Hindrances to the adoption of green walls: a hybrid fuzzy-based approach

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Abstract: Green walls – comprising living walls and green facades – are being widely touted as environmentally friendly products in architectural design. Green walls can be viable in every aspect of sustainability; they benefit building occupants in various ways – economic, social and environmental advantages. Despite this, the adoption rate is still in its infancy. And research on barriers that inhibit their wider adoption is scarce. To address this gap, this paper aims to identify and assess the relative importance of hindrances to green wall adoption in Hong Kong. To this end, fuzzy Delphi method (FDM), and Fuzzy Parsimonious Analytic Hierarchy Process (FPAHP) are used in ranking the identified hindrances. Findings provide a list of ranking for the identified barriers; financial barriers and difficulties in installation and maintenance turn out to be the most critical hindrances to green wall adoption. This paper offers illuminating insight into the challenges of green wall adoption for researchers. In practical terms, findings provide lessons for clients, designers and all key stakeholders of building projects. Discussions raise awareness of policy makers too, especially to reconsider the financial incentives for green wall installers. These all would facilitate wider adoption of green walls in the building industry.

Keywords: Sustainability; green building; design; MCDM methods

1. Introduction

Green Walls (GWs), colloquially known as vegetated walls, are considered a passive design solution and an element of green infrastructure (Liberalesso *et al.*, 2020). They positively contribute to all aspects of sustainability: water management, reducing urban heat island effect, improving air quality, aesthetic

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value, energy saving, and providing biodiversity among other things (Radić, Dodig and Auer, 2019; Prodanovic *et al.*, 2020). The benefits of GWs in each aspect varies and depends on some factors like climate, type of vegetation used, and maintenance style. That said, there is no deterministic value for the benefits of GWs (Mahdiyar *et al.*, 2016). For instance, it has been reported that GWs are capable of energy saving between 33% and 60% (Shen, Zhang and Long, 2017), while the additional required costs for installation and maintenance varies. In terms of sustainability aspects, GWs have high potential to be installed in a large scale building – new or retrofitted (Castiglia Feitosa and Wilkinson, 2020).

Despite the above facts, GWs' potential in all aspects of sustainability have been overlooked by designers, due to some hindrances to their adoption. A review of the literature shows that very few studies, if any, are conducted on analysing the hindrances to GW adoption. Systematic attempts to identify hinderances and assess their relative importance are non-existent. To address the gap, this paper is aimed at investigating these barriers and analysing their relative importance in Hong Kong. Hong Kong is selected as the context of the study in view of its proven record in adopting GWs; its favourable climate, and its concentrated high-rise environment (Mohandes, Zhang and Mahdiyar, 2019).

2. Background

Green Walls (GWs) are defined as vertical greening systems that cover walls of buildings for sustainable purposes. These are classified into two major systems, green facades and living walls (Manso and Castro-Gomes, 2015; Medl, Stangl and Florineth, 2017). Traditional green facades are categorised as direct green facades, while indirect green facades consist of continuous guides and modular trellis. Continuous guides are based on a single support structure that leads plants' direction along the entire surface, while green facades with modular trellises comprise several modular elements (vessels for plants rooting) and an individual support structure along the surface (Laurenz *et al.*, 2005).

Living walls are the modern type of GWs for integrating green surfaces in high-rise buildings. Rapid growth, uniform coverage of large vertical surfaces and the possibility of using various plant species are the main advantages of living walls (Manso and Castro-Gomes, 2015). Based on application methods, living walls are categorised into continuous and modular. In continuous living walls, which are also known as vertical gardens, plants are inserted in permeable and lightweight screens (Bribach, 2011). However, modular living walls consist of elements with specific dimensions and an intermediate layer for plant growth. Each element of modular living wall – trays, vessels, planter tiles or flexible bags – is either directly or indirectly fixed to the vertical surface (Dunnett and Kingsbury, 2008).

