LIFE-CYCLE COSTING: INSIGHTS, OVERSIGHTS, FORESIGHTS

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Abstract:

The potential benefits of performing Life Cycle Costing (LCC) are well documented in the extant literature. However, there are many practical and methodological challenges that limit their reliability and adoption for building project evaluation. The aim of this paper is to present the state-of-the-art of LCC in buildings and to map-out the methodological and practical challenges in LCC approach. The paper details a critical analysis of the modelling approaches, building-types and data sources used in the LCC modelling.

Our study argues that existing LCC modelling techniques are generally static and are not flexible enough to incorporate decisions taken over the life of the buildings. The impact of disruptive technologies like Big Data, BIM and virtual prototyping, hold a real potential to enhance the accuracy of LCC methods and enhance their usefulness over the lives of building assets.

Specifically, we observe that LCC is a complex subject. It thrives on the assumption of hypothetical variables and drives decisions that affect an unknown or unknowable future. This paper, therefore, seeks to provoke a critical discourse and rethink of existing methodological approaches to LCC in an attempt to develop approaches that might be better at capturing the data required in LCC of buildings. In addition, we advocate for Big Data as a frontier to improve the processing, visualisation and synthesis of data in LCC modelling. In conclusion, we articulate the insights, oversights and foresights that underpin life-cycle costing in buildings.

Keywords: Building Appraisal, Life-cycle costing (LCC), Modelling, Uncertainties, Big Data

INTRODUCTION

Buildings are inanimate - they embody a crucial part of human advancement and ambition. Buildings are somewhat imperishable; their lives could be indefinite (Ashworth, 1996). Buildings are in principle, a cluster of many parts consisting of systems, materials, components, and affected by the external space they occupy. Buildings have embedded costs, often conferred by location, perception and design. In building projects, life-cycle consideration could largely focus on building spaces, as places where human interactions occur while ignoring its economic and social context, thus simplifying the variables in life cycle costing. In this paradigm, the regular 'clock-time' period of interactions in these buildings becomes crucial. Schools, for instance, differ from hospitals, homes or leisure centres. This school-of-thought is noticeable in the works of Salway (1986), Ashworth (1996) and Hoar and Norman (1990) amongst others. The characteristic of such inclusion largely relates to the magnitude of operational and maintenance cost variables, staff or occupant cost, and also disposal costs (Cole & Sterner, 2000; J. R. Evans & Olson, 2001; Hughes, Ancell, Gruneberg, & Hirst, 2004).

The need for buildings to be costed and valued is the basis of the quantity-surveying profession *vis-a-vis* cost engineering (Rawlinson, 2017). However, the principles of building appraisal especially when considered on a life-cycle basis leaves much to be desired. The conception of life-cycle costing (LCC) as a definitive science has been richly ingrained in the psyche of estimators and building practitioners.

There is, however, evidence that the science is poorly understood (Gluch & Baumann, 2004). The roots of life-cycle costing (LCC) in buildings can be traced to Flanagan and Norman (1983) in a research sponsored by the Royal Institution of Chartered Surveyors (RICS) in the UK. Since then, its principles have hung on the tapestry of building appraisal science, and yet there have been asymmetries in matching its intent and purpose, to the objective realities of buildings.

Life-cycle costing (LCC) is a complex subject - it thrives on the assumption of hypothetical variables, and drives decisions that affect an unknown or unknowable future. In many public sector building projects, LCC has become a pre-requisite in many tender pre-qualification processes (Boussabaine & Kirkham, 2008; Davis-Langdon-Management-Consulting, 2007), yet its results are rather questionable, and the context is mostly missing (Zuo et al., 2017). Notwithstanding, LCC has been found beneficial in providing a more comprehensive perspective on building costs (Goh & Sun, 2016). In addition, LCC helps in selecting the most effective choice amongst a spectrum of competing building designs (Mohammed Kishk, 2005). Zuo et al., (2017) summarised the challenges of LCC as:

i. A dominant lack of understanding regarding its purpose and intent
ii. Inability to establish its scope and context
iii. Difficulty in identifying and obtaining relevant and reliable data
iv. Limitations in the methodological tools and techniques

The aim of this paper is to present the state-of-the-art of life-cycle costing (LCC) in buildings by critically examining the extant literature to map-out the methodological, theoretical and practical challenges in LCC approaches. The intention is to provoke critical discourse and a rethink of existing methodological approaches to life-cycle costing in an attempt to develop approaches that might be better at capturing the uncertainties and complexities in LCC of buildings. The rest of the paper is structured as follows: a background on LCC is provided; insights regarding the methodological advances in LCC are stated, oversights pertaining to the existing methods and then foresights accomplished through Big data is articulated.

