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Enhancing Cost Estimation with Building Information Modeling (BIM) in the Construction Industry: A Case Study in Kuala Lumpur

Cheok Ka Yee[1], Seow Ta Wee[1,2,*], Goh Kai Chen[1,2], Md Asrul Nasid Masrom[1,2]

[1] *Department of Construction Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, MALAYSIA*
[2] *Centre of Sustainable Infrastructure and Environment Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, MALAYSIA*

*Corresponding Author: tawee@uthm.edu.my
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Abstract

Cost estimation is a critical component of construction project management, directly influencing project success by ensuring economic feasibility and effective resource allocation. However, traditional cost estimation methods in Kuala Lumpur, Malaysia, struggle to meet the increasing demands of urbanization and complex project dynamics, often leading to inaccuracies and cost overruns. The purpose of this study is to assess the accuracy of traditional cost estimation methods, to investigate the relationship between Building Information Modeling (BIM) and cost estimation, and to recommend strategies to enhance the adoption of BIM in the construction industry. Data were collected through a quantitative survey of 234 respondents and analyzed using SPSS and Microsoft Excel with descriptive statistics, reliability analysis, and Pearson correlation techniques. The results of the study indicate that traditional methods have significant limitations and are not adaptable to dynamic market conditions and project complexity. BIM has the potential to improve the accuracy of cost estimates, reduce errors, and enhance collaboration among stakeholders. However, barriers such as high implementation costs and a lack of expertise hinder its widespread adoption. The discussion highlighted the need for government incentives, affordable training programs, and clearer guidelines to encourage BIM implementation. Future research should explore the integration of machine learning models and statistical methods to further improve prediction accuracy, as well as expand research to other regions. These efforts will support the development of more accurate and efficient cost estimating practices, ultimately advancing the construction industry.

1. Introduction

Cost estimation is a critical component of construction project management, influencing a project's financial success and feasibility. Accurate estimates ensure efficient resource allocation, prevent cost overruns, and maintain financial stability throughout a project's lifecycle (Ahiaga-Dagbui *et al*., 2017). While traditional methods, such as historical data analysis, expert judgment, and benchmarking, have been effective for smaller-scale projects, they increasingly fall short in addressing the complexities of modern construction (Elfaki *et al*., 2014). This limitation is particularly evident in Kuala Lumpur, where rapid urbanization and infrastructure growth often lead to budget overruns and inefficiencies, underscoring the need for more precise and adaptive cost estimation techniques.

Building Information Modeling (BIM) presents a promising solution to these challenges by integrating detailed digital representations of a building's physical and functional characteristics. BIM enables improved cost forecasting, better resource management, and more effective control of construction costs. Additionally, advancements in statistical models and machine learning enhance accuracy by reducing human error and incorporating variables like project scope and market conditions (Asadi *et al*., 2023). This study seeks to assess the accuracy of traditional cost estimation methods and explore the transformative potential of BIM in Kuala Lumpur's construction industry, providing insights into how emerging technologies can address the demands of modern construction.

Accurate cost estimation is a fundamental aspect of construction project management, yet traditional methods in Kuala Lumpur often fail to account for the increasing complexity and dynamic nature of modern construction projects. As a result, cost overruns, delays, and resource mismanagement have become prevalent issues. Traditional methods, such as expert judgment, historical data, and unit pricing, are often based on assumptions that do not reflect the evolving demands of large-scale urban construction projects. These outdated approaches often lead to significant discrepancies between estimated and actual costs, jeopardizing project success and stakeholder satisfaction.

The adoption of modern technologies, such as Building Information Modeling (BIM), could significantly improve the accuracy and efficiency of cost estimation by providing a more comprehensive and data-driven approach. However, the implementation of BIM has been slow in Malaysia's construction industry, primarily due to high initial implementation costs, a lack of skilled personnel, and resistance to change. As of 2021, the adoption rate of BIM in Malaysia's construction industry was approximately 55% (CIDB, 2021), indicating that many construction companies continue to rely on traditional methods despite the potential advantages of BIM.

The slow pace of BIM adoption in Malaysia raises concerns about the industry's ability to keep up with the evolving needs of construction projects. This study seeks to address the gap between the current state of cost estimation in Kuala Lumpur's construction industry and the potential for improving it through modern technologies. It will explore the challenges of traditional cost estimation methods, investigate how BIM can overcome these limitations, and evaluate strategies to increase BIM adoption to enhance project outcomes in the future.

