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Review of cost estimation practices for building projects using BIM

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Abstract: Cost management remains one of the key challenges in architectural, engineering, and construction (AEC) projects. Building Information Modeling (BIM) has gained popularity among AEC industry professionals due to its better visualization and clash detection abilities. The present study, therefore, attempts to review the cost estimation practices for building projects using BIM. The objective of the present study is to find answers to the research questions viz., 1) What are the various methodologies adopted for estimating building cost using BIM? and 2) Is BIM popular tool among cost management professionals? The literature review is divided into four parts. The first part of the literature review deals with general observations addressing issues and challenges of using BIM for cost estimation. The second part of the literature review covers different types of models and frameworks developed by researchers for estimating the cost of building projects using BIM. The third part of the review investigates key observations by various associated stakeholders on the usage of BIM for estimating building cost. The interpretation through various case studies is discussed in the last part of the literature review.

Keywords: Cost estimation; Cost management; BIM

1. Introduction

Project cost management and project schedule management remain some of the most challenging tasks for engineers and project managers associated with engineering projects. The activities associated with these two knowledge areas often go in integrated manner to ensure that there are minimal cost and schedule overruns. The application of Building Information Modeling (BIM) for estimating cost of buildings has gained popularity among cost management professionals in recent years. One of the biggest advantages of using BIM for cost estimation lies in the faster quantification of data and its analysis compared to the traditional method. The increasing use of technologies to perform automatic quantity takeoff has helped quantity surveyors achieve sustainable development throughout the building life cycle [1].

2. Research Objective and Methodology

The main aim of this study is to review the cost estimation practices for building projects using BIM. The objective is to review the various studies done by past researchers on integrating BIM for estimating cost of buildings. The rationale behind selecting this topic is to conduct a literature review and investigate the answers to the two research questions:

1. What are the various methodologies adopted for estimating building cost using BIM?
2. Is BIM a popular tool among cost management professionals?

The above research objectives are investigated by referring to the secondary data in form of research publications and case studies.

3. Literature Review

An exhaustive review of literature was performed by searching in high-quality journals and using one or combination of keywords such as “cost,” “cost estimation,” “BIM”, and “buildings”. Out of 48 articles that were reviewed, 37 articles (77 %) were shortlisted, aligning with the research objectives for this study.

The literature review is divided into four parts. The first part of the literature review deals with general observations addressing issues and challenges of using BIM for cost estimation. The second part covers different types of models and frameworks developed by researchers for estimating the cost of building projects using BIM. The third part investigates the key observations by various associated stakeholders on the usage of BIM for estimating building cost. The interpretation through various case studies is discussed in the last part of the literature review.

3.1. BIM for cost estimation

Ma & Liu (2014) presented an approach to collect the necessary construction information for automatic cost estimation of building projects based on BIM designs [2]. Data exchange remains one of the key challenges in the architectural, engineering, and construction (AEC) industry. BIM provides the necessary assistance in sharing the required information systematically and accurately amongst the AEC stakeholders. The traditional costing methodology is mostly text-oriented, whereas BIM provides visual data management that helps in the clear understanding of building projects. This minimizes the chances of errors and avoids the wrong interpretation of data [3]. BIM provides a good alternative to quantity surveyors for cost estimation. However, Wu et al. (2014) observed that the quantity surveyors are unable to take the maximum benefit of BIM due to several limitations, such as low-quality BIM models, inconsistency in level of design information, data exchange issues, and inconsistent formats, among others [4]. The authors reviewed the capabilities of four BIM software for estimation. The software reviewed were Solibri Model Checker 8, Autodesk QTO 2012, CostX 3.5 and BIM Measure 16.4. Seven criteria (exchange, visualization, quantification, reliability, customization, change, and report) were selected for reviewing the mentioned software. The findings suggested that each of this software had its own unique capabilities to assist the quantity surveyors. However, the authors highlighted the need for some additional work in BIM software to take maximum benefit of BIM technology, especially for projects in United Kingdom (UK). In another investigation Sunil et al. (2015) reviewed the importance of BIM for cost management in UK construction sector [5].