Like green buildings and other green-based elements used in buildings (such as green roof), the adoption of GWs is affected by some hindrances. Of these, one of the most crucial hindrances to the adoption of GWs are unanimously believed to be their high installation costs (Perini *et al.*, 2011). Installed GWs need to be irrigated and pruned regularly, hence cost of maintenance is another major hindrance to their wider adoption, as argued by Riley (2017). Overconsumption of drinkable water represents another barrier to the adoption of green facades; however this problem is eased off, thanks to the use of new technology (Terblanche, 2019). A review run on previous studies on the hindrances to the adoption of GWs. A list of major barriers identified and culled from previous studies in the field is illustrated in Table 1.

Table 1. Summary of identified hindrances in previous studies

ID	Hindrance	Reference(s)
H1	Climate adaptability	(Hopkins and Goodwin, 2011)
H2	High environmental burden of some materials	(Ottelé *et al.*, 2011)
H3	High maintenance cost	(Riley, 2017)
H4	High installation cost	(Perini *et al.*, 2011)
H5	Sophisticated implementation	(Perez *et al.*, 2011)
H6	High water and nutrients consumption	(Terblanche, 2019)
H7	Uncertainty in accepting a new technology	(Duda, 2009)
H8	Lack of policy and standards (such as design-related standards)	(Duda, 2009)
H9	Lack of published costs stipulated in guidelines	(Terblanche, 2019)
H10	Insufficient lighting for the plants	(Smith *et al.*, 2010)
H11	Possible damages to the back wall	(Manso and Castro-Gomes, 2015)
H12	Paucity of technical tools (for conducting required simulation)	(Ascione *et al.*, 2020)
H13	Necessity of involving qualified designers	(Ascione *et al.*, 2020)
H14	Inducement to fire	(Manso and Castro-Gomes, 2015)
H15	Vulnerability to fungus, insects, etc.	(Fleck *et al.*, 2020)
H16	No/limited incentives provided by governments	(Liberalesso *et al.*, 2020)
H17	Difficulty of maintenance	(Kontoleon and Eumorfopoulou, 2010), (Perez *et al.*, 2011)

As inferred from the list of hindrances in Table 1, research on the topic comprises a collection of very few studies allocated to the topic. Besides, existing studies are scattered and comprise a collection of piecemeal papers and publications. There is an obvious dearth of research; studies that comprehensively identify and accordingly analyse existing hindrances are non-existent. As such, conducting further research on this fecund, yet overlooked area is justified. In practical terms, such research will facilitate and pave the way for further adoption of such green-based features in the building industry and can raise awareness among key stakeholders and policy makers alike.

3. Research methods

Fuzzy Delphi method (FDM) is used to identify and refine the hindrances to the adoption of GW, and fuzzy parsimonious analytic hierarchy process (FPAHP) is developed to calculate relative importance weights, as well as prioritise the identified hindrances. Judgement sampling is used for both methods, where twenty-one and seven experts are involved in FDM and FPAHP respectively, as suggested by Mahdiyar et al.,(2020). Purpose sampling is used for data collection following the lessons by Mohandes et al. (2020), who recommended the criteria for the pool of experts: five years of related experience in construction engineering and management, and at least a related undergraduate degree.

3.1 Fuzzy Delphi Method

Fuzzy Delphi method is an effective method for the aims and objectives of this paper, namely, identifying and prioritising the barriers to GW adoption (Mohandes and Zhang, 2019; Mahdiyar *et al.*, 2020; Zhang and Mohandes, 2020). This method entails three steps: 1) determination of barriers through synthesising the findings of previous studies; 2) designing the questionnaire survey and administering it among experts; and 3) analysing the relative importance of barriers.

The outcome of step 1 is shown in Table 1 – a pool of barriers culled from the literature. In step 2, a questionnaire survey is developed based on the identified barriers, using a five-point Likert scale (see Table 2).

Table 2. FDM scale and linguistic

Level of Significance	Description	TFN
1	very low significant	$(1, 1, \frac{3}{2})$
2	Low significant	$(\frac{3}{2}, 2, \frac{5}{2})$
3	moderately significant	$(\frac{5}{2}, 3, \frac{7}{2})$
4	significant	$(\frac{7}{2}, 4, \frac{9}{2})$
5	very significant	$(\frac{9}{2}, 5, 5)$

This survey was then distributed among twenty-one qualified experts in Hong Kong, who met the specified requirements. Triangular fuzzy numbers (TFNs) are used to fuzzify the experts' point of view, which are in the form of crisp values, as indicated in Table 3. Table 3 illustrates a summary of experts' profile involved in the study.