The following objectives for this study are to identify the accuracy of traditional cost estimation methods. To investigate the relationship between Building Information Modeling (BIM) and Cost Estimation and to recommend construction industry to increase the adoption of Building Information Modeling (BIM) in the construction industry in the future. This research examines the challenges of traditional cost estimation methods in Kuala Lumpur's construction industry, emphasizing their limitations in managing increasing project complexity amid rapid urbanization. It evaluates the accuracy of these methods and explores how Building Information Modeling (BIM) can improve cost forecasting. By engaging key stakeholders, including project managers and procurement officers, the study gathers insights into current practices, identifies BIM's potential benefits, and addresses adoption barriers. The findings aim to optimize cost estimation practices and enhance the efficiency and sustainability of construction projects in Kuala Lumpur.

This study is vital for construction contractors and project managers in Kuala Lumpur, aiming to enhance cost estimation practices, reduce budget overruns, and improve project management through modern techniques like Building Information Modeling (BIM). It provides government authorities and policymakers with insights to promote BIM adoption, foster sustainable construction, and support the sector through training and incentives. Academically, the research contributes to cost estimation knowledge in rapidly urbanizing regions, addressing gaps in BIM adoption studies. Ultimately, it supports sustainable development by improving resource efficiency, construction quality, and reducing environmental impacts, benefiting both the industry and the wider community.

2. Literature Review

2.1 Cost Estimation

Cost estimation is a vital component of project management, providing the financial framework required for project delivery. It ensures realistic budgeting, effective resource allocation, and mitigation of financial risks (Meredith *et al*., 2017; Schwalbe, 2015). By analyzing historical data, market conditions, and project-specific factors, cost estimation enables project managers to plan effectively and maintain financial control (PMI, 2017; Kerzner, 2017). Accurate estimates are essential for managing today's complex and dynamic business environments, preventing budget overruns and resource inefficiencies (Fleming, 2019; PMI, 2021). Continuously updating cost estimates improves decision-making and enhances the likelihood of successful project outcomes.

In construction, cost estimation is fundamental to project success, providing a basis for planning, execution, and risk management (Mubarak, 2015). During the design phase, it supports detailed budgeting and prevents financial shortfalls (Halabi & Soman, 2018). Accurate estimates optimize resource allocation, reduce waste, and ensure sufficient materials and labour during peak periods (Aljohani, 2017). They also help identify financial risks, enabling contingency planning and timely project completion (Mohanad & Al-Taie, 2021).

Cost estimates inform critical decision-making, allowing comparison of design options and selection of the most cost-effective solutions. In contract management, they define terms and prevent disputes, ensuring cash flow and project progress (Nguyen *et al*., 2019). Additionally, cost estimation supports performance monitoring, enabling project teams to compare actual expenses against budgets and address deviations effectively (Aibinu & Pasco, 2018). Overall, accurate cost estimation drives economic efficiency and project success.

2.2 Traditional Cost Estimation Methods

Cost estimation is a critical aspect of project management, providing a foundation for planning, budgeting, and control (Schwalbe, 2015). Traditional cost estimation methods rely on historical data, industry standards, and expert judgment, making them prevalent in construction and engineering despite advances in technology (Memon *et al*., 2014). While they are simple, proven, and widely adopted, these methods face challenges in adapting to complex, dynamic projects and situations with limited historical data (Shafiei & Said, 2013; Kerzner, 2017).

2.2.1 Types of Traditional Cost Estimation Methods

Table 1 *Types of Traditional Cost Estimation Methods*

Types	Advantages	Challenges
Analogy Estimation	Simple and fast	Less accurate for projects differing from past ones
Parameter Estimation	Suitable for a data-rich project	Requires complex models and large data
Bottom-up Estimation	Accurate and detailed	Time-consuming and needs a work breakdown structure.
Expert Judgment	Flexible for innovative projects	Subjective and biased
Three-point Estimation	Accounts for uncertainty	Requires detailed analysis and more work
Unit Cost Method	Simple to apply	Limited to standardized projects

2.2.2 Limitations of Traditional Cost Estimation Methods

Traditional cost estimation methods have several limitations. First, they rely heavily on historical data, which may not accurately reflect new or innovative projects. The subjectivity of expert judgment introduces bias, leading to inconsistent estimates. These methods also fail to adapt to changes in project scope or market conditions, making them less reliable as project circumstances evolve. Moreover, traditional methods often struggle with the complexity of modern construction projects, which have diverse stakeholders and advanced technologies. Finally, they are not well-integrated with modern tools like BIM, limiting their ability to provide real-time, dynamic cost estimates.

