93 Standardization of Whole Life Cost Estimation for Early Design Decision-Making Utilizing BIM

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Abstract

It is becoming increasingly clear that there is a gap between the expected and actual performance of buildings. A growing body of evidence suggests that the most common barrier to achieving design intent is the absence of comprehensive information during design and construction stages, leading to poor decision-making which impacts on performance and Whole Life Cost (WLC). Building Information Modelling (BIM) has the potential to facilitate a more comprehensive and accurate design approach from the early stages. A detailed and accurate model can allow designers and clients to understand the wider impacts of design changes, and to track this information through construction stages. However, dependencies between design decisions and WLC have yet to be understood. This paper is based on a project that focuses on the Private Rental Sector (PRS), which is the fastest growing new sector in the UK housing market, also known as Build-to-Rent (BTR). The study adopts a mixed method approach for the development and validation of a structured standardised process for more accurate WLC estimation through BIM. As a result, the main problems in WLC BIM management are identified, and coordinated into a reverse-engineered systematic process that uses the Integrated DEFinition (IDEF) 3 structured diagramming modelling technique, and the Industry Foundation Classes (IFC) as a basis for large dataset management. The research outputs aim to enhance BIM lifecycle management through a smart decision-making approach that is integral to the natural design development process.

Keywords

Building information modelling (BIM) • Process modelling • nD modelling • Whole life cost (WLC) • Integrated definition (IDEF) language

93.1 Introduction

Several UK construction industry reports have documented the fact that the sector has been suffering from low innovation, and underperformance in terms of productivity and quality of the final product [1, 2]. Hence, the UK Government's target is to achieve a 20% reduction in the capital cost of buildings (CapEx) [1] and a 33% reduction in Whole Life Cost (WLC) [2]. In fact, research has shown that over a 30-year life, the cost of operating the asset could be as much as four times the cost of designing and constructing the building, and that 80% of the operation, maintenance, and that replacement costs of a building can be influenced in the first 20% of the design process [3, 4]. However, buildings rarely perform as expected [5, 6]. This can impact on sustainability and building performance, but also factors such as energy consumption and operational costs (OpEx) [3, 7]. It has been argued that the most common barrier to achieving design intent is the absence of

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comprehensive information during design and construction stages, leading to poor decision-making, which impacts on performance and WLC [8, 9].

As a consequence, the need for a more holistic approach to building design is gaining momentum. There are several technologies that are expected to play a part in the transition from linear to circular economic growth: the internet of things, the cloud, big data, and Building Information Modelling (BIM). BIM has proven its potential to facilitate the building development process during planning, designing, construction, and operation [10]. Nevertheless, to date, BIM has focused on the design and construction of the built asset. Therefore, although the use of BIM for calculating CapEx has become commonplace, its potential to be used for estimating WLC is not yet utilized. Several BIM software solutions have been developed with the aim of calculating WLC, but none of them offers the complete solution [11]. Thus, there is the need to bring together different approaches into a standardised framework that utilises the existing technological enablers by establishing links between them. More importantly, it is essential to specify information requirements and exchange procedures.

To achieve this step change, current working processes have to be re-examined and re-engineered [12] so as to follow a more concurrent approach for WLC assessment [3]. Concurrent Engineering (CE) principles have been successfully implemented in manufacturing, for mapping the design process so as to make it explicit. Process mapping (using structured diagramming techniques) helps in the identification of tasks that add value to the project, and the elimination of bottlenecks. However the mapping of building design processes presents bigger challenges since its nature and variability is fundamentally different from the manufacturing process [8], particularly due to the bespoke nature of buildings. Nevertheless, it is believed that a CE approach would ensure sustainable development at every stage of the building life cycle, hence upholding the principles of designing to a cost, as opposed to costing a design [13]. A detailed and accurate model can allow designers and clients to understand the wider impacts of design changes, and to track this information through construction stages.

This paper is based on a project that examines how BIM policies, technologies, and processes can facilitate more accurate prediction of WLC more efficiently in terms of time and effort involved to achieve quality assurance. As such, WLC considers all significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements. This holistic approach could produce high-performance buildings that are both cost-effective and sustainable, but also mitigate risks to building owners. The project will demonstrate how cost information related to maintenance and performance of a completed building can be incorporated during design delivery, from the early stages, in order to make decisions that are critical for the timely assessment of WLC. This paper provides an overview of the state-of-the-art of WLC assessment through BIM, investigating factors that affect its efficient implementation. Then, it describes a standardised approach for its implementation using conceptual process modeling and the Integrated DEFinition (IDEF) 3 structured diagramming technique.