Table 3. Experts' profile information

NO	Role	Degree	NO of projects	Experience
1	Designer	Master's in architecture	2	Within 5 and 10 years
2	Facility manager	Master's in construction management	4	Within 5 and 10 years
3	Designer	Master's in architecture	4	Within 10 and 15 years
4	Facility manager	Bachelor's in civil engineering	4	Within 10 and 15 years
5	Project manager	Master's in construction management	2	Within 5 and 10 years
6	Contractor	Bachelor's in architecture	6	Within 10 and 15 years
7	Designer	Master's in architecture	4	Within 10 and 15 years
8	Designer	Master's in architecture	2	Within 5 and 10 years
9	Contractor	Bachelor's in civil engineering	3	Within 5 and 10 years
10	Project manager	Master's in construction management	2	Within 5 and 10 years
11	Contractor	Bachelor's in architecture	3	Within 5 and 10 years
12	Contractor	Bachelor's in civil engineering	3	Within 5 and 10 years
13	Designer	Master's in architecture	3	Within 5 and 10 years
14	Project manager	Master's in construction management	2	Within 5 and 10 years
15	Facility manager	Bachelor's in civil engineering	4	Within 10 and 15 years
16	Designer	Bachelor's in architecture	4	Within 10 and 15 years
17	Contractor	Master's in construction management	4	Within 10 and 15 years
18	Project manager	Bachelor's in civil engineering	5	Within 10 and 15 years
19	Designer	Bachelor's in architecture	2	Within 5 and 10 years
20	Contractor	Bachelor's in civil engineering	3	Within 5 and 10 years
21	Designer	Master's in architecture	2	Within 5 and 10 years

After fuzzifying the responses, *n* experts' points of view concerning *z* barriers of GW in Hong Kong are aggregated, using Eqs. 1 and 2. As all responses from experts are fuzzified, the aggregation of *n* experts' responses for z barriers are TFN.

$$F_j(b) = (p_j, q_j, r_j), j = 1, 2, \dots, n \quad (1)$$

$$AG\ (b)\ =\ (p_A, q_A, r_A)\ =\ (min\ p_j\ , GM\ q_j, max\ r_j), j\ = 1, 2, \dots , n \tag{2}$$

in which $F_j(b)$ stands for the expert j point of view regarding barrier b in the form of TFN. Additionally, the aggregated experts' points of view regarding barrier b or AG (b) is shown in Eq. 2, where *GM* is the abbreviation of Geometric Mean in Eq. 2. To attain crisp value as each barrier significance, aggregated responses of experts are defuzzified based on Eq. 3. According to Eq. 4, a threshold is determined for identifying important barriers (Bouzon *et al.*, 2016).

$$DF_{AG\,(b)}\ =\ (p_A\ +\ 4 \times q_{AG}\, , r_{AG})/6 \tag{3}$$

$$TH = \frac{\sum_{b=1}^{z} DF_{AG(b)}}{z} \tag{4}$$

where, $DF_{AG\,(b)}$ stands for the defuzzification of aggregated responses for barrier b. TH denotes the defined threshold, hence barrier b is considered as an important one when $D_{A\,(a)} \geq T$, otherwise it should be eliminated.

3.2 Fuzzy Parsimonious Analytic Hierarchy Process

Analytic Hierarchy Process, has been used as one of the most common techniques of decision making in construction research (Jato-espino *et al.*, 2014). This method is capable of converting intangible variables/factors into quantitative values for further analysis. It however suffers from several weaknesses like vague judgements, and difficulties in pairwise comparison, especially when several criteria/factors are involved (Mahdiyar *et al.*, 2019). Considering the aims and objectives of the present study, fuzzy parsimonious analytic hierarchy process (FPAHP), as a new hybrid method is used to calculate the importance of barriers to GW installation with fewer required number of pairwise comparison and achieving accurate results using fuzzy numbers.