LIFE CYCLE COSTING

Industry awareness on the principles of Life Cycle Costing (LCC) dates back to the 1950's, when the Building Research Establishment (BRE), UK sponsored a research on the "costs-in-use" of buildings (Mohammed Kishk et al., 2003a). Afterwards, professional bodies such as the Royal Institute of Chartered Surveyors (RICS) started taking more interest as demonstrated in the work, published by Flanagan and Norman (1983), through a funded research, by the RICS Education Trust. Since then, there has been a progression of studies on the subject of LCC.

The BSI - ISO:15686-5 (2008), is the first international standard for property life cycle costing, and defines LCC as a "methodology for the systematic economic evaluation of life cycle costs over a period of analysis, as defined in the agreed scope". LCC is a cascade of costs across the continuum of a building's expected life. The principal phases in the life-cycle cost assessment of a building are the construction and operational phase. In recent times, phases such as refurbishment, disposal and maintenance constitute valid consideration in LCC calculations (Aye, Bamford, Charters, & Robinson, 2000). The refurbishment, disposal and maintenance periods, however, tend to be much shorter and their cost impacts on buildings are more difficult to ascertain.

LCC is often used by clients and building owners in establishing whether a higher capital cost is justified based on the potential reduction in future costs and helps in assessing the cost-effectiveness amongst a host of competing alternatives. Aye et al. (2000) utilised LCC in comparing four options in a commercial building – renovate existing property, buy another property and renovate, buy land and build or do nothing. Neroutsou and Croxford (2016) also conducted LCC using a residential building undergoing retrofitting, based on a range of insulation and energy-efficient measures. The major issues with LCC based on both studies i.e. Aye et al. (2000); Neroutsou and Croxford (2016), are the risk and uncertainty pertaining to data, scope changes in building design, the reliability of cost data and lack of information about future decisions. These issues bother on the quality of data and the integrity of methods uses in life cycle costing assessment.

Data-requirements in Life Cycle Costing

Life-cycle costing (LCC) is a data-intensive process. Three main sources of data in life-cycle costing include historical records, manufacturers and supplier's specifications, and predictive models (Roger Flanagan, Norman, & Meadows, 1989). Historical data are obtainable from existing buildings but these tend to be contextually embedded and may not be readily transferable to other contexts (Ashworth & Perera, 2013). For instance, energy or maintenance costs from one project may not be exactly the same for another. However, building price books which are commonly location-dependent, may also not accurately recognise such contextual disparity. Ferry and Flanagan (1991) advised that extensive historical data are not indispensable to life-cycle cost (LCC) modelling.

Common practice in LCC often separates cost data into capital and future elements. The general basis of this approach relates to the time of occurrence of each cost element. Usually, for purposes of ease and convenience, many life-cycle costing exercises separate costs into just "initial capital" and "running" cost categories. Kishk and Al-Hajj (1999) expressed that by separating costs into capital and running categories, a peculiarity has been established. Capital costs are predictable with some degree of certainty at the design stage of a project. However, future costs are largely unpredictable due to future legislative changes in buildings, changes in resource consumption (i.e. energy, water, sewerage) and alterations to facilities throughout life) (Ashworth & Perera, 2013). This generalisation tends to harness data attributes based on the period of occurrence but fails to recognise the contextual drivers such as rates from utility providers, technological adaptations, and building occupancy levels. Also, the impact of uncertainties in life-cycle costing analysis based on these contextual drivers is not sufficiently treated (Geng et al., 2017; Goh, 2016).