93.2 Background and Related Work

The project focuses on the Build-to-Rent (BTR) housing sector [14]. Affordable housing tenure under a single management, and assessed viability that recognizes distinct tenure economics are key principles for increasing the quality and quantity of BTR [15]. Thus, for the investor, assessing the long-term viability of such developments is a critical issue. For that reason, WLC evaluation must provide a careful breakdown of cashflow that goes beyond the CapEx. This includes level of amenities offered along with maintenance decisions. Nevertheless, current research that demonstrates performance gaps [5, 6] represents a significant threat. It is proposed that BIM can provide a more integrated and rigorous approach for assessing viability of BTR schemes while maintaining high performance standards for quality, thus offering a competitive approach through improved customer service.

93.2.1 WLC Definition and Scope

WLC has been defined in BSI ISO 15686-5:2008 [16] as a methodology for systematic economic consideration of all significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements over a period of analysis, as defined in the agreed scope. Nevertheless, researchers have stressed the lack of standard methods and format for calculating WLC as the main barrier for its implementation [17]. This creates the urgent need for the development of standardised protocols for BIM-enabled WLC estimation, integrated from the early design stages. However, WLC cannot be the only measure for assessing a project's viability, nor the only indicator that should be used as a method for future-proofing a design. Intangibles such as user comfort, amenity and efficiency lead to increased occupant satisfaction, and are associated with financial implications [3].

93.2.2 Sources of Data

The accuracy of WLC assessment substantially depends on the quality and availability of data from all phases of a building [12]. Sources of data can be [7]: (i) Unstructured historical data; (ii) Structured historical data; (iii) Data from modelling; and (iv) Data from manufacturers, suppliers and specialist contractors. While historical data are used for prediction during design, dynamic data from sensors are used for monitoring actual performance so as to make comparisons. Over time, the data could also be used to generate a historical database that in turn will be used for briefing, as well as predictive design. At present the literature suggests lack of longitudinal studies that focus on monitoring the performance and reliability of systems [18, 19]. A major problem that limits the effectiveness of building decision support tools is the difficulty to obtain accurate data from various sources related to a building [20].

93.2.3 Integrative Design Process

During development, WLC integration can assist designers to identify optimal solution and areas where performance may be threatened. Such decisions placed in a strategic (organizational) framework, can create added value for the asset and help to identify the most cost-effective operations and maintenance regime. Related research efforts have attempted to integrate aspects of WLC within BIM processes by linking CapEx assessment to design development [21, 22], while others have focused on environmental aspects [20, 23, 24]. Studies that aimed to integrate WLC with BIM have resulted in solutions that are not comprehensive [11], or require manual inputting of cost data [25]. A CE process enables decision-making to be integrated within the design development process, creating soft-gates between hard-gates (design stages) during phase-gate review. Following this principle, conflicts are highlighted, compared to the initial plan, and thus resolved in a timely manner.

93.3 Research Strategy and Methods

This study adopts an abductive approach, utilizing mixed methods, for the development and validation of a structured standardised process for more accurate WLC estimation through BIM.

93.3.1 Framework Development

The first phase of the research was exploratory. Methods implemented include literature review and purposive sampling, which included a series of interviews and workshops with a design team, two tier-1 contractors, two major national developers, engineers, product manufacturers, software providers/developers, an insurance company, and a cost consultant specialist in WLC for the BTR. Thematic analysis [26] was implemented to develop a theoretical framework that identified the main problems in WLC BIM management.

93.3.2 Conceptual Process Modeling Using IDEF3

The second phase is an iterative process of developing a detailed model that clearly links information requirements to design decisions that are critical for the timely assessment of WLC during the delivery of BTR projects. The chain of interdependencies is determined following the Critical Decision Method [27]. These are coordinated explicitly into a reverse-engineered systematic process that uses the IDEF3 structured diagramming modelling technique [28]. The research outputs aim to enhance BIM lifecycle management through a smart decision-making approach that is integral to the natural design development process. The IDEF3 method was selected due to its high descriptive power, which is considered appropriate for detailed processes that handle know-how knowledge. IDEF3 captures descriptions about sequences of activities, while also identifying critical decision points, or milestones, of the process from different perspectives [28]. IDEF3 has specifically been developed to model stories (situation or process) as an ordered sequenced of events and activities [29]. It is a scenario-driven process flow modelling method created to map descriptive activities. The goal of IDEF3 is to provide a structured method for expressing the domain expert's knowledge about how a particular system, or organization, works (ibid.).

93.4 Findings and Results

The following aspects of WLC estimation have been found to be critical for its successful implementation through BIM.

