematic Literature Review Approach on the Role of Digitalization in Construction Infrastructure and Sustainable City Development in Developing Countries

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Abstract: The continuous surge of humans from the rural areas to the cities in search for livelihood has assumed an unprecedented dimension in recent years. More disturbing is the dearth of supportive infrastructure to meet the growing need for decent housing and other social amenities. The use of digital technology in virtually every field of human endeavor has become common place and a contemporary value driven approach to resource allocation, mobilization, utilization, and performance. Many of a nations' economic sectors have recorded improved performance and resource optimization through the adoption of digital technologies. Notable among these include manufacturing, agriculture, healthcare, banking, to mention a few. Unfortunately, only a little can be said about the adoption of digital technology in the various and complex activities and operations of the construction industry value chain, hence the need for an expository study that would harness the benefits of numerous emerging digital technologies in the sector. This study adopted a systematic literature review (SLR) methodology on a rigorous and extensive study, involving recent relevant scholarly researches (2016-2020) to assess the role of digital technology in infrastructure provisioning and sustainable cities development. It also examined the benefits and challenges of construction industry digitalization in developing countries. Findings of the study showed lack of government support, financial constraints, and lack of technical know-how, as major impediments towards the adoption and implementation of digital technologies in developing countries. The study concluded that the benefits of digitalization of the construction industry is enormous and includes sustainability of the environment, society, and economy amongst several others.

Keywords: Digital technology, Infrastructural development, Sustainable cities, Developing countries

1. Introduction

Digitalization of operations and processes in various sectors of a nation's economy is growing in significance, and this has seen technological trends impacting positively on most businesses. The dynamics introduced by digitalization has left businesses with no better option than to review business techniques, corporate culture, and organizational values to meet customers ever evolving needs and aspirations. This means businesses are required to embrace processes that need to be digitalized [1], gather data from varied sources [2], establish organized and effective consumer interaction [3], and ensure efficient information exchange in a digital manner [2]. Such measures will incorporate the usage of digital drivers like smartphones, computers, smart wearable devices, as well as the internet [4]. Drawing from these, [5] revealed that about 90% of businesses across different sectors and countries would be repositioned digitally, and this would give them competitive edge among best of class. Notably businesses that have accepted disruptive change in recent years through digital technologies include the food industry [6], healthcare sector [7], energy sector [8], finance sector [9], transport sector [10], and education sector [11]. A general framework that would bring to the fore digitalization with advanced data analytic processes will set the stage for business organizations to reap associated benefits.

Despite the wide adoption of digital processes across various economic sectors, its application in infrastructure projects in emerging economies is relatively low [12,13], albeit the steady growth being recorded [14]. Generally, this low drive in the adoption of digital technologies can be attributed to the over reliance on traditional approaches, fragmentation or lack of collaboration amongst built environment professionals, and casualness in embracing change in the realization of infrastructure projects [15,16]. In Africa, alongside other developing economies, various factors have hinged on the successful delivery of infrastructure projects. [17] argue that inadequate power serves as a barrier in infrastructure development in most African countries where in 2015, about 50% of the world's population without electricity are from Sub-Saharan Africa, thus hindering sustainable development initiatives. Also, there is the problem of lack of proper attention to issues of environmental sustainability in low-income settlements. The low-income dwellers constitute a larger proportion of dwellers in growing cities as residents often times become victims of urban development inequalities; hence their vulnerability to the effects of climate and ecological change [18]. Furthermore, corrupt practices within the construction project delivery framework severely impacts on infrastructure development performance in the developing nation of Nigeria [19]. Other factors include governments' favouratism towards certain ethnic groups thus hindering sustained growth [20]. [21] argues that the sustainability and economic growth of African urban areas is largely connected to the quality and quantity of roads and other supportive infrastructure. The deplorable condition of roads in African cities constitute major challenge towards city growth and development. The aforementioned studies and a plethora of others allude to the various barriers or challenges that plague the development of infrastructure in Africa. It is therefore, pertinent to draw from existing literature relating to developing economies that infrastructure development greatly affects the low-income communities as they constitute the majority of population. The application of digital technologies could fast track the needed global progress in achieving sustainable development.