2.3 Modern Cost Estimation Method – Building Information Modeling (BIM)

Building Information Modeling (BIM) transforms cost estimation through its digital, integrated approach. It combines detailed project data with advanced visualization, significantly improving accuracy and collaboration (Ghaffarianhoseini *et al*., 2016). Building Information Modeling (BIM) enhances cost estimation by offering detailed, integrated models that include all project elements. Visualization and quantity takeoff in BIM allow estimators to view the project in 3D and generate accurate material quantities. BIM also integrates cost data with the design, providing 5D BIM, which includes time and cost dimensions. This integration enables real-time updates to cost estimates, improving accuracy and efficiency throughout the project lifecycle. The result is more precise, dynamic, and reliable cost estimation.

2.4 The Adoption of BIM in Malaysia

Building Information Modeling (BIM) is playing an increasingly important role in Malaysia's construction industry by improving accuracy, speed, and communication. As adoption rates increase, the benefits of BIM become more apparent, with a growth from 17% in 2016 to 55% in 2021, as shown in Table 2. Initially, limited adoption was due to awareness, investment costs, and staffing constraints. However, as the advantages of BIM, such as better visualization, cost estimation, and collaboration, became evident, adoption rose steadily. The 55% adoption rate in 2021 reflects widespread recognition of BIM's value, particularly in large-scale projects.

Table 2 *Adoption Rate of BIM in Malaysia from 2016-2021 (CIDB, 2021)*

Year	Adoption Rate
2021	55%
2019	49%
2016	17%

Despite the clear benefits of BIM, several challenges hinder its widespread adoption in Malaysia. One significant barrier is the lack of awareness and understanding of BIM's potential among industry stakeholders, especially small and medium-sized enterprises (SMEs). Many companies do not fully comprehend how BIM can improve their project outcomes, making them reluctant to invest in its implementation. Additionally, the high initial costs associated with BIM adoption, including expenses for hardware, software, and staff training, pose another obstacle, particularly for SMEs with limited budgets. Even though BIM can yield long-term savings, the upfront costs are often seen as prohibitive.

Another challenge is the insufficient training and education available for construction professionals. The shortage of skilled workers proficient in BIM technology makes it difficult to maximize its potential. More comprehensive training programs are needed to equip the workforce with the necessary skills to implement BIM effectively. Additionally, there is resistance to change within the Malaysian construction industry, which tends to be traditional and reluctant to adopt new technologies. Many professionals are accustomed to older methods, and fear of the unknown or concerns about job security may contribute to this resistance. Overcoming these barriers will require a concerted effort to demonstrate the benefits of BIM and provide the necessary support to ease the transition.

2.5 Comparative Studies of Traditional and Modern Cost Estimation Methods

Cost estimation plays a crucial role in construction project management, directly influencing project feasibility and success. Traditional methods of cost estimation, such as analogous, parametric, and bottom-up estimating, rely on expert judgment and historical data. While these methods can provide initial cost insights, they are prone to biases and inaccuracies due to their reliance on human judgment and limited data. In contrast, Building Information Modeling (BIM) enhances the accuracy of cost estimation by integrating 3D models with detailed project data, which allows for real-time updates and a more reliable estimate of costs.

In terms of efficiency and time savings, traditional methods can be slow and labour-intensive, requiring manual calculations and data collection. BIM, however, automates many aspects of the estimating process, significantly reducing the time required to generate accurate cost estimates. This automation also enables project teams to respond more quickly to changes in the project scope or customer needs. Regarding integration and collaboration, traditional methods often create communication barriers between different stakeholders, such as designers, engineers, and contractors. BIM, on the other hand, integrates all project data into a common digital environment, facilitating seamless collaboration and ensuring that all stakeholders have access to the most up-to-date information.

Flexibility and adaptability are other key differences between traditional methods and BIM. Traditional cost estimation methods struggle to accommodate design changes, often requiring extensive revisions to cost estimates. BIM allows for dynamic project management by providing the ability to simulate various scenarios and evaluate the impact of design modifications or alternative construction methods on cost and schedule. Finally, cost-effectiveness is a significant advantage of BIM over traditional methods. While traditional methods may seem cheaper upfront, they often lead to inefficiencies, rework, and cost overruns. BIM's initial investment is higher, but over the project lifecycle, it can save significant costs by improving accuracy, reducing errors, and optimizing project delivery.

In summary, BIM's integration of technology provides significant advantages over traditional methods in terms of accuracy, efficiency, collaboration, flexibility, and long-term cost-effectiveness. This makes BIM a crucial tool for modern construction project management, offering better results and enhanced control throughout the project lifecycle.