According to A Al-Hajj et al. (2001), life-cycle cost data constituents can be broadly mapped into four levels. The first level of data required in a typical life-cycle costing (LCC) exercise is the economic data, regarding the discount and inflation rates, over the analysis period. Gluch and Baumann (2004) argue that the most influential variable in LCC is the discount rate. This is because discount rates are politically determined (Morrissey, Meyrick, Sivaraman, Horne, & Berry, 2013), and the values used by respective estimators tend to subjective and arbitrary (Tan, Anderson, Dyer, & Parker, 2010). The second level of data includes the capital cost, maintenance costs, and utility costs. Capital costs are often based on elemental costing in buildings. Capital cost can also be estimated from proprietary cost databases, such as the Building Cost Information Service (BCIS), or CoStar group. Commercial sources of this kind of data tend to provide generic information based on the Gross Floor Area and Location. The maintenance costs and utilities cost in a typical LCC study, as well as the staff and business operating costs constitute a significant proportion of the running costs (R. Evans, Haryott, Haste, & Jones, 2004; Hughes et al., 2004), although in some cases, disposal costs could be included. The maintenance cost is dependent on the behaviour of the occupiers, and the quality of building materials and components used. Sources of maintenance data include historical data from clients and surveyors' records, cost databases and building price books (Mohammed Kishk et al., 2003a), such as Wessex, Rawlinson or Laxton. Another possible source for maintenance and utility cost data in a typical LCC study is through heuristics (Havard, 2013). The third level of data in a typical LCC study includes the times in the life cycle of the project. This is hardly predictable, and even more difficult to verify. The actual life of a building will depend on a number of factors including the type of building, physical characteristics of the building materials, exposure to the elements, maintenance regime, the frequency of use, as well as the behaviour of the occupiers (Cort, Dirks, Hostick, & Elliot, 2009)

Life-cycle cost modelling has traditionally focussed on "hard-data", which are quantitatively defined (Healy, 2015), and have failed to harness subjective, and less-quantitatively defined data, which could enrich the data interphase in LCC modelling, and enhance the credibility of LCC predictions. There are different genre of data in life-cycle costing – real data (obtainable from case studies including i.e. economic data - discount rates, social data - demographics and demand-level, political data - legislative changes), hypothetical data and simulated data based on forecasts. *Table 1* provides a description of each data-type and summarises their advantages and disadvantages.

Table 1 Data Genres used in Life-cycle Costing of Buildings

Data Type	Advantages	Disadvantages
Real-life	• This provides objective assessment in buildings • It has high credibility	• It is very difficult to access • It is expensive to obtain
Simulated	• It provides an alternative to real data • It provides a cheaper way to conduct LCC	• It has limited credibility • It is mostly applicable to a singular context
Hypothetical	• It helps to illustrate the features of a model	• It has no empirical basis

The purpose of life-cycle costing is to facilitate logical and realistic decision outcomes in building investment appraisals (Ashworth & Perera, 2013). To achieve this, the data used in LCC needs to have reasonably high fidelity. The evidence from the built environment literature, however, raises doubt on the ability of LCC models to robustly appraise buildings. There is a need to recognise that LCC scenarios involve a complex set of decision events, actions, outcomes, with significant interdependencies (Tokede & Ahiaga-Dagbui, 2016). Therefore, LCC exercises may not solely establish the scope and level of cost data, but also an appropriate means of representation.

Methods in Life Cycle Costing

In the current built environment literature, there are different approaches in evaluating the life cycle costing (LCC) estimates of buildings. LCC methodologies can be broadly classified into three types: Closed-form mathematical, Probability-based, and Real-Option-based methods. *Table 2* below provides a summary of the potentials and limitations of each LCC modelling approach:

Table 2 Summary of Life-cycle costing (LCC) modelling approaches

Method	Strengths	Weaknesses
Closed-form LCC method	It is straight-forward and easy to follow It provides precise descriptions for	It assumes little uncertainty Opportunities for future decisions are ignored

	systems with little complexity	
Probability-based LCC method	It allows variability in the cost items to be represented. It allows input from statistics, regression and other artificial intelligence techniques	It only accounts for uncertainties as a result of randomness.
Real-options LCC method	It allows certain decisions to be taken in the future with better information It allows different kind of uncertainties to be represented.	It heightens computational rigour in LCC Its practical benefit remains unproven

The most common approach in LCC in buildings is the mathematical closed-form (M-CF) approach. Table 2 details some of the strengths and weaknesses of the different methods adopted in LCC. These methods, however, only address specific facets in LCC modelling. However, there is a scope to integrate the features of these techniques in order to harness their full benefits. The practice of LCC modelling in buildings has mostly focused on individual facets, thus perpetuating a rather incomplete perspective in building appraisal.