93.4.1 WLC Software Capabilities

Selection of the most appropriate software is extremely important in order to streamline the working process and achieve doing more with less effort [30]. The questions that designers should consider regarding a software tool fall within the categories of ease of use, time and cost, interoperability, input, output, and accuracy [31]. Furthermore, in terms of transparency, computer-based WLC programs can be distinguished between glass box and black box ones depending on the visibility of the process [7]. Table 93.1 contains a comparison of the WLC assessment software tools reviewed. It has been found that while the use of BIM for calculating CapEx has become commonplace, its potential for calculating OpEx has not yet been utilized. Some tools (CATO by Causeway, and Impact from BRE) have claimed that are able to estimate WLC, but further investigation has revealed that they implement simplistic approaches. For example, CATO has no links to databases containing cost data, whereas WLC estimation is based on a simple entry of a service life for the whole building, resulting in a high-level generic estimation. The BRE Impact cost database is static (does not get updated) and its current focus has shifted towards environmental assessment. Bionova's One Click LCA has been found to be the most comprehensive option for WLC estimation, since it utilizes data from several cost databases that get updated on a regular basis, while also being compliant with British Standards [3].

93.4.2 Interoperability and Data Structure

It has been inferred that the BIM-enabled estimation process is not completely automatic, as BIM-based quantity take-offs do not provide all the necessary data to create the cost estimate and a bill of quantities [32]. In fact, researchers have claimed that the bill of quantities exported from the BIM is often unreliable and inaccurate [33]. Nevertheless, review of state-of-the-art readily available software tools, and demonstrations by their providers, has shown a fully automated process for extraction of quantities. Further research is necessary to determine the quality of information extracted, which is dependent partly on the modelling method followed, but also on technological limitations, irrespectively of the modelling method used.

The use of open standards is recommended for enabling information exchange that is not restricted by proprietary formats, assisting in better communication between project team members that utilize specialised software tools. This study

Table 93.1 Comparison of WLC estimation software tools

Tool	CapEx	OpEx	LCA	BIM	Location
Causeway CATO	X	X		X	UK
One Click LCA	X	X	X	X	Finland
IMPACT	X	X	X	X	UK
Butterfly	X	X	X		UK
Beck Tech Destini	X			X	Texas
CostX	X			X	UK
RICS BCIS		X			UK
Tocoman	X			X	Finland
Trimble VICO	X			X	USA

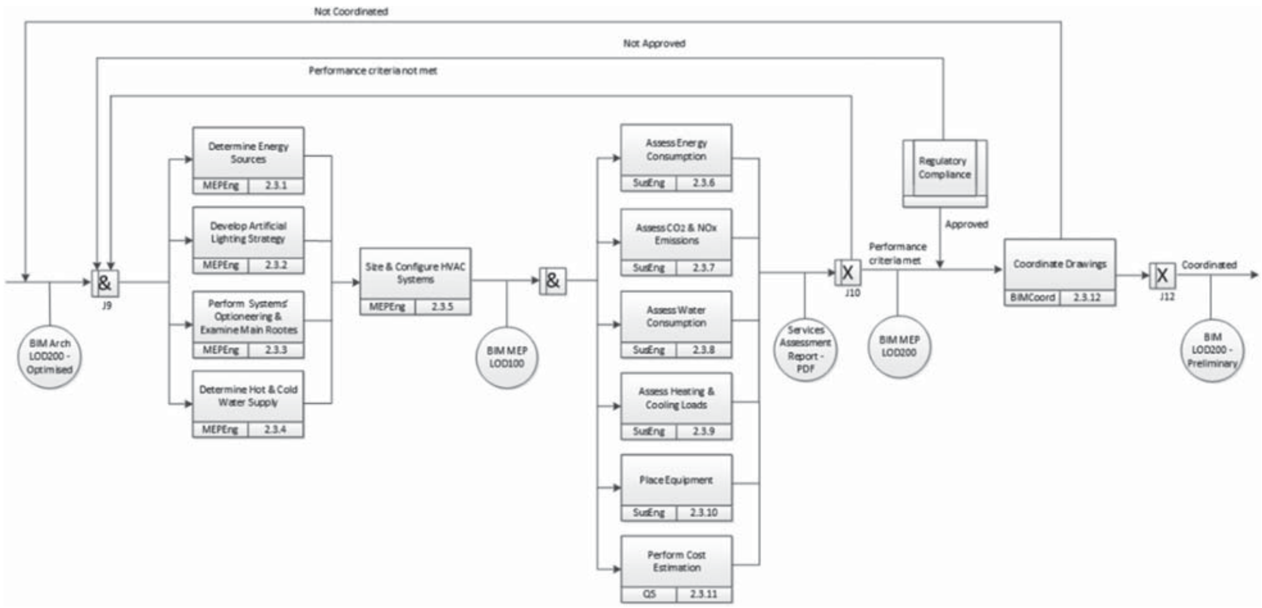

Fig. 93.1 IDEF3 decomposition of UOB "configure mechanical services"

utilizes the IFC, which has a hierarchical structure. Its basic building blocks are equivalent to real elements, including their properties. Although the IFC format can cover a wide range of data, various BIM systems do not fully comply with this standard [34]. To find out how much of WLC information can be integrated into the BIM model (as it is used for Level 2 compliance), the Construction Operations Building Information Exchange (COBie) and IFC structures have been mapped to indicative economic lives (CIBSE Guide M) and maintenance data requirements (SFG20).