2.6 Recommendation for the Construction Industry to Increase the Adoption Rate of BIM

2.6.1 Education and Training Initiatives

To boost BIM adoption, it is essential to close the skills gap through education and training. Integrating BIM courses into university curricula and offering certification programs will provide future professionals with a strong understanding of the technology. Training should be available for both new engineers and experienced professionals seeking to enhance their BIM skills. Mentoring programs can further support knowledge transfer, while keeping professionals updated with webinars and industry conferences ensures they stay current with evolving BIM technologies (Zou *et al*., 2017; Uhm *et al*., 2017; Sacks *et al*., 2018).

2.6.2 Leadership and Organizational

Successful BIM implementation requires strong leadership and organizational commitment. Organizations must align BIM adoption with their business goals and allocate resources for training, software, and hardware. A well-defined change management strategy can address resistance, and appointing BIM champions can encourage adoption at all levels. Defining performance indicators and offering incentives can further motivate employees to embrace BIM (Ahn *et al*., 2016; Bosch-Sijtsema *et al*., 2018; Oraee *et al*., 2017).

2.6.3 Investment in Technology and Infrastrure

A solid technological foundation is critical for BIM success. Organizations must select appropriate software and hardware, invest in cloud-based platforms for real-time collaboration, and ensure data security through robust cybersecurity measures. Mobile-compatible BIM solutions and high-capacity networks are also necessary for efficient project management. Incorporating AR and VR technologies into BIM environments can enhance visualization and stakeholder engagement (Arayici *et al*., 2017; Antwi-Afari *et al*., 2018; Elghaish *et al*., 2019).

2.6.4 Collaboration and Demonstrating Value

Widespread BIM adoption depends on demonstrating its value through collaboration. Engaging all project participants within the BIM framework ensures better synchronization and project outcomes. Advocating for open BIM standards can enhance data sharing across platforms. Case studies showcasing the benefits of BIM can encourage clients to invest more, while collaboration between industry stakeholders and government agencies can help develop standards and best practices (Liu *et al*., 2016; Ghaffarianhoseini *et al*., 2016; Succar & Kassem, 2015; Charef *et al*., 2018).

2.7 Previous Studies

Traditional cost estimation methods like analogous, parametric, and bottom-up estimating have been used for decades. While these methods are widely accepted, they are often inaccurate, especially for unique or new projects. BIM has introduced a more integrated approach to cost estimation, enhancing accuracy and efficiency by providing up-to-date models and improved collaboration among stakeholders. Although BIM-based cost estimation shows promise, challenges such as high setup costs and the need for skilled personnel remain. Further research is needed to explore the real-world application and cost benefits of BIM, as well as the training required for its effective use (Bryde *et al*., 2013).

3. Research Methodology

3.1 Research Design

The research flow for this study followed a systematic approach divided into three stages. In the preliminary stage, the research problem, objectives, and literature review were established, along with the formulation of research questions and hypotheses. The second stage involved data collection through a structured questionnaire and the review of secondary data, with pilot testing conducted for reliability and validity. In the final stage, statistical analysis was performed using SPSS and Microsoft Excel to interpret the data and present the results in a structured format. A visual representation of the research flow is shown Appendix A.

This study utilizes a quantitative research design to collect and analyse numerical data, focusing on the effectiveness of BIM in improving cost estimation accuracy. A structured questionnaire was used for data collection, allowing for consistency and statistical comparison between traditional and BIM-based methods. The use of statistical tools like SPSS and Excel ensures accurate analysis, providing valuable insights into BIM's impact on cost estimation in Kuala Lumpur's construction industry.

3.2 Data Collection

Data for this study was collected in two parts: primary data through a structured questionnaire and secondary data from academic and industry sources.

- *Primary Data*

Primary data was collected directly from Grade 7 registered contractors in Kuala Lumpur using a structured questionnaire. The survey aimed to assess the accuracy and efficiency of traditional versus BIM-based cost estimation, contractors' perceptions of BIM adoption, and factors influencing its use in cost estimation practices. This method ensured data relevance and quality, contributing original insights to the study.

- *Secondary Data*

Secondary data was obtained from academic journals, industry reports, and publications. These sources provided a theoretical foundation and identified knowledge gaps, complementing the primary data with broader contextual insights. Secondary data was gathered from academic journals, industry reports, and case studies on cost estimation, construction management, and Building Information Modeling (BIM). These sources provided context and helped identify knowledge gaps, complementing the primary data and supporting the research's theoretical framework.