With the global move that cities become sustainable due to the increase in urban population [22], it is imperative that cities become smart through digitalization, hence setting the pace towards the realization of smart sustainable cities [23]. Smart cities incorporate investments in innovative technologies and services that involve energy, transport, and ICT sectors towards the delivery of more efficient services for its occupants [24], thus, fostering inclusive growth. Inclusive growth mean that citizens in such a system will be technologically empowered to promote sustainable goals. According to [25], over 68% of the global population live in the urban areas with concentration in Asia, Latin America and Africa with the fastest growing urban areas situated in Africa. In such case, the smart cities concept bears a lot of promise for the African continent which is mostly in need of sustainable development [26]. This will mean a massive technology uptake by cities to improve urban services as seen in the study of [27]. The study presented the case of the city of Windhoek in Namibia in its drive to become a smart city as it leverages on ICT developments supported by initiatives from ICT service providers, thus ensuring rapid technological advancement. In sum, digital technologies play key roles across the various sectors of an economy in ardent pursuit of sustainable smart cities. The state of healthcare can be improved as seen in a health tech firm in Nigeria where Artificial Intelligence (AI) is utilized for fast and remote medical diagnosis coupled with information on where to purchase drugs. In transportation, intelligent transport systems like advanced traveler and traffic management systems can predict congestion and proffer alternative route options to vehicles in real time, thus improving the efficiency of travel. People can equally receive information on the best time to leave their homes. Such a system can also provide information on traffic accidents and weather conditions which can allow people to plan for their journey [28]. Furthermore, ICT innovations in Africa exemplified by Worldspace, Eneza, and eGranary are recording giant strides in shaping the educational system more efficiently. Additionally, the use of ICT alongside Building Information

Modelling (BIM) presents a collaborative platform through which the public can participate with relevant stakeholders in real time for mass customized housing development [29]. While the sectors discussed are areas that any smart city initiative is meant to capture, it is pertinent to state efforts towards their actualization should be channeled towards sustainable energy efficiency as this is the key driver. Studies reveal that a low-carbon initiative is required for the actualization of low carbon cities, and this is a fundamental aspect of smart cities [30-32].

The discourse from literature has presented digital technologies and smart cities as novel approaches with immense potential towards the drive for efficient infrastructures and smart sustainable cities. Observably, although digital penetration in the built environment is relatively slow, there are huge prospects awaiting developing nations to exploit using mobile phones and the internet. From the foregoing perspectives, this study uses a systematic literature review approach to assess the role of digital technologies in infrastructural development and sustainable cities, and examines the benefits and challenges of digitalization in developing countries.

2. Methodology

The study fundamentally involved a systematic review of relevant literature from Google Scholar search engine and ScienceDirect databases. The choice of these sources was predicated on the fact that they offered a simplified advanced way of searching many sources of information such as academic and professional publications, conferences proceedings, online repositories, and other web sites. This method is similar to those employed in earlier studies where a systematic review of literature was conducted [33-36]. The search was restricted to peer reviewed journal articles and conference proceedings published between 2016 and 2020. The keywords used for the search were “digital technology”, “infrastructural development”, “sustainable cities”, “construction”, and “developing countries”. The result of the search is presented in Tables 1 and 2 below.

Table 1: Search results from ScienceDirect database using the specified keywords

Publication Type	2016	2017	2018	2019	2020
Conference Proceedings	12	21	5	16	23
Journal Article	16	23	16	45	43
Report	-	1	1	-	-
Generic	-	1	1	1	-
Total	28	46	23	62	66

Authors, (2021)

Table 2: Search results from Google Scholar using “Challenges of digitalization in developing countries”, “benefits of digitalization in developed countries” as keywords

Publication Type	2016	2017	2018	2019	2020
Conference Proceedings	15	20	11	18	16
Journal Article	22	14	24	28	35
Total	37	34	35	46	51

Authors, (2021)

The publications from the searches were further analyzed and sorted according to relevance and availability using the following criteria;

- Focused only on digitalization in the construction industry with the keyword “Challenges of digitalization in developing countries”, “benefits of digitalization in developed countries”, “Digital technology”, “Infrastructural development” “Sustainable cities”, “Construction Industry”, and “Developing countries”.
- Written in English language
- Published between January, 2016 and December, 2020.

- Excluded publications focused on 'digitalization of agricultural sector', 'smart manufacturing', 'digitalization in education', 'digital entrepreneurship', 'digital marketing', 'digital banking'.