Closed-Form LCC Models

The closed-form mathematical (M-CF) approach, commonly known as the standard method summarily aggregates costing elements into capital cost, operation cost, maintenance cost and other relevant costs to yield a single estimate (Mohammed Kishk, 2005). Mathematically, the LCC formulae can be represented as:

$$LCC = \sum_{t=0}^{T} \frac{C_t^i}{(1 + D_R)^{\,t}} \qquad (1)$$

Where C_t^i = Equivalent cash flow,

$D_R = \text{real discount rate}$

$\text{t, T} = \text{time (in years)}$

Over the last three decades, a number of works have proposed modified closed-form mathematical algorithms, to improve on the future cost forecasts of building investments in life-cycle costing scenarios. The LCC model developed by Bromilow and Pawsey (1987), for instance, considers maintenance activities, as non-annual recurring costs while Al-Hajj (1996) developed cost significant factors to further enhance the data inputs in LCC modelling. Kishk (2005) concludes that many of these works, have had limited impacts on the practice of life-cycle costing. Caplehorn (2012) surmised that industry perception LCC in buildings, has hardly changed since its inception. The closed-form (M-CF) approach is fairly straight-forward and simple to follow. The major challenge with the M-CF, is its reliance on robust and clear identification of all cost elements over a building's life. While initial costs are relatively clear and predictable at the design stage, the future costs are rather volatile and uncertain (CIFPA, 2011; Pellegrini-Masini, Bowles, Peacock, Ahadzi, & Banfill, 2010). Over the years, there have been a number of improvements in M-CF modelling. Even with advanced uncertainty modelling techniques, the data required cannot be reliably ascertained, and hence life-cycle cost estimates remain difficult to verify. The closed-form mathematical expressions tend to provide precise descriptions for systems with little complexity and hence assume little uncertainty (Ross, 2009).

Probability-based LCC Models

Another common approach to modelling, largely based on consideration of uncertainty are probability-based models. A good example of the probability-based approach is the whole life-cycle costing approach developed by Boussabaine and Kirkham (2008). In the probabilistic LCC approach, all uncertainties are assumed to comply with the behaviour of a random process (Mohammed Kishk et al., 2003b). This implies that uncertainties are a product of stochastic variability, and can be modelled by means of a Probability Distribution Function (PDF). Monte Carlo simulation (MCS) is perhaps the archetype of simulation efficiency, as far as probabilistic techniques are concerned. MCS allows the evaluation of multiple uncertain variables (Keršytė, 2012), in a manner that produces the fairest summary. The computational efficiency of the MCS has enhanced its popularity in uncertainty modelling for different industrial applications, as well as in LCC evaluations. There are a few conceptual shortcomings regarding the use of MCS for uncertainty modelling. Hollmann (2007), stated three of these, namely – dependencies between model variables not properly considered; the relationship between risk-drivers and cost outcomes not explicit; and lastly relationship between market risk (which is, diversifiable) and technical risk (which is undiversifiable) not recognised. MCS is also limited in accommodating asymmetries in cashflow distributions introduced by the recognition of real options (Keršytė, 2012).