Plebankiewicz et al. (2015) developed a costing system, BIMestiMate, which allows direct estimation of cost from BIM model for the Poland region [6]. Azhar et al. (2008) analyzed the benefits, risks and challenges of using BIM for AEC industry [7]. The authors highlighted the need for standardization of the BIM process and defining relevant guidelines for its implementation. The study conducted by Bryde et al. (2013) indicated that BIM has a noteworthy contribution in managing construction projects effectively [8]. The authors reviewed that cost is one of the most significant components that has been positively impacted by implementation of BIM. The perspective of cost consultants on the usability and impact of BIM was investigated by Goucher & Thurairajah (2012). The authors have documented the potential advantages as well as the challenges for cost consultants using BIM [9]. Khaddaj & Srour (2016) reviewed the literature covering BIM and sustainability [10]. The authors proposed a research agenda to increase the applicability of BIM for building retrofit projects. To perform the life cycle assessment (LCA) of buildings, one of the significant challenges is the data exchange between BIM and LCA [11].

3.2. Framework and cost estimation models

Cheung et al. (2012) developed a multi-level cost estimation BIM tool to analyze the building design aspects at its early stage [12]. The authors proposed Low Impact Design Explorer (LIDX) as the knowledge-based tool for the assessment of design using Google SketchUp environment. The tool can make profile-driven estimates, which can be revised in real-time. Elbeltagi et al. (2014) developed a comprehensive cost estimation and monitoring model [13]. The model can be integrated with BIM and enables the user to visualize actual costs spent and compare them with the budgeted cost. The study deals with integration between project cost estimation, monitoring, and control techniques with BIM. Lee et al. (2014) proposed an ontological approach to overcome the subjectivity of cost estimators [14]. The study developed a work condition ontology comprising of determinants to select work items, work item ontology, and semantic reasoning rules. This methodology can automatically determine the most appropriate work item based on the work conditions through the use of semantic technology. Choi et al. (2015) proposed an open BIM-based quantity takeoff process for schematic estimation. It comprises four steps: BIM modeling for schematic estimation, physical quantity verification to increase accuracy, verification of property (data quality), and quantity takeoff [15].

Abanda et al. (2017) developed and demonstrated use of ontology for cost estimation using BIM [16]. The ontology was developed based on New Rules of Measurement (NRM) for cost estimation. BIM-based construction cost estimation needs effective communication between BIM authoring software and specialized cost estimating software. The study demonstrated the use of ontologies in reasoning and performing quantity takeoffs, which can subsequently be used for cost estimation. Whole building development needs methods, workflows, and tools to implement integration of LCA with BIM [17]. The authors proposed a methodology for companies working in Switzerland to perform LCA using well-established BIM structure. Fazeli et al. (2020) successfully demonstrated the linkage between Iran's cost estimation standard (FehrestBaha) and the CSI standards of UniFormat and MasterFormat [18]. The authors developed a BIM-based extension in Autodesk Revit with five primary functions using C# programming. This enabled the automation of cost estimation process and also ensured that the cost estimation standard of Iran became compatible with the BIM environment. Errors in BIM models can cause deviations in the quantity takeoff, especially for compound building elements such as walls and floors. Therefore, to address this issue, Khosakitchalert et al. (2019) proposed a methodology, 'BIM-based compound element quantity takeoff improvement (BCEQTI)' [19]. The study also validated the implementation of BCEQTI through a few case studies. The methodology is based on integrating the concept of BIM-based clash detection to support the BIM-based quantity takeoff process. The authors highlighted that BCEQTI is based on the general concept of calculation algorithm and can be used with any BIM software.

3.3. Surveys and Interviews

This section documents the experiences of various cost management professionals on the use of BIM for cost estimation.

The application of BIM by construction companies in the United States (US) was investigated by Sattineni & Bradford (2011) [20]. The authors used a web-based survey to understand the viewpoints of various respondents, including owners, vice presidents, BIM managers, BIM engineers, estimators, and architects. The most common application of BIM was for visualization. A majority of the respondents highlighted the use of BIM for cost estimation. The respondents also indicated that BIM improved the quality of cost estimation and reduced the overall time needed for cost estimation. Smith (2014) studied issues related to implementation of BIM by project management professionals in the construction industry [21]. Interviews were conducted with three medium-sized firms (10–20 employees) and three large firms (20-plus employees) in Australia. The issues highlighted by the respondents included: the quality of BIM models, documentation accuracy, lack of standards, and legal/contractual issues, among others. Aibinu & Venkatesh (2014) investigated the BIM experience of quantity surveying firms and cost consultants in Australia [22]. The data collection included forty responses and two in-depth interviews. CostX and Buildsoft estimating software were among the commonly used BIM software reported in this study. Time savings was the most important advantage of using BIM, as observed in the study. The most challenging task reported by respondents was automation of quantity takeoff through the BIM model, followed by scarcity of skilled employee using BIM.