3. Results

A total number of 428 publications made up of 225 from ScienceDirect and 203 from Google Scholar were retrieved. After the screening based on the specified criteria bothering on relevance and availability, one hundred and seventy-three (173) publications were selected from which 21 publications focusing on digitalization in the construction industry were extracted as presented in Table 3 below.

Table 3: Publications on digitalization in the construction industry

Source	Title	Document Type	Objective(s) of Study	Study's Methodology	Main Findings	Limitation of Study
Praharaj, *et al.* [37]	Innovative Civic Engagement and Digital Urban Infrastructure: Lessons from 100 Smart Cities Mission in India	Conference Proceedings	To explore the relationship between active civic engagement and the availability of basic digital infrastructure and socio-economic standards in Indian cities.	A mixed method design: Literature review, secondary data, and semi structured interviews.	This study provided insights on factors that lead to the success or failure of cities' online citizen engagement platforms.	The disparity in digital infrastructure between different socio-economic demographics is a challenge for cities in emerging economies.
Nasiri, Ukko, Saunila and Rantala [4]	Managing the digital supply chain: The role of smart technologies.	Journal Article	To examine how digital transformation of companies can fuel smart technologies, to improve relationship performance.	Questionnaire survey	Digital transformation of the companies alone cannot enhance relationship performance, it needs to be integrated with smart technologies to achieve this goal.	The use of cross-sectional data.
Wang and Moriarty [38]	Energy savings from Smart Cities: A critical analysis.	Conference Proceedings	Assessed the potentials for smart city policies to help make significant energy savings in urban transport and building construction and operation.	Literature review	Existing potentials will not be realised unless supporting policies are in place. There is need to overcome the challenges of data privacy, security and reliability.	Need for case studies /empirical data on the application of smart technologies for energy saving.
Mark and Anya [39]	Ethics of Using Smart City AI and Big Data: The Case of Four Large European Cities;	Journal Article	To provide fresh insights into the field of smart information systems (SIS) in urban European contexts and how developers are approaching the ethical implementation of such technologies.	Case studies, Interviews	The effects of using SIS within smart city projects have not yet materialised, because of their infancy.	Lack of empirical research done on smart cities, specifically analysing how they ethically use SIS technologies.

Source	Title	Document Type	Objective(s) of Study	Study's Methodology	Main Findings	Limitation of Study
Davila Delgado, *et al.* [40]	Robotics and automated systems in construction: Understanding industry-specific challenges for adoption	Journal Article	Investigation into the industry-specific factors that limit the adoption in the construction industry.	Literature review, and an online questionnaire were conducted.	Identified challenges were grouped into four categories and ranked in order of importance: contractor-side economic factors, client-side economic factors, technical and work-culture factors, and weak business case factors.	Focused only on robotics.
Shah, *et al.* [41]	A survey of smart city infrastructure via case study on New York	Conference Proceedings	Explored the technologies and projects implemented in New York City of the USA to make it a smart city.	Case study	Many technologies have already been implemented in New York City as an initiative to make it a smart city.	Limited to New York City.
Theofilatos, *et al.* [42]	Identifying infrastructure risk factors in Africa.	Conference Proceedings	An overview of the infrastructure risk factors in African countries.	Secondary data analysis	In-depth discussions on macroscopic (generic level) and microscopic (infrastructure element level) potential risk factors.	Unavailability of data
Kodongo and Ojah [43]	Does infrastructure really explain economic growth in Sub-Saharan Africa?	Journal Article	Examined the relationship between infrastructural development and economic growth	System Generalized method of moments (GMM)	Spending on infrastructure and increments in the access to infrastructure that influence economic growth and development in Sub-Saharan Africa	Silence on the adoption of digital technologies for infrastructural development
du Toit *et al*[34]	Urban green infrastructure and ecosystem services in sub-Saharan Africa	Journal Article	To consolidate research undertaken on urban green infrastructure and the associated ecosystem services in sub-Saharan African cities.	Systematic review	The most represented ecosystem services were regulating and provisioning, with supporting services getting the least attention.	Lack of in-depth studies on all ecosystem services.
Arimah [21]	Infrastructure as a Catalyst for the Prosperity of African Cities	Conference Proceedings	Investigated how the provision of infrastructure contributes to the prosperity of African cities.	Expert Opinion Survey from a diverse selection of cities.	High degree of water shortage characterizes majority of African cities, poor road infrastructure in African cities poses a major challenge to prosperity.	Absence of digital technologies to drive these infrastructural development.