The benefits of statistical techniques in life-cycle cost modelling have been discussed by Mohammed Kishk and Al-Hajj (1999). Regression, neural networks and other artificial intelligence techniques have proven to be valuable tool in life cycle cost analysis. Regression requires systematic collection of relevant cost data, to decipher the relationship between individual cost elements (Smith & Mason, 1997). However, the benefit of regression is limited to buildings with similar configuration. Given that buildings evolve over time, the regression model developed for buildings erected about thirty years ago will most likely be different from those constructed in recent times. Regression also relies on the accumulation of cost data, which could be onerous to obtain. Neural network is another powerful tool in establishing cost estimating relationships (Seo, Park, Jang, & Wallace, 2002). Neural networks have no restrictions on the number of variables because they have the inherent ability to self-organize and learn (Ahiaga-Dagbui, Tokede, Smith, & Wamuziri, 2013). De la Garza & Rouhana (1995) have argued that the formulation of the neural network architecture for life-cycle costing could be problematic.

Heuristic LCC Models

Heuristics are another approach that has also been employed in life-cycle costing scenarios. Tietz (1987) illustrated a situation in which the future costs of a building estimated over a 50-year period is likely to be 0.8 – 1.3 times the capital cost. Heuristics have equally been popular in LCC computations. Heuristics minimise the laborious computations in LCC and eliminates the need for expansive accumulation of data. Heuristic models are useful in shortlisting a host of competing building options prior to conducting more precise analytical comparison (Cole & Sterner, 2000) and provides a snapshot into the proportion of cost expended in different building development phases.

In heuristic LCC models, the context of buildings are however seldom addressed and there is a possibility for making sweeping assumptions about data to be made. It is therefore unsurprising, that there is little agreements regarding the relative proportion of LCC data in buildings. For instance, Holness (2010) stated that in the life-cycle of a building, initial construction cost represents only 2%; operational and energy cost are 6%, while the rest of the 92% is the cost of occupants. Evans *et al.,* (2004) under the aegis of the Royal Academy of Engineering, conducted a study on the long-term cost of owning and using buildings, and proposed that the construction cost, maintenance cost, and business operating cost of commercial office buildings in the UK, over their lifetime have a ratio of 1: 5: 200 respectively. Hughes *et al.,* (2004) have contested this ratio, and based on another set of published data opined that the more realistic ratio is 1: 0.4: 12, over an estimated life of 25 years. Heuristic models could be realistically termed ill-structured analytical models (Asiedu & Gu, 1998), with an inclination to produce a satisficing solution. Kishk and Al-Hajj (2000) further suggest that LCC does not fit completely into the framework of probability and statistics theories. However, this opinion does not seem to have been well taken in the practice of life-cycle costing in buildings.

RESEARCH APPROACH

This work attempted to critically examine the existing approaches to life-cycle costing, draw-out the challenges and methodological weakness, in an attempt to establish the basis for charting possible direction for future LCC research. The research conducted a systematic literature analysis to identify the various research methods, modelling approaches, building-types, and data-sources used in the LCC modelling. The research therefore considered different semantic descriptions of LCC such as through-life costing, terotechnology, life-cycle costing, total costing, whole-life cycle costing, and whole-life appraisal. The work also identified diverse and heterogeneous literature sources including books, journal papers, thesis, reports, conference proceedings and government publications. *Table 3* provides examples of published work on life-cycle costing spanning four decades~~.~~ These works have been selected based on the modelling foci, in their development. Table 3 presents the sources of data, and the modelling methods used in LCC of different genre of buildings. From *Table 3*, the predominant data used in LCC are hypothetical, and in some cases simulated. The evaluation mechanism in many LCC exercises hinged on closed-form mathematical modelling. The underpinning of the models is largely directed at determining an overall LCC estimate, with much less emphasis on justifying and accommodating economic decisions in respective building scenarios. However, focusing on the output rather than the processes in LCC undermines the benefits of the technique.

Table 3: Modelling techniques in LCC for Buildings

	Closed-form expression	Heuristics	Probability	Fuzzy Logic	Monte-Carlo simulation	System Dynamics	Simulation	Neural Network	Statistics / Regression	Genetic Algorithm	Real-Options	Decision Techniques
R Flanagan and Norman (1983)	•											
Roger Flanagan et al. (1989)	•		•									
Bromilow and Pawsey (1987)	Δ											
Tietz (1987)		•										
A. N. Al-Hajj (1991)	♦	♦										
Zhi (1993)							•					