In the first step of FPAHP, experts are asked to rate the importance of barriers to GW installation in Hong Kong, which is called initial rates (IR). The scale of ranking is similar to conventional AHP scale (from one to nine representing the lowest and highest importance), to make it consistent with the following steps and easier to follow by the experts. As shown in Table 4, TNFs are used to fuzzify the AHP crisp values to improve the accuracy of results (Mohandes and Zhang, 2019; Mahdiyar *et al.*, 2020). In the second step, the required numbers reference evaluation barriers (r) are selected based on the guideline provided by Abastante et al. (2019). In the third step, a conventional fuzzy AHP process is conducted to obtain the weights of reference evaluation barriers. Following the studies conducted by Mahdiyar et al. (2019), once the pairwise matrix is generated using AHP scale, the consistency of responses must be checked before proceeding to fuzzify the numbers.

Table 4: FAHP scale used to evaluate the importance of barriers (Keprate and Ratnayake, 2016)

Intensity of importance	Fuzzy (a, b, c)	Reciprocal Fuzzy (a, b, c)
1	$(\frac{1}{2}, 1, 3)$	$(\frac{1}{2}, 1, 3)$
3	(1, 3, 5)	$(\frac{1}{5}, \frac{1}{3}, 1)$
5	(3, 5, 7)	$(\frac{1}{7}, \frac{1}{5}, \frac{1}{3})$
7	(5, 7, 9)	$(\frac{1}{9}, \frac{1}{7}, \frac{1}{5})$
9	(7,9,9)	$(\frac{1}{9}, \frac{1}{9}, \frac{1}{7})$

Once the consistency of the responses is confirmed, the weights of reference barriers are calculated and following the parsimonious AHP concept (as presented by Abastante et al. (2019)), the weights of barriers are calculated.

4. Result and discussion

Based on the results of FDM, H1, H6, H9, and H12 (see Table 1 and Figure 1) were perceived as non-significant hindrances to the implementation of GWs. As for H6, due to a great deal of raining in Hong Kong, the need for irrigation of the GWs installed on buildings facades is negligible, where Hong Kong climate is not a barrier for GW adoption. When it comes to the lack of published data on costs associated with GW, it is believed that firms involved in the field have all the detailed expenses of installation, they also can provide information to clients on the expenses during maintenance and operation phase. As a result, a majority of experts are of the opinion that H9 is not a significant barrier in Hong Kong, as illustrated in Figure 1. Likewise, there are many simulation tools for analysing GW installation like energy and building, TRANSYS, among others. These tools are freely available for interested researchers, institutions, companies, and government bodies in Hong Kong; hence, H12 was unanimously perceived to be a less significant hindrance in Hong Kong.

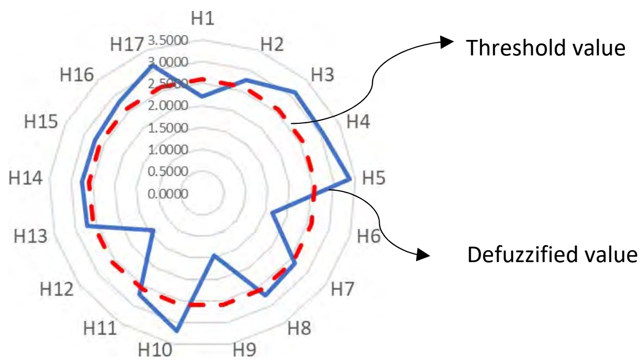

Fig. 1. FDM results

According to the results of FDM, thirteen barriers are perceived as important, as illustrated in Table 5. As discussed, parsimonious concept is used for pairwise comparison, hence, instead of thirteen comparing hindrances pair wisely, only four hindrances must be compared. As a result, the required number of pairwise comparison has been reduced significantly at approximately 87% (from ($\frac{13\times12}{2}=78$) to ($\frac{5\times4}{2}=10$)). During the first step of FPAHP, experts were asked to rate the barriers based on their experience. Four hindrances (i.e. H3, H8, H17, H7) were selected as the reference points. In reference selection, a wide range of priority is considered to increase the consistency of results. Then, the experts were asked to conduct pairwise comparison between these four hindrances and the weights and ranks of all hindrances were calculated (see Table 5).