Source	Title	Document Type	Objective(s) of Study	Study's Methodology	Main Findings	Limitation of Study
					Telecommunications is the most developed form of infrastructure in African cities.	
Adegun [44]	Developing Green Infrastructure in a Johannesburg Informal Settlement: Investigating Residents' Willingness to Pay	Conference Proceedings	This paper considered the development of green spaces in an informal settlement in Johannesburg, South Africa.	Questionnaire survey	It suggests preference for a user-pay model within this informal and low-income context.	-
Sovacool, *et al.* [45]	The decarbonisation divide: Contextualizing landscapes of low-carbon exploitation and toxicity in Africa	Journal Article	To document and humanize how communities cope with the negative impacts of decarbonisation, to reveal tensions and tradeoffs between global climate policy and local justice concerns, and to steer more informed local, national, and global sustainability action.	Triangulation approach; case study and interviews.	Revealed that the ongoing transitions to low-carbon societies are being underwritten by serious social and ecological injustices at opposite ends of the supply chain	Too conceptual
Kunkel and Matthess [46]	Digital transformation and environmental sustainability in industry: Putting expectations in Asian and African policies into perspective	Journal Article	Examined the potential linkages between structural change and digitalization, identified the drivers of structural change as well as the economic impacts of digitalization on these drivers.	Literature review	There is a lot of evidence that suggests linkages between digitalization and structural change, but not done in an explicit manner.	Conceptual in nature
Oke, *et al.* [47]	Drivers of sustainable construction practices in the Zambian construction industry.	Conference Proceedings	Assessed SC in Zambian Construction Industry (ZCI)	Questionnaire survey	An average level awareness but low implementation. Major drivers towards the adoption of SC practices include; legal requirement, building regulations, advocacy and	Not integrating digitalization with sustainable construction

Source	Title	Document Type	Objective(s) of Study	Study's Methodology	Main Findings	Limitation of Study
					awareness, developing regulatory mechanisms, and clients demand.	
Okereke, *et al.* [48]	Governing green industrialization in Africa: Assessing key parameters for a sustainable socio-technical transition in the context of Ethiopia.	Journal Article	Explored the conception and implementation of green industrialization in Ethiopia.	Used the socio-technical transition (STT) perspective framework for assessing sustainable transition programmes.	(i) An imperative for climate change mitigation and economic growth; (ii) strong government commitment to a greening agenda; and (iii) evolving innovation system.	Absence of digital technologies to drive green Industrialization.
Pardo-Bosch, *et al.* [49]	Key aspects of building retrofitting: Strategizing sustainable cities.	Journal Article	To capture the principal needs and challenges of building retrofitting replication and scale-up strategies	Business model tools for strategizing sustainable cities.	Municipalities need to develop business models to guide their transition from a traditional city to a sustainable one.	A business perspective
Ershova and Posokhov [50]	Comparative Analyze of Infrastructure in Developed Countries.	Journal Article	To understand and find the ways the infrastructure in the UK, Brazil and Russia will be developed in near future by analyzing the finished projects in last 10 years.	Comparative analysis and Literature review	Under the right conditions, market should grow to over $120 billion in five years.	Conceptual in nature
Colla and Santos [51]	Public safety decision-making in the context of smart and sustainable cities.	Conference Proceedings	To identify, within the context of smart and sustainable cities, how the strategic decision-making process in the area of public safety in a small Brazilian city.	Semi-structured interviews	There are limited resources in several aspects of the police departments for the effective management of their ICT infrastructures.	Public safety perspective
Jin and Fu [52]	The development experience and inspiration of urban energy system in developed countries.	Conference Proceedings	The study focused on analyzing comparatively the practice of supply, consumption, technology and mechanisms about energy system of the topical foreign cities.	Literature review and space–time series clustering	The key factors that influence the evolution of urban energy supply pattern include economic and social factors, resource endowment, policy system, and technology development	Integration of digital technologies in the provision of smart energy