Assem Al-Hajj and Horner (1998)		Δ							Δ			
Sobanjo (1999)				•								
Aye et al. (2000)	Δ	Δ										
Bartlett and Howard (2000)	•											
Mohammed Kishk and Al-Hajj (2000)	•			•								
M Kishk, Al-Hajj, Pollock, and Aouad (2002)	•	•		•								
Kirkham, Boussabaine, and Awwad (2002)	♦								♦			
Mohammed Kishk (2004)	•			•	•							
R. Evans et al. (2004)		•										
Hughes et al. (2004)	Δ	♦										
Mithraratne and Vale (2004)	Δ						Δ					
N Wang, Horner, and El-Haram (2004)	•	•		•								
W. Wang, Zmeureanu, and Rivard (2005)	Δ									Δ		
Ellingham and Fawcett (2006)	•		•		•						•	
Ive (2006)	Δ	Δ										
Boussabaine and Kirkham (2008)	•		•		•			•	•	•		
Kshirsagar, El-Gafy, and Sami Abdelhamid (2010)	Δ					Δ						
Pellegrini-Masini et al. (2010)	Δ		Δ									
Tuhus-Dubrow and Krarti (2010)	Δ											
Wong, Perera, and Eames (2010)	Δ		Δ				Δ		Δ	Δ		
Nannan Wang (2011)	•			•								•
Sacks, Nisbet, Ross, and Harinarain (2012)	♦											
Smit (2012)	•				•		•					
Ammar, Zayed, and Moselhi (2013)	•	•		•								
Goh (2016)		•										
Bonomo, Frontini, De Berardinis, and Donsante (2017)	•	•										

• hypothetical data, ♦ case studies Δ simulated data

From Table 3, the predominant use of closed-form mathematical method used in aggregating capital costs and future costs of buildings. The practice of aggregating capital cost and future costs has been criticised widely as it can result in an inaccurate estimate for the time-value of money in LCCs (e.g.(Assaf, Al-Hammad, Jannadi, & Saad, 2002; Ellingham & Fawcett, 2006; Mohammed Kishk et al., 2003b). Furthermore, Ferry *et al.* (1999) and Bordass (2000) added that it is inappropriate to equate capital costs and future costs, as this may be akin to adding apples and oranges.

Figure 2 highlights the mathematical variants of LCC used in buildings. Out of the 32 papers, 26 implemented closed-form mathematical modelling (M–CF); 6 incorporated some form of fuzzy logic mathematical modelling procedures (M-FL), 6 utilised some probabilistic modelling including Monte Carlo simulation; 4 utilised simulation (excluding Monte Carlo) and 1 attempted to use system-dynamics. There was a clear distinction in the methods based on the years of publication. Works from the 1980's mainly considered closed-form mathematical modelling (M – CF). It was not until the 2000's that system-dynamics became a prime consideration. Simulation seem to have started a bit later, but the earliest work found was from 1993. These perhaps indicated that closed-form mathematical modelling has been the predominant approach in LCC although this is being more recently augmented by fuzzy logic (M – FL), and in some instances, probabilistic modelling (M – PL). System-dynamics is being considered, but this approach seems to have been less popular due to difficulties in obtaining data required for long-term costing.