3.3 Instrument

A structured questionnaire was developed and distributed via Google Form. Section A, which covers General Information, were measured using frequency analysis. Section B, focused on Traditional Cost Estimation Methods, were utilize multiple-choice questions and a Likert scale to gather responses. Section C, which examines Building Information Modeling (BIM) and its relation to cost estimation, were also employ multiple-choice questions and a Likert scale. Section D, discussing Future Prospects and Recommendations, were rely on a Likert scale to measure participants' opinions. Finally, Section E, which seeks Additional Comments, were feature open-ended questions to gather qualitative insights from respondents.

3.4 Population and Sampling

- *Sampling Size*

The Krejcie and Morgan method was used to calculate the sample size for this study, ensuring statistical reliability with a 95% confidence level and an appropriate margin of error. With 1,807 Grade 7 contractors in Kuala Lumpur (*MCP*, 2024), the sample size is 317 respondents, as per the Krejcie and Morgan table.

- *Sampling Method*

Stratified sampling was used, with the sample divided based on company size, years of experience, and types of projects. This approach ensured diverse representation across different contractor subgroups, enhancing the reliability and validity of the research.

3.5 Process Data Collection

The research data was meticulously prepared for accuracy and reliability, incorporating both primary and secondary sources. The primary data was collected through closed-ended and open-ended questionnaires tailored for contractors, providing quantitative data for statistical analysis and qualitative insights into their experiences. Krejcie and Morgan sampling methods were employed, with surveys distributed via email and online platforms. The secondary data was gathered from academic journals and industry reports, focusing on cost estimating practices and BIM's role in the construction industry. The collected data was thoroughly checked for completeness before analysis, ensuring a comprehensive and balanced exploration of the topic.

3.6 Data Analysis

The collected data were thoroughly analysed to gain meaningful insights into BIM's impact on cost estimation accuracy in Kuala Lumpur's construction industry. Both quantitative statistical techniques and qualitative coding for open-ended responses were used. SPSS Version 30 and Microsoft Excel were served as the primary tools for statistical analysis and data visualization.

4. Results and Data Analysis

4.1 Cronbach's Alpha Reliability Analysis

To verify the consistency and reliability of the data, reliability analysis was performed using Cronbach's alpha for each research objective. The analysis confirmed the questionnaire's internal consistency, demonstrating reliability scores above acceptable thresholds. Table 3, summarizing the reliability results for each objective, is provided to support this section, offering insight into the robustness of the data.

Table 3 *Result of Reliability Analysis of Each Objective*

Variable	Cronbach's Alpha	Internal Consistency
Objective 1: Accuracy of Traditional Cost Estimation Methods	0.961	Excellent
Objective 2: Relationship Between BIM and Cost Estimation	0.987	Excellent
Objective 3: Recommendation on Increasing the Adoption of BIM in the Construction Industry	0.979	Excellent

4.2 Respondent Demographics

The demographic profile of the respondents reveals a diverse group of participants from various roles within the construction industry, including project managers, executives, and procurement officers. Insights were also gathered on the participants' years of experience and their familiarity with cost estimation techniques. The detailed data of the respondent demographics is placed in Appendix B.

The respondents' positions within their companies were categorized into four groups: contractors, project managers, quantity surveyors, and procurement officers. The highest frequency of responses came from contractors, with 112 respondents (47.9%), followed by project managers with 57 respondents (24.4%), quantity surveyors with 34 respondents (14.5%), and procurement officers with 31 respondents (13.2%).

In terms of experience in the construction industry, 110 respondents (47.0%) had 0-5 years of experience, 65 respondents (27.8%) had 6-10 years of experience, 52 respondents (22.2%) had 11-15 years of experience, and only 7 respondents (3.0%) had more than 15 years of experience.

Regarding experience with cost estimation, the majority of respondents, 115 (49.1%), had 0-5 years of experience, while 65 respondents (27.8%) had 6-10 years of experience, 47 respondents (20.1%) had 11-15 years of experience, and 7 respondents (3.0%) had more than 15 years of experience.

The adoption of BIM for cost estimation among the 234 respondents' companies. The results reveal a 100% adoption rate, with all respondents indicating that their organizations have integrated BIM into their cost estimation processes.

Most respondents (84.2%) reported 1-4 years of experience, indicating that BIM adoption for cost estimation is a recent trend. Additionally, 7.7% had less than 1 year of experience, representing recent adopters, while 8.1% had over 5 years, highlighting early adopters with more mature usage. This distribution reflects BIM's growth trajectory in cost estimation, with most companies in early to intermediate adoption stages.