Source	Title	Document Type	Objective(s) of Study	Study's Methodology	Main Findings	Limitation of Study
Maruf, *et al.* [53]	Adaptation for sustainable implementation of Smart Grid in developing countries like Bangladesh.	Journal Article	Highlighted the required adaptation of the potential prime features of Smart Grid technology to the context of Bangladesh.	Review	Bangladesh's renewable energy sources heavily depend on the solar sector which also needs to be diversified with wind energy and tidal energy	Conceptual approach.
Maskuriy, Selamat, Ali, Maresova and Krejcar [36]	Industry 4.0 for the Construction Industry—How Ready Is the Industry?	Journal Article	The study explored the state of Industry 4.0 in the construction Industry; identified its key areas; evaluated and interpreted the available evidence.	Systematic Review	This review demonstrates the lack of a complete understanding on what Industry 4.0 entails for the construction industry.	Lack of theory and a limited number of available studies.

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A compilation of 35 randomly selected papers from the authors' collection were analyzed based on the following co-occurred keywords; A - Sustainable construction/infrastructure of Smart cities; B - Digitalization/Digital Technologies; C - Zero Energy; D - Context of Developing Countries; and E - Context of Developed Countries. This is necessary because sustainable construction of smart cities is driven through the adoption of digital technologies, while the concept of sustainable construction and smart cities is incomplete without efficient design and practices to deliver buildings with minimal energy consumption. The idea of zero energy building is to drastically reduce the cost of emission of carbon and energy by minimizing the use of non-renewable energy [54]. There are few publications in Africa that captured the co-occurred keywords, however, scanty literatures were found in South Africa, Nigeria, Kenya, Ethiopia, Zambia, Botswana, and Ghana [47,48];[55]; [43]; [56]; and [57]. About 50% of the papers analyzed in this category as shown in Table 4 had at least 3 or more of the co-occurred keywords (A - E), while 46% and 40% respectively were in the context of developing (comprising some countries in Sub-Saharan Africa, and the Middle East) and developed countries.

Table 4: Cluster of co-occurred keywords of 35 targeted papers

Source	No. of Studies	A	B	C	D	E
[21,43,47,48,55,58,59]	7	√			√	
[38,49,60,61]	4	√	√	√		√
[37,39,62,63]	4	√	√			√
[64-66]	3	√	√		√	
[41,67,68]	3	√				√
[56,57]	2		√		√	
[53,69]	2		√	√	√	
[70,71]	2	√	√			
[54]	1	√		√		

[52]	1			√		√
[72]	1	√	√	√		
[45]	1	√		√	√	
[73]	1	√	√	√	√	
[74]	1	√		√		√
[40]	1		√			
[75]	1		√			√

Authors, (2021)

4. Discussion of findings

4.1 Challenges of digitalization in the construction industry

The major limitation of this study was the unavailability of sufficient data to give a generalized view on the adoption level of digital technologies for the provision of smart cities in African countries. This limitation according to [76] could be attributed to the region's low literacy level, income and technological penetration. In view of this, the study identified through literature the challenges facing the adoption of digital technologies in the construction industry which is applicable to most developing countries especially in Africa. These challenges were categorized into nine (9) major factors as shown in Table 5 below. Financial constraint, technological barrier, data security amongst several others were identified as major impediments in the adoption of digital technologies. Many developing countries are plagued with poor economy with huge debt profile, technological backwardness and lack of practical experience on digitalization by construction industry professionals amidst moderate level awareness [35,70,77-81]. Despite being a key success factor, awareness alone is not enough due to the complexity and high technological requirements of digitalization in the construction industry. Other limiting factors challenging the adoption of digital technologies in the construction industry are lack of qualified personnel [77,78,82], lack of government support [70,79], resistant to change [70,78], data management [35], and internet facility [84].

Table 5: Challenges facing the adoption of digital technologies

Drawbacks to the adoption of digital technologies	No. of Studies	Source
Financial constraint	7	[35,70,77-81]
Technological Barrier	4	[70,77,78,82]
Data Security	3	[33,78,83]
Lack of qualified personnel	3	[77,78,82]
Lack of Government Support	2	[70,79]
Resistant to change	2	[70,78]
Lack of awareness	1	[81]
Lack of data management	1	[35]
Internet facility	1	[84]

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4.2 The benefits and role of digitalization in the development of sustainable smart cities