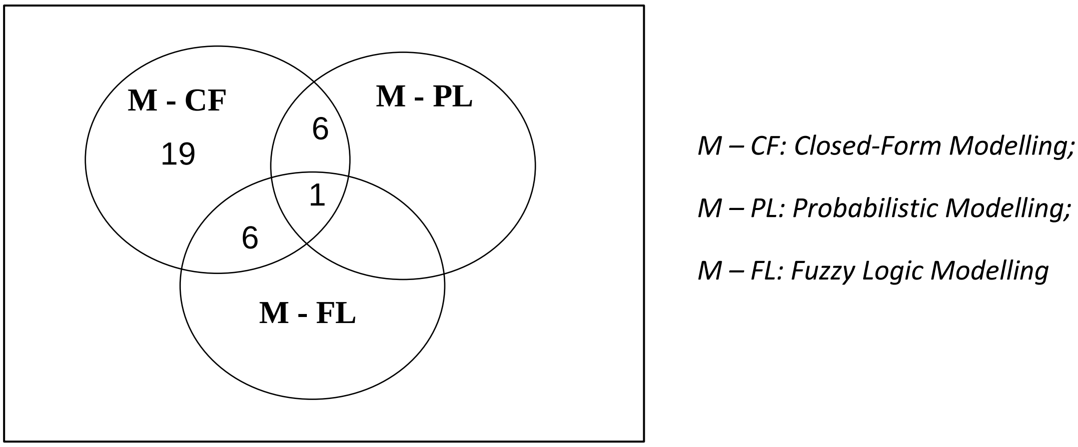

Figure 1 Mathematical modelling variants in life-cycle costing

Also, the type of buildings investigated in these works were mostly generic. These was indicative of the data used in the research. It can be seen from Figure 2, the building types commonly assessed in LCC exercises. 26 of the 32 works assumed a generic building-type and did not specify the type of building used. While nine of these buildings were commercial buildings; out of which seven were offices. Another 9 buildings were used for different buildings including teaching, residential, laboratory, retail, leisure, and recreational facilities.

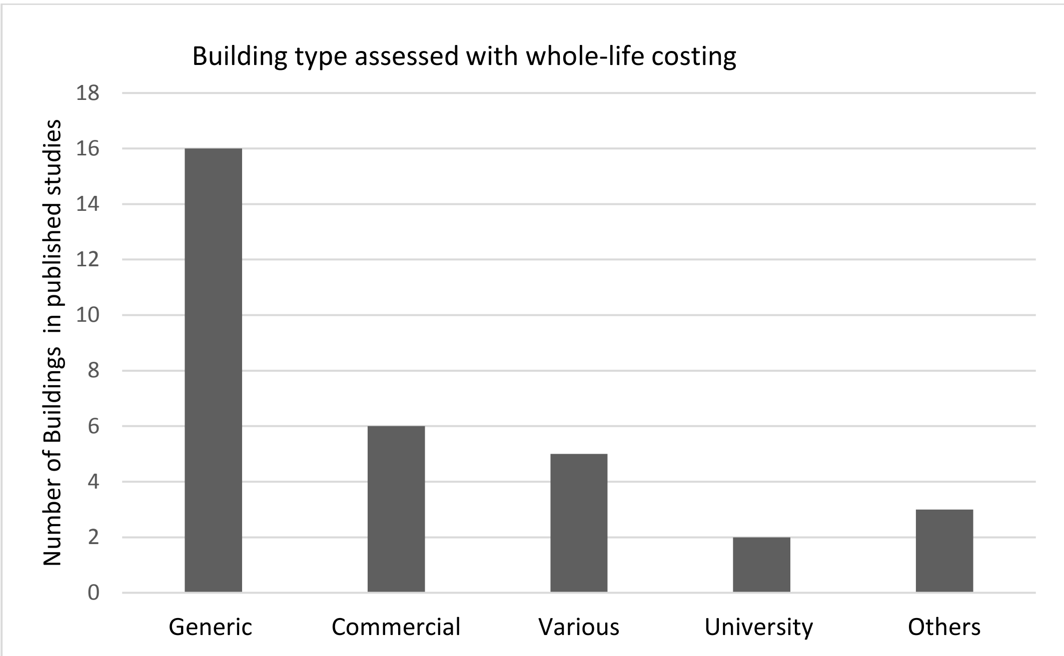

Figure 2 Building type assessed with life-cycle costing in the survey

These perhaps suggest that commercial buildings provide the most convincing context for life-cycle costing (LCC) analysis. Regarding the data type used, in the 32 modelling works – 17 used hypothetical data, 11 utilised simulated data and 4 were based on case-studies. The invalidated data capture in LCC modelling of built assets, as previously stated by Kirkham (2005) therefore seems justifiable.

The research on life-cycle costing seems to be truncated, recursive and largely speculative. Many early researchers including Flanagan, Kirkham, Kishk, Al-Hajj, Boussabaine, and Clift, have expressed insightful thoughts on LCC, but the relevance and credibility of estimates remain unproven. The impacts of modern discoveries, such as BIM and virtual prototyping, which holds the potential to enhance improved processes has not permeated the practice of LCC.