Harrison & Thurnell (2015) investigated the benefits and barriers of 5D BIM implementation through survey and interviews within a single large multinational consultancy in New Zealand [23]. Though the respondents were only five in number, they were all experienced and qualified quantity surveyors. The benefits of BIM reported by the respondents included: enhanced visualization, efficient data extraction for estimation at both the preliminary and detailed stages, efficient data extraction for preparing schedule of quantities, rapid identification of design changes, and improved coordination, among others. The barriers to using 5D BIM, summarized by the respondents, included: software inter-operability issues, incompatibility with quantity surveying formats, lack of industry standards/protocols to facilitate design embedment, and lack of context for construction methods, among others. Taihairan & Ismail (2015) analyzed the use of BIM among the quantity surveyors working with consultancy firms and government agencies in Malaysia [24]. Twenty-five respondents participated in the questionnaire study, followed by semi-structured interviews with five respondents. The dominant factors of using BIM for cost estimation reported were: more value-added activities during estimation and better visualization. The study also identified collaboration and information sharing between project teams and software investment as important barrier to BIM implementation.

The survey conducted by Franco et al. (2015) highlighted accuracy and precise takeoff with the help of BIM [25]. The study also highlighted the need of proper mechanism of BIM adoption amongst subcontractors. BIM has certainly gained popularity in past few years in terms of quantity takeoff and cost estimation. Olsen & Taylor (2017) performed a questionnaire survey (14 respondents), followed by interviews with four respondents [26]. The respondents were working either as estimators or virtual design and coordination (VDC) coordinators in the southeastern US. Autodesk Revit, Bentley, Vico, Assemble and Autodesk Navisworks were among the popular BIM software identified in this study. The majority of the respondents in the survey preferred Assemble, followed by Autodesk Revit for quantity takeoff. Visualization and speed were the common advantages of using BIM for cost estimation, whereas BIM models with incorrect data and software complexity were some of the limitations reported in this study. Mayouf et al. (2019) conducted semi-structured interviews (20 respondents) to investigate the role of quantity surveyors within the BIM process [27]. The first group (10 respondents) had a research and academic background, while the remaining group were quantity surveying practitioners (most of these practitioners used CostX tool for 5D BIM). The respondents from academia followed an information-driven approach, whereas practitioners adopted a process-change approach when working with BIM. The authors highlighted the need for more collaboration between academia and industry for the effective teaching of BIM. The study revealed a lack of understanding of the BIM workflow and the identification of missing information from the BIM model as some of the challenges for implementing 5D BIM. Babatunde et al. (2019) analyzed the use of BIM for detailed cost estimation and the drivers for BIM adoption [28]. The study included survey of 37 quantity surveying firms (13 BIM users and 24 non-BIM users) from Nigeria. It was found that Microsoft Excel is more often used along with 3D BIM. The commonly used BIM software for detailed cost estimation were Autodesk QTO, Navisworks, Innovaya composer and CostX. The major drivers for BIM adoption were quantity automation, time savings in quantity preparation, enhance decision-making quality, data coordination, and improvements in design quality.

3.4. Case analysis

This section covers the findings of three case studies in which researchers have demonstrated the benefits of BIM for cost estimation across different project phases.

3.4.1. Quantitative evaluation of the BIM-assisted construction detailed cost estimates

Shen & Issa (2010) evaluated the effectiveness of BIM-assisted detailed estimating (BADE) tools in generating detailed construction cost estimates [29]. The evaluation was done based on four parameters: generality, flexibility, efficiency, and accuracy. Entry-level users found BADE tools to perform better compared to traditional estimating methods. The authors also presented a simple case of brick veneer quantities to highlight the effect of construction methods and trade knowledge on detailed quantity breakdowns. Following were the key findings through this case study:

1. Detailed cost estimation involves calculation of product/procurement quantities (PPQ) as well as estimating process quantities (PCQ).
2. The variation in PPQ is negligible, but PCQ will vary significantly from one contractor to another. PCQ will depend on several factors such as construction process/methods and job-specific conditions.
3. Even though BADE tools are available, the estimator's manual interpretation and analysis are still critical for extracting correct PCQs from the BIM model.