4.3 Objective 1: Accuracy of Traditional Cost Estimation Methods

The accuracy of traditional cost estimation methods was analysed based on responses from 234 participants, with the findings ranked according to the Relative Importance Index (RII). The highest-ranked factor was Handling Risks and Uncertainty, with an RII of 0.934, indicating the effectiveness of traditional methods in managing predictable risks. The second-ranked factor, Dependence on Historical Data, had an RII of 0.901, highlighting the importance of reliable historical data for accurate cost predictions. Use of Familiar Data and Tools ranked third with an RII of 0.896, emphasizing the role of familiarity in improving accuracy. Reliability of Expert Judgment was ranked fourth with an RII of 0.891, underlining the value of experienced professionals in traditional cost estimation. The lowest-ranked factor, Flexibility in Handling Project Changes, achieved an RII of 0.888, pointing out a limitation in adapting to significant project changes. The detailed breakdown of RII and rankings is provided in Table 4.

Table 4 *Accuracy of Traditional Cost Estimation Methods in Predicting Actual Project Costs*

No.	Item	RII	Overall RII	Ranking
A1	Dependence on Historical Data		0.901	2
1.	Traditional cost estimation methods provide reliable estimates when based on up-to-date historical data.	0.935		
2.	Historical data used in traditional methods helps in predicting costs accurately for similar projects.	0.869		
3.	In my experience, traditional methods based on past data have been accurate in most projects.	0.863		
4.	Historical data is an effective foundation for cost estimation in traditional methods.	0.937		
A2	Flexibility in Handling Project Changes		0.888	5
1.	Traditional cost estimation methods allow for manageable adjustments.	0.897		
2.	Traditional cost estimation methods can accommodate small project changes efficiently.	0.847		
3.	Traditional cost estimation methods can maintain accuracy even with minor project alterations.	0.937		
4.	Traditional cost estimation methods are useful in controlling project costs.	0.874		
A3	Reliability on Expert Judgment		0.891	4
1.	Experienced professionals' judgment greatly enhances the accuracy of traditional cost estimation methods.	0.935		
2.	Traditional methods benefit from the expertise and knowledge of seasoned professionals in cost estimation.	0.856		
3.	Expert judgment helps in providing reliable estimates in a project using traditional methods.	0.936		
4.	The input of industry experts makes traditional cost estimation methods more dependable.	0.838		

Table 4 *Accuracy of Traditional Cost Estimation Methods in Predicting Actual Project Costs (continue)*

A4	Use of Familiar Data and Tools		0.896	3
1.	Traditional methods offer accuracy due to the familiarity of the data and tools used.	0.932		
2.	The familiarity tools and techniques in traditional methods enhances their reliability for cost estimation.	0.834		
3.	Traditional methods benefit from widely recognized and trusted data sources.	0.944		
4.	The well-established processes of traditional methods ensure consistent cost estimation outcomes.	0.873		
A5	Handling Risks and Uncertainty		0.934	1
1.	Traditional methods can accurately manage project risks in predictable environments.	0.950		
2.	Traditional techniques handle common risks effectively, ensuring cost control.	0.958		
3.	Risk assessment in traditional methods supports accurate cost estimation for typical project risks.	0.895		

4.4 Objective 2: Relationship Between BIM and Cost Estimation

The accuracy of BIM for cost estimation was assessed based on five key factors, ranked by their overall Relative Importance Index (RII), as summarized in Table 5. The highest-ranked factor was Real-time Data Integration (RII: 0.942), emphasizing BIM's ability to provide accurate and up-to-date cost estimates through real-time updates. Detailed Quantity Takeoffs ranked second (RII: 0.923), highlighting the role of automation in improving precision and reducing human error. Collaboration and Coordination were third (RII: 0.908), reflecting their importance in aligning stakeholders and minimizing discrepancies. Fourth was Scenario Analysis and Risk Management (RII: 0.897), showcasing BIM's capability to incorporate risk assessments and scenario planning. Lastly, Improved Visualization ranked fifth (RII: 0.895), underscoring the value of 3D modeling in enhancing cost estimation accuracy. These results confirm BIM's superiority over traditional methods in delivering precise and reliable cost estimations.