DISCUSSIONS

Existing LCC techniques are static (Ellingham & Fawcett, 2006; Koskela, Siriwardena, & Rooke, 2008; Tan et al., 2010), they consider buildings as investment projects, with clearly known variables. Buildings could often be retrofitted, refurbished or reconfigured and this could impose new variables. A number of variables that could emerge include:

- sustainability cost – cost to ensure that building incorporates features that make it more environmentally-friendly;
- revocability cost – the potential for variability in the future costs of owning a building;
- disruption cost - cost over which a building may be unusable due to repair or refurbishment work.

These variables are often products of decisions taken over the life of the building by their owners and stakeholders. Building variables could thus be unknowable, and transcend traditional classifications such as 'initial' and 'future' costs that constitute the principal components in LCC calculations. A number of authors have therefore argued that future costs are indeterminate during the initial design of a building (Kirkpatrick, 2000; Mohammed Kishk & Al-Hajj, 2000; Vennström, Olofsson, Fawcett, Dikbas, & Ergen, 2010). The complexities in LCC is therefore intricately bound to the conception of the model, and the fidelity of its claims. An approach to counteract the difficulties in LCC valuation is to allow for uncertainties in the modelling process. However, this requires an understanding of the nature, scope and type of uncertainties affecting LCC variables

Potentials for Big Data in LCC Modelling of Buildings

Life-cycle costing has a complex scope of variables and influencing factors to consider. This thus requires a holistic approach in advancing the processes in life-cycle costing. A new field of interest that has shown promising potentials in handling the growing data volume in LCC is termed Big Data. "Big data refers to both large volumes of data with high level of complexity and the analytical methods applied to them which require more advanced techniques and technologies in order to derive meaningful information and insights in real time" (HM-Government, 2014, p. 2). According to a report by Manyika et al. (2011), opined that Big Data will facilitate transparency in decision-making, enable experimentation, segmentalise populations to customise action, replace/support human decision-making with the automated algorithm and ensemble competitive advantage.

Many industries like construction focus on just numerical and text data, whereas more advanced sectors had multimedia data encodes including video, images, audio. The Big Data revolution is understandably pioneered by internet companies such as Google, Amazon, Yahoo and the likes (HM-Government, 2014), but its impact is fast-reaching other sectors such as medical technology, finance, agriculture, biotechnology and many others. Big data is the next frontier in driving innovation, productivity, growth, value capture, and new modes of competition.

Big-data builds on traditional data analytic principles and encompasses descriptive, predictive and prescriptive analytics. However, LCC in buildings has mostly utilised the descriptive and predictive analytics and more so at a low-level of technology. There is a need for construction organisations to develop sophisticated approaches to process, visualise and synthesise meaning from big data in construction and buildings. Building Information Modelling is a frontier where data capture and retention has been improved. However, the data captured in BIM tends to be mostly numerical data, and hence may still be limited to the opportunities provided by Big Data. Goh and Sun (2015) conclude that the potential benefits accruable from BIM are speculative, and evidence on this remains inconclusive.

Conclusion

This paper undertakes a critical review of life-cycle costing (LCC) and examines the insights, oversights and foresight with regards to data and the modelling techniques used in building appraisal. This paper acknowledges and highlights the practical difficulties in matching the intention of LCC to the objective reality of buildings. Specifically, we conclude that life-cycle costing (LCC) is a complex subject. It thrives on the assumption of hypothetical variables and drives decisions that affect an unknown or unknowable future. In this paper, we articulate the insights, oversights and foresights underpinning life-cycle costing in buildings.

Our intention is to provoke a critical discourse and rethink of existing methodological approaches to LCC in an attempt to develop approaches that might be better at capturing the data in LCC of building. The paper also details a critical analysis of the modelling approaches, building-types and data sources used in the LCC modelling. There is scope to further enhance the impact of modern discoveries, such as BIM, virtual prototyping, and Big Data which holds the potential to enhance improved LCC modelling. Future research should, therefore, seek to develop integral modelling approaches that allow interdisciplinary and collaborative data capture in LCC exercises.

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