93.4.3 Information Flows—Process Model Development

Previous research supports the idea that traditional processes cannot be employed to achieve complex high-performing buildings, and that a CE design process approach to WLC assessment is essential [8, 9]. During the traditional building design process, each stakeholder passes fixed information to the next one, which results in compromised design outcomes. What the CE approach suggests, is that design solutions are developed, assessed, and revised collaboratively, as design progresses [35]. Thus, a single linear prescribed process is not viable, because the complexity, amount of specialization and individual project needs do not permit the process to be defined without iterations.

In fact, the importance of decision points has been stressed in PAS 1192-2:2013 [36] as a critical aspect of the collaborative process. For this reason, this research strives to identify the critical decision points for WLC and align these with the appropriate WLC considerations and criteria. The decision points comprise two types of gates; hard-gates when the design freezes until the review is conducted, and soft-gates that allow the project to proceed in parallel, enabling a CE approach. It is suggested that the hard-gates serve the purpose of committing to decisions collectively, while soft-gates are identified throughout the process so that critical decisions occur in parallel. Instead of design participants working in isolated silos, between the hard-gates (start and end of design stages), the soft-gates identified during the Work-in-Progress (WIP) phase can facilitate communication by triggering design tasks so as to clarify the process for practitioners and reduce uncertainty. Figure 93.1 shows an example of a detailed IDEF3 decomposition of UOB "Configure Mechanical Services".

93.5 Discussion and Conclusion

The paper discusses the need for a holistic approach to BIM management through a dynamic process of integrating WLC estimation gradually during design development as opposed to costing a design at specific stages. Defining information requirement granularity, while considering trade-off relationships between economic and environmental factors, streamlines the design development process, and allows committing to decisions safely, reducing rework and delays. However, the lack of common methodologies for WLC in the construction industry has resulted in issues such as scope and definition rarely being clearly recorded [3]. The research findings support the idea that BIM technologies can assist in the accurate estimation of WLC of an asset, from the early design stages, through the implementation of standardised information exchange procedures as it enables a more holistic approach to what is currently a fragmented development system. It can therefore be assumed that, for BTR, repeatable tasks and similar workflow patterns, roles and responsibilities can be identified. This finding enables the development of a systematic approach for BIM-enabled WLC assessment, based on CE principles [35]. This approach would allow lessons learnt from operation to be incorporated in the design of future buildings and bridge the design/operating performance gap by providing the feedback loop that is so lacking at present. Thus, it is argued that BIM processes have the potential to optimize performance of all design and construction stages, and during post-occupancy, closing the loop of the building design delivery, reducing performance gaps, and achieving the triple-bottom-line goals of sustainability. Despite the potential, there remain many challenges to be faced before accomplishing fully automated, integrated, and interoperable data, as described by the Level 3 BIM maturity definition.

93.5.1 Challenges to WLC Estimation Using BIM

The study revealed several issues that hinder the use of BIM for a whole-of-life approach:

- Models delivered by project team members are not fit for purpose containing insufficient or unproperly structured information.
- Technological capabilities limit the integration of WLC information into BIM models.
- Availability, accuracy, reliability of cost and performance data as well as accessibility and structure of available data.
- Skills and involvement of design team's members and facilities' managers (e.g. lack of experience to interrogate the quantities/assessments produced).
- Procurement strategies are focusing on CapEx instead of OpEx.

93.5.2 Next Steps

Further work needs to be done to establish the effectiveness of the developed process. The next step is to test this concept through the design of a BTR project (or several PRS projects at different design stages) in order to inform and refine the initial model. Moreover, Post Occupancy Evaluation (POE) studies will supplement the validation of the process model by identifying gaps between actual and predicted performance, and more importantly the reasons that cause them. For that purpose, both qualitative and quantitative data need to be collected so as to triangulate the research findings. More research is also required to determine:

- Granularity of information that is possible and efficient to be incorporated into the BIM model (including dynamic feedback from sensor data).
- Criticality of design decisions, prioritization of design criteria, and trade-offs between design parameters.
- Tolerances that can be estimated and attributed to BIM components in order to reflect the level of uncertainty of performance and cost predictions.
- Ways to analyze and visualize WLC assessment results into simpler representations so that they can be used by the design team to set performance targets and inform decision-making during design development.

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