Table 5 *Accuracy of BIM for Cost Estimation*

No.	Item	RII	Overall RII	Ranking
B1	Real-time Data Integration		0.942	1
1.	BIM improves cost estimation by integrating real-time data into the estimation process.	0.946		
2.	The use of real-time data in BIM allows for more accurate and up-to-date cost estimates.	0.940		
3.	BIM enables continuous updates to cost estimates through real-time data synchronization.	0.940		
B2	Detailed Quantity Takeoffs		0.923	2
1.	BIM enhances the accuracy of cost estimation through automated and detailed quantity takeoffs.	0.930		
2.	The detailed quantity takeoffs generated by BIM are more precise compared to traditional methods.	0.896		
3.	BIM reduces human error in quantity takeoffs, leading to more accurate cost estimates.	0.944		

Table 5 *Accuracy of BIM for Cost Estimation (continue)*

B3	Improved Visualization		0.895	5
1.	BIM's 3D visualization helps to improve the accuracy of cost estimation by providing a clearer understanding of the project.	0.892		
2.	With BIM, the improved visualization of project elements enhances the precision of cost estimates.	0.898		
3.	BIM's visual models allow for better identification of project components, improving cost estimation accuracy.	0.894		
B4	Collaboration and Coordination		0.908	3
1.	BIM facilitates better collaboration and coordination among project stakeholders, leading to more accurate cost estimates.	0.935		
2.	The improved communication and coordination provided by BIM reduce discrepancies in cost estimation.	0.857		
3.	BIM's collaborative environment enhances the accuracy of cost estimates by ensuring that all stakeholders are aligned.	0.932		
B5	Scenario Analysis and Risk Management		0.897	4
1.	BIM supports scenario analysis, which improves the accuracy of cost estimation by considering different project outcomes.	0.934		
2.	Through BIM, risk management is more effectively integrated into cost estimation, increasing its accuracy.	0.879		
3.	BIM is able to perform scenario analysis and risk assessments, leading to more reliable and accurate cost estimates.	0.878		

The efficiency of BIM for cost estimation was evaluated based on five key factors, ranked by their Relative Importance Index (RII), as shown in Table 6. The top-ranked factor, Automation of Cost Calculations, had an RII of 0.932, highlighting BIM's ability to save time and improve efficiency through automated processes. Flexibility and Adaptability ranked second with an RII of 0.912, emphasizing BIM's capability to handle project changes efficiently. The third-ranked factor, Reduction of Errors and Rework, achieved an RII of 0.911, showcasing BIM's precision in minimizing errors and reducing rework. Integration with Other Project Systems was fourth, with an RII of 0.908, reflecting its role in streamlining workflows by linking various project management systems. Lastly, Enhanced Collaboration also had an RII of 0.908, underscoring the importance of BIM's collaborative features in improving project efficiency. These results affirm BIM's significant advantages over traditional methods in enhancing cost estimation efficiency.

Table 6 *Efficiency of BIM for Cost Estimation*

No.	Item	RII	Overall RII	Ranking
C1	Automation of Cost Calculations		0.932	1
1.	BIM improves efficiency by automating the cost calculation process.	0.898		
2.	The automated cost calculations in BIM are faster and more efficient compared to manual methods.	0.938		
3.	BIM reduces the time required for cost estimation through its automated calculation features.	0.961		
C2	Integration with Other Project Systems		0.909	4
1.	BIM enhances efficiency by integrating seamlessly with other project management systems.	0.883		
2.	The integration of BIM with design, scheduling, and procurement systems improves overall project efficiency.	0.897		

3.	BIM is able to link with other project tools, reducing the need for repetitive data entry, increasing efficiency.	0.945

Table 6 *Efficiency of BIM for Cost Estimation (continue)*

C3	Reduction of Errors and Rework		0.911	3
1.	BIM increases efficiency by reducing errors and minimizing the need for rework in cost estimation.	0.942		
2.	The precision offered by BIM reduces costly mistakes compared to traditional cost estimation methods.	0.898		
3.	By identifying potential issues early, BIM decreases rework and improves overall project efficiency.	0.893		
C4	Flexibility and Adaptability		0.912	2
1.	BIM offers greater flexibility and adaptability in cost estimation, improving project efficiency.	0.943		
2.	The ability of BIM to easily adapt to project changes makes it more efficient than traditional methods.	0.903		
3.	BIM’s flexibility in adjusting to scope changes enhances the efficiency of the cost estimation process.	0.890		
C5	Enhanced Collaboration		0.908	5
1.	BIM improves efficiency by enhancing collaboration among project teams during the cost estimation process.	0.938		
2.	The collaborative features of BIM reduce delays caused by miscommunication in traditional cost estimation.	0.890		
3.	BIM's shared platform allows for more efficient coordination, speeding up the cost estimation workflow.	0.897		

The Pearson correlation between the accuracy and efficiency of BIM in cost estimation was calculated using SPSS, with results shown in Table 7. A coefficient of 0.971 and a significance (2-tailed) value of <0.001 indicate a highly significant positive correlation. This reflects a strong interdependence between BIM's accuracy and efficiency, where improvements in one aspect enhance the other. The significance (2-tailed) value tests whether the observed correlation is due to chance. A value of <0.001 confirms that the relationship between accuracy and efficiency is statistically significant, underscoring BIM's dual role in addressing cost estimation challenges.