3.4.2. Project-based quantification of BIM Benefits

In this case study Li et al. (2014) revealed the BIM benefits in resource management and real-time costs control [30]. The authors documented the lessons learnt from the project 'Shanghai Disaster Recovery Centre'. The case study was analyzed in three areas: BIM in MEP design review, 4D simulation of construction scheme, and BIM-based materials management and control. Following were the key findings through this case study:

1. The use of BIM helped in resolving MEP design issues before and during construction. This resulted in total savings of approximately 66 days of schedule and 3% of the total MEP construction cost.
2. The pre-discussions and real-time coordination using BIM shortened the construction schedule by three months.
3. BIM can help project managers in procurement audit and achieve cost savings by increasing the efficiency of the procurement process.

3.4.3. Cost comparison of a building project

Haider et al. (2020) performed a comparative cost analysis between traditional method and BIM for a building project [31]. The following were the key findings from this case study:

1. The cost comparison was conducted for activities comprising brick work, RCC slab, plaster work, PCC for flooring, floor tile work, skirting, paint work, false ceiling, doors, and aluminum work.
2. The total cost difference between manual and BIM estimation method was approximately 5%. The authors observed that BIM-assisted estimates have better performance compared to the traditional (manual) method.

Table 1 summarizes a few additional case studies on cost estimation using BIM.

4. Conclusions

The present study attempted to find answers to the research questions viz., 1) What are the various methodologies adopted for estimating building cost using BIM? and 2) Is BIM a popular tool among cost management professionals? A systematic literature review conducted provides the requisite findings to the research questions. The BIM approach provides an acceptable range of cost estimation for various design scenarios [18]. However, there is a need to integrate relevant standards to develop a comprehensive bill of quantities [27].

It is revealed through the present investigation that BIM is becoming a more popular tool among cost management professionals due to better visualization, reliability, and documentation, among other factors. The various BIM software mentioned in this study have their own unique characteristics to support quantity surveyors. Expert opinion is necessary along with the use of BIM software. Revisions in the construction methods and technological advancement is necessary depending upon the nature of work item [14]. Barlish & Sullivan (2012) argued that the success of BIM depends on the project and the organization [37]. The present study provides significant insights to the associated stakeholders from AEC industry on the use of BIM for cost estimation of building projects.

Table 1. Additional case studies on BIM

Authors / Year	Topic	Observations
Azhar et al. (2008) [7]	"Building information modeling (BIM): benefits, risks and challenges"	The case deals with hotel project. The use of BIM had a cost benefit of $600,000 due to removal of clashes and 1143 hours of savings in the scheduling.
Naneva et al. (2020) [17]	"Integrated BIM-based LCA for the entire building process using an existing structure for cost estimation in the Swiss context"	Developed a methodology to integrate life cycle assessment (LCA) with BIM. The methodology helps to minimize the rework of data entry and also helps in decision making.
Jalaei & Jrade (2014) [32]	"Integrating BIM with green building certification system, energy analysis, and cost estimating tools to conceptually design sustainable buildings"	Proposed an integrated method that helps for green building certification.
Wasmi & Castro-Lacouture (2016) [33]	"Potential impacts of BIM-based cost estimating in conceptual building design: a university building renovation case study"	Analyzed the impact of building design modifications on cost using BIM tools.
Forgues et al. (2012) [34]	"Rethinking the cost estimating process through 5D BIM: A case study"	Investigated the advantages and challenges of cost estimation using BIM.
Franco et al. (2015) [25]	"Using building information modeling (BIM) for estimating and scheduling, adoption barriers"	Demonstrated use of BIM through a case study.
Le et al. (2021) [35]	"A BIM-database-integrated system for construction cost estimation"	Developed a workflow for automatic quantity takeoff and cost calculation using Dynamo and Python.
Fazeli et al. (2020) [18]	"An integrated BIM-based approach for cost estimation in construction projects"	Applied the proposed BIM-based approach for estimating the architectural cost of a residential complex in Iran.
Pandit et al. (2018) [36]	"Operational Feasibility of BIM Applications in Indian Construction Projects"	Performed cost analysis for a residential building using Autodesk Revit and Navisworks. Also made a comparative analysis between traditional and BIM estimate.

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