The benefits of digitalization and its role in the development of sustainable smart cities is enormous. Many cities are becoming smart to improve the quality of life for their residents. In fact, smart cities allow the right balance between economic, social and environmental costs. Smart cities that represents a conceptual model of urban development [85] is based on human, collective, and technological capital exploitation. [86] describes a smart city "as a city with smart network infrastructure, and consists of smart citizens who live in smart homes (buildings), which are located in a smart environment under a smart security and safety system, that benefit from a smart education and smart healthcare system, and managed by a smart governance and administration system that makes smart policies, especially in a smart economy and smart finance". Thus, a major driver to achieving these is through digital transformation of the construction industry. Some of these practical benefits were identified from few active practices in some developed countries. For instance, [87] posits that the digitalization in building construction optimizes building elements such as walls and slabs for thermal insulation and structural capabilities. Similarly, [78] identified innovative technologies as answers to perennial problems of project performance with respect to completion on-time, within budget, and to customers' requirements. [88] in their study also categorized benefits of digitalization into stakeholder engagement, design support and review, construction support, operations management, and training as shown in Table 6. Cumulatively, this study identified 27 benefits from selected papers as shown in Table 6. According to a study by [89], the applicability of integrated BIM, IoT, and blockchain technology to design intelligent construction systems was elaborated.

Table 6: Benefits of Digitalization in the construction industry

Source	**Benefits of digitization in the construction industry**
Chowdhury, Adafin and Wilkinson [35]; Reynolds, Henderson and Roche [84]; Foresti, Rossi, Magnani, Guarino Lo Bianco and Delmonte [85]	Increase in collaboration; Integration; Monitoring; Safety; Cross reference of knowledge; Competitive advantage; Improve productivity; Increase IT security and data protection; Better risk management
Aghimien, *et al.* [90]; Salta, *et al.* [91]	Saves time; Increases Productivity; Increases speed of work
Ghaffarianhoseini, *et al.* [92]	Technical benefits; Knowledge Management; Diversity Management benefit; Standardization benefit; Integration benefits; Economic benefit
Kaufmann, *et al.* [93]	Reduced sourcing costs through optimized specifications; Quantities, and facilitated negotiations; Reduced security incidents; Facilitated risk awareness; Eased construction progress tracking
Davila Delgado, Oyedele, Demian and Beach [88]	Stakeholder engagement; Design support & review; Construction support; Operations management

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There is a marked evidence from secondary data obtained from relevant case studies on the roles digital technologies towards the development of sustainable infrastructure and smart cities around the world. It is noteworthy that the Authors could not find any substantial case studies in Africa, as study results presented in Table 7 were majorly from Europe. Methodologies, case study location, as well as main findings of 14 selected papers were presented. According to the study of [41], the role of digital technologies is evident in the transformation of New York city to a smart one, while the use of technologies have been adopted for disaster management in the smart city of Jakarta [94]. The study of [95] in Spain showed how technologies have improved mobility and living condition in major Spanish cities (Barcelona, Madrid, Valencia). The study of [68] on the smart cities of Porto and Ahmedabad proposed the use of digital technologies to reduce traffic congestion, promote green energy, and increase tourism to replicate the rapid development of cities such as New York, Singapore, Barcelona and many others. A similar study in Bogota, Colombia by [96] discussed how artificial intelligence (AI) was used to solve the issue of traffic congestion. Another study by [4] posits that smart technologies facilitate the relationship between digital transformation and relationship performance. In addition, earlier studies of [97,98] support the significant role digital technologies play in sustainable construction practices. The former opined that adequate IT infrastructures drive smart city development, while the latter asserts that mobile technology greatly impact on the sustainability of all industries. Similarly [80] supported previous authors that digital technologies is applicable in virtually all aspects of the construction industry, but practical application is still at formative stages when compared with other sectors. The study further reiterated the view of several scholars that digitalization is imperative in contemporary construction practices in achieving sustainable development.