Table 5. Weights of hindrances to GW installation

Hindrances	Weights	Ranks
H3	0.17	1
H4	0.14	2
H17	0.13	3
H5	0.11	4
H14	0.10	5
H10	0.09	6
H7	0.06	7
H16	0.06	7
H2	0.05	8
H11	0.04	9
H8	0.02	10
H15	0.02	10
H13	0.01	11

As illustrated in Table 5, the most important barriers to GW installation are financial aspects (H3 and H4) followed by difficulties in installation and maintenance (H5 and H17). These results are consistent with previous studies conducted on GW and green roof installation, though any additional cost can be potentially offset by the financial benefits of their adoption (Rosasco and Perini, 2018). Besides, the net present value and payback period are fraught with uncertainties, which result in the lack of adoption of GWs by clients and developers. In terms of difficulties in installation and maintenance, various types of GWs have different characteristics and requirements; special expertise is required for the installation. Moreover, due to the long lifespan of GWs, regular maintenance is required, which has been considered as an additional task during the whole lifespan. The performance of GWs depends on the health and quality of plants and its structure. These further highlight the significance of regular maintenance.

The next important barrier is H14 as plants are vulnerable to cause fire. As a result, installing GWs for buildings exposes buildings to extra safety and financial risks. In terms of required lighting for GWs, and given that Hong Kong is home to many skyscrapers and high-rise buildings, many locations might lack the required adequate level of natural lighting, especially in central business districts. That said, various types of plants need different levels of lighting, therefore, H10 can be overcome if the GW is designed with suitable plants.

When it comes to the adoption of sustainable methodologies, governments tend to provide financial incentives through tax abatements or by partially covering any additional costs of installation. Though GW installation facilitates achieving green building certificates with financial gains for clients/developers, GW installers are not eligible for financial incentives where green building certificate is not achieved (Liberalesso *et al.*, 2020). As a result, it can be considered as a hindrance to GW adoption. In is notable to mention GWs might have some adverse impact to the environment when plastic is used in the vessels to accommodate the plants. These plastics have adverse impact on the environment if landfilled after the GWs lifespan, similar to the case of green roofs as investigated by Peri eta al. (2012)). Given that all types of GWs plastics do not require plastics, H2 is considered as an important hindrance.

According to Table 5, there are some other barriers, ranked as the least important ones: H11, H15, H8, H13. The damage might happen to the back wall due to waterproofing flaws and the moisture retention. Moreover, roots and branches might be the source of damage while the wall is vulnerable to fungus and insects. These damages are however almost entirely preventable if the GW is regularly maintained, therefore, their lower importance compared to other barriers is justified. The expertise needed for the designers to consider GW in their designs has been perceived as the least significant hindrance, mostly due to the availability of sources and guidelines in the market.

5. Conclusion

Although a few studies have touched on the topic of barriers to the adoption of GWs, the study presented here is the first systematic effort in identifying the barriers to widespread adoption of GWs in Hong Kong, based on empirical data. Original views, new insights and trends emerged as the outcome of this study, encapsulated in the form of a list of barriers that thwart efforts towards wider uptake of GWs, as the first empirically validated list in its kind. Examination of the list reveals that while most of the major barriers are presented in previous studies, some act as the root causes for a lack of intention to adopt GWs. They must be given top priority, that is, they nurture a wide range of barriers and addressing them can enable project stakeholders to eliminate the underlying reasoning behind the lack of interest in GWs. The clear message is about proposing a way forward that will address the issues of installation, maintenance and costs uncertainties, relying on technological innovations to revolutionise the current practices of installing and maintaining GWs, as a result of which people will be more willing to use them in their buildings. The practical implication is that building researchers and professionals are called to allocate resources to improve GWs installation and maintenance practices and methods to eliminate the underlying causes of key stakeholders' unwillingness to use them. This involves giving priority to addressing these with better technology.

Despite the contributions, findings of the study must be viewed considering several limitations that affect the findings. Chief among all is that direct application of findings in countries other than Hong Kong must be treated with caution. Besides, findings are based on the perception of experts in the field, rather than analysis of performance measures or quantitative assessment of using GWs outcomes and various factors. This however provides the field with fertile grounds for future research. Future studies can assess the applicability of findings in other countries and contexts, propose solutions for addressing the identified barriers and their root causes and define methods to assess the performance of GWs based on hard data and quantitative methods.

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