Table 7 *Pearson Correlation for BIM’s Accuracy and Efficiency for Cost Estimation*

Correlations	Mean Accuracy	Mean Efficiency
Mean Accuracy	1	0.971
Mean Efficiency	0.971	1
Significance (2-tailed)	-	<0.001

4.5 Objective 3: Recommendations to Increase Adoption of BIM

To increase BIM adoption for cost estimation, several recommendations were ranked based on their overall RII values, as shown in Table 8. The top recommendation, with an RII of 0.944, is to demonstrate BIM's long-term cost benefits, including ROI and case studies of successful implementation. Ranked second, government incentives, such as subsidies and tax breaks, achieved an RII of 0.939, highlighting their importance in encouraging adoption. Third, the need for clear guidelines and standardized frameworks for BIM integration had an RII of 0.938, emphasizing the role of structured policies in reducing uncertainties. Fourth, addressing the high cost of training through affordable programs was ranked with an RII of 0.937, underscoring its potential to reduce the skills gap. Better Collaboration Among Stakeholders follows in fifth place with an RII of 0.920, showcasing BIM’s role in fostering communication and coordination. Lastly, more transparency has an RII of 0.922, emphasizing enhanced clarity in cost estimation for better decision-making. These recommendations point to a holistic strategy combining financial incentives, clear policies, and cost-effective training to boost BIM adoption.

Table 8 *Efficiency of BIM for Cost Estimation*

No.	Item	RII	Overall RII	Ranking
D1	Government Incentives		0.939	2
	Providing government incentives would encourage companies to adopt BIM for cost estimation.	0.934		
	Government subsidies or tax breaks would make it more attractive for firms to invest in BIM.	0.944		
D2	More Affordable Training Programs		0.937	4
	Offering more affordable and accessible training programs would increase BIM adoption for cost estimation.	0.927		
	Lowering the cost of BIM training will encourage companies to upskill their workforce for cost estimation purposes.	0.938		
	Providing more cost-effective training options will reduce the skills gap, promoting wider use of BIM.	0.945		
D3	Demonstrating Long-term Cost Savings		0.944	1
	Companies are more likely to adopt BIM if its long-term cost savings are clearly demonstrated.	0.937		
	Showing case studies of successful BIM adoption will help convince companies of its long-term financial benefits.	0.944		
	Highlighting the long-term return on investment from BIM will encourage more firms to consider its use in cost estimation.	0.951		
D4	Clearer Guidelines for BIM Adoption		0.938	3
	Providing clearer and more standardized guidelines would facilitate the adoption of BIM for cost estimation.	0.938		
	Government and industry bodies should develop clear policies to guide companies in adopting BIM for cost estimation.	0.935		
	Well-defined frameworks and guidelines for BIM use will help firms understand the process and reduce uncertainty.	0.940		
D5	Better Collaboration among Stakeholders		0.920	5
	BIM enhances collaboration among stakeholders, leading to more efficient cost estimation in the long term.	0.929		
	Over time, BIM encourages better communication and coordination between project teams and stakeholders.	0.891		
	The long-term use of BIM strengthens stakeholder relationships, improving project outcomes.	0.939		
D6	More Transparency		0.922	6
	BIM promotes greater transparency in cost estimation, providing all stakeholders with better insights.	0.936		
	Long-term adoption of BIM leads to increased transparency in project costs, reducing misunderstandings.	0.885		
	BIM ensures that cost estimation data is more transparent, which improves decision-making over time.	0.944		

5. Conclusion

This study highlighted the limitations of traditional cost estimation methods and the transformative potential of BIM in enhancing accuracy, efficiency, and collaboration. BIM's real-time data integration, automation, and collaborative features were found to significantly improve cost estimation practices. Strategies such as showcasing long-term cost savings, government incentives, and standardized guidelines provide a roadmap for increasing BIM adoption. While the study's regional focus and reliance on self-reported data pose limitations, the findings underscore BIM's ability to revolutionize construction cost estimation. By addressing these challenges, the construction industry can achieve greater precision, sustainability, and innovation.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Cheok Ka Yee, Seow Ta Wee;* ***data collection:*** *Cheok Ka Yee;* ***analysis and interpretation of results:*** *Cheok Ka Yee, Seow Ta Wee;* ***draft manuscript preparation:*** *Cheok Ka Yee, Seow Ta Wee, Goh Kai Chen, Md Asrul Nasid Masrom. All authors reviewed the results and approved the final version of the manuscript.*

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