Table 7: Case studies on the role of digitalization in the infrastructural development of sustainable cities

Source	Title	Document Type	Case study	Objectives	Methodology	Main Findings
Yu, *et al.* [99]	Slum Upgrading Programs and Disaster Resilience: A Case Study of an Indian 'Smart City'	Journal Article	India: Ahmedabad	To identify slum residents' current disaster management (DM) strategies, their perceived needs, and preferences for infrastructural upgrades.	Interview, focus group discussions, and case study	Some physical and non-physical infrastructure needs were not considered in traditional slum upgrading strategies. Hence, the need to reconsider Ahmedabad smart city development plan.
Shah, Kothari and Doshi [41]	A survey of smart city infrastructure via case study on New York	Conference Proceedings	USA: New York City	Explored the technologies and projects implemented in New York City to make it a smart city.	Case study	Many technologies have already been implemented in New York City as an initiative to make it a smart city
Heller, Liu and Gianniou [97]	Enhancing Urban Resilience through Technology and Social Media: Case Study of Urban Jakarta	Conference Proceedings	Indonesia: Urban Jakarta Smart City	To analyze the progress and impact of technology in disaster management	Interview, Secondary data, and field assessment	The use of technology and social media to improve disaster management through effective planning, response and decision making.
Aletà, Alonso and Ruiz [95]	Smart Mobility and Smart Environment in the Spanish cities	Conference Proceedings	Spain: A case of 62 cities	To show dynamically and graphically the scope of development of Spanish Smart City initiatives in terms of mobility and environmental issues.	The holistic concept of Smart Cities was adopted	Spanish smart cities are characterized by mobility and quality-of-life factors. However, environment results require improvement.

Source	Title	Document Type	Case study	Objectives	Methodology	Main Findings
Girardi and Temporelli [100]	Smartainability: A Methodology for Assessing the Sustainability of the Smart City	Conference Proceedings	Italy. Expo Milano 2015 site	To evaluate to what extent the smart cities' development pursues sustainable development goals.	Smartainability approach of estimation	The implementation on the Expo Milano 2015 site demonstrates that Smartainability methodology is able to give decision makers useful information on benefits generated by smart solutions deployment.
Praharaj, Han and Hawken [37]	Innovative Civic Engagement and Digital Urban Infrastructure: Lessons from 100 Smart Cities Mission in India	Conference Proceedings	India: 100 smart Cities Mission	Explored the relationship between active civic engagement and the availability of basic digital infrastructure and socio-economic standards in Indian cities	The case study analysis from smart city initiatives in the form of 'Talk London' and 'My Ideal City Bogota'	Engaging people in online platforms for civic deliberations is not simply a matter of digital infrastructure, but is influenced by a complex set of socio-economic and political variables.
Walnum, Hauge, Lindberg, Mysen, Nielsen and Sørnes [61]	Developing a scenario calculator for smart energy communities in Norway: Identifying gaps between vision and practice	Journal Article	Norway: Furuset in Oslo	Presents a scenario calculator designed to link detailed measures with overall climate goals	Scenario calculator using Key performance indicators, Demonstration, and Interviews	The tool is relatively detailed, as it enables input on energy use, energy technologies and energy carriers down to the level of the individual building.
Heller, Liu and Gianniou [97]	A Science Cloud for Smart Cities Research	Conference Proceedings	Denmark: Sønderborg	Presents the solution to flexible infrastructure based on open source technologies, and its application in a city and building research.	Visualization tools, Case application	Smart City research involves huge amounts of data from various sources, and the availability of powerful IT infrastructures that can handle this complexity and volume of data is vital.
Girardi and Temporelli [101]	Industry 4.0 technologies assessment: A sustainability perspective	Journal Article	World Economic Forum, 2018	Examined Industry 4.0 technologies in terms of application and sustainability implications.	Developed a hybrid multi-situation decision method integrating hesitant fuzzy set, cumulative prospect theory and VIKOR, sensitivity analysis.	The results showed that mobile technology has the greatest impact on sustainability in all industries.

Source	Title	Document Type	Case study	Objectives	Methodology	Main Findings
Thellufsen *et al* [74]	Smart energy cities in a 100% renewable energy context	Journal Article	Denmark: municipality of Aalborg	Presents a methodology to design Smart Energy Cities within the context of 100% renewable energy at a national level.	Guiding principle that; local action should be balanced to match national or global action.	A Smart Energy System vision for Aalborg to become 100% renewable in 2050 was designed in such a way to fit into a common best solution in Denmark.
Mark and Anya [39]	Ethics of Using Smart City AI and Big Data: The Case of Four Large European Cities	Journal Article	European cities: Amsterdam, Helsinki, Copenhagen, and Hamburg	To provide fresh insights into the field of smart information systems (SIS) in urban European contexts	Case studies, Interviews	The effects of using SIS within smart city projects have not yet materialised, because of their infancy.
Nasiri, Ukko, Saunila and Rantala [4]	Managing the digital supply chain: The role of smart technologies	Journal Article	Finland: SMEs	To examine how digital transformation of companies can fuel smart technologies, to improve relationship performance.	Questionnaire survey	The study affirms that smart technologies stimulate the growth in relationship performance.
Solaimani and Sedighi [102]	Toward a holistic view on lean sustainable construction: A literature review	Journal Article	NA	Provided a comprehensive understanding of "how Lean helps achieve and maintain sustainability in construction sector"	Systematic Literature Review	The current body of knowledge of sustainable construction is skewed toward economic values.
Alaloul, Liew, Amila, Zawawi and Mohammed [80]	Industry Revolution IR 4.0: Future Opportunities and Challenges in Construction Industry	Journal Article	NA	Presented a general idea of Industrial Revolution (IR) 4.0 in Construction Industry development	Review	Digitization affects all practices, but practical applications are still in infancy stage. IR 4.0 concepts should be integrated with construction production, novel expertise must be applied to the intellectual engineering of modern construction, enhance the level of incorporation to achieve the sustainable development.

Authors, (2021)

In view of the expositions obtained from numerous case studies and extensive scholarly reviews from literature, the Authors assessed the role of digitalization in the development of smart cities and sustainable construction practices. Majority of the study's findings are traceable to Europe, and a few North American and Asian countries. However, lessons learnt from these could be adopted in developing countries to up-skill the construction industry for sustainable environment, economic, and social development of the region, considering the massive infrastructural deficit, natural resource depletion, and unprecedented level of environmental degradation. Infrastructure is essential for the growth, development and functioning of cities to achieve economic improvement and higher livability standards. Infrastructures such as road networks, power and communication facilities improve urbanity, which is crucial for economic emancipation and social development. [103]'s study on ECOWAS countries observed how these infrastructural deficits had affected the agricultural sector resultant from inadequate access to water, absence of storage facilities, insufficient health services, and a bad transportation system [104]. Thus, through effective implementation of digitalization, we will be striving towards achieving Sustainable Development Goal (SDG) 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and communities) to keep up with the global trend. Although some developing African countries are currently in the process of digital transformation of certain economic sectors -manufacturing, production, IT, aviation, banking, etc. Unfortunately, the construction sector is not fully imbued. The latter is partly due to the unique and complex nature of the sector, coupled with several other challenges identified in this study. Nonetheless, it is important to note that the construction industry makes and a key economic player of most nations, hence the growing emphasis for the sectors' full digitalization of operations in her quest for infrastructural development, sustainable construction practices, and provision of smart cities.

5. Conclusion

Harnessing the potentials of emerging digital technologies in the construction sector is imperative considering the salutary effects and the advantages it confers to other economic sectors that have long embraced this revolutionary trend, for example- manufacturing, production, IT, aviation, and banking. This paper primarily sought to investigate the role digitalization (digital technologies) plays in the infrastructural development of sustainable smart cities. Robust studies involving extensive literature reviews and case studies gave insight on the adoption level, benefits and challenges of digitalization in construction sector of developing countries. The systematic literature review (SLR) approach on related studies across the globe revealed some existing smart city initiatives in the European region driven by emerging digital technologies. Critical result findings show that digital transformation of smart cities led generally to improved living condition, efficiency, sustainability, and promotion of green energy. The studies also revealed that the adoption of smart technology improved waste management, air quality, water management, park management, smart public transportation, and city lighting. Regrettably, studies showed low application of digital technology in construction practices in Africa, with South Africa having just a few. Study results show that the low-level deployment of digital technologies in most countries of the African continent was as a result of bad governance and political instability, poor economic performance, and social insecurity. The study categorized the major challenges of adopting digital technology in the construction industry as financial constraint, technological barrier, data security, lack of qualified personnel, lack of government support, resistant to change, lack of awareness, and poor internet facility. Of note, the studies showed that the application of some digital technologies have not fully materialized in the construction industry as many are at conceptual stages of development with few practical applications.

The study recommends that government substantially fund innovative technologies and fix the challenges that militate against their development and application, by strengthening their economies, good governance, political stability, priority to security of lives, properties, and general livability standards. The study further recommends improved awareness and technical know-how of construction personnel, creation of smart home ownership incentives, and the development of policy and institutional frameworks that will engender the construction of smart homes in the sub-region.

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