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Applying Building Information Modelling (BIM) Technology in Pre-Tender Cost Estimation of Construction Projects: A Case Study in Iran

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Abstract: The pre-tender cost estimation serves as the foundation for determining the project cost in the early stages and is crucial for all parties involved in the tendering process. It is expected to be highly accurate. However, industry surveys have advocated that in the Iranian construction industry, the pre-tender estimated costs of construction projects are not sufficiently accurate during the bidding stage. Building information modelling (BIM) technology is a modern digital tool deployed in the construction industry that has seen substantial growth of application. It employs useful tools in different sectors and has extended its involvement in various stages of the project lifecycle, including feasibility studies, planning, design, construction, and operation and maintenance. This study examines and assesses the status of BIM development in Iran for its applicability in the pre-tender cost estimating process in construction projects. The findings of this study indicate that while there is a limited number of Iranian building projects' BIM models that possess the required quality and capabilities for BIM-based cost estimation, the results obtained are more precise when compared to existing manual methods. Additionally, utilising BIM-based cost estimation significantly reduces the time required for this process by enhancing the speed of cost estimation operations. An innovative evaluation framework for assessing the quality and functionalities of BIM models is presented, which improves the accuracy of cost estimation before the bidding process in Iran's construction industry. The research findings demonstrate the enhanced accuracy and effectiveness of BIM as compared to conventional approaches. It also suggests the incorporation of AI technology for model evaluation, which has the potential to become an established global industry standard.

Keywords: BIM technology; pre-tender cost estimation; construction bidding; quantity surveying; Iran

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1. Introduction

Cost estimation is utilised in many phases of the construction project life cycle for diverse purposes, but one of the primary uses is pre-tender cost estimating, which establishes the project cost foundation in bidding documents [1]. Meanwhile, the quantity of take-off significantly influences the reliability as well as the precision of the predicted cost. The accuracy of the cost estimate is contingent upon several aspects, including the level of detail (LOD) in the drawings and specifications, the amount of time spent on the estimation procedure, the knowledge and competence of the estimators, and the stage at which the cost estimate is made [2–4]. The dependability of the predicted cost relies on the precision of the quantities provided [5].

Building information modelling (BIM) offers a significant advantage by providing precise geometric representations of building elements inside a unified information framework [6]. BIM technology has brought about a novel method for quantity take-off known as BIM-based quantity take-off [7]. The automated measurement of quantity can be achieved by collecting both the geometric data and semantic attributes of individual building elements from BIM models. This technique immediately retrieves measurements from the BIM model, resulting in more dependable results and requiring less time and expenses [8].

Competitive bidding is the predominant approach for outsourcing in Iranian construction projects [9]. During the pre-tender stage, cost estimates are typically prepared using a traditional approach that involves manual methods. This procedure is time-consuming and prone to errors since it relies on measurements taken from 2D construction plans and human interpretations [10].

According to previous theories, the use of BIM can result in the creation of an intelligent structure. This can lead to a reduction in the time and manpower required for cost estimation, while also improving the accuracy and reliability of the results. Additionally, BIM can provide a clearer understanding of project costs during the early stages for all involved parties [11]. Nevertheless, other research has demonstrated that multiple variables influence the efficacy of using building information modelling in the process of cost estimation. One of the contributing aspects is the BIM model developed specifically for the project. Based on these investigations, incomplete or faulty BIM models can result in insufficient or wrong extracted values. To obtain accurate outcomes, it is important for a BIM model to closely resemble the real-world construction conditions [12]. Nevertheless, in the event that the BIM model is not fully or accurately constructed, the quantities derived from it may be inadequate or imprecise. To achieve precise measurements, it is necessary to generate a BIM model that closely resembles the physical construction.

This study examines and assesses the status of building information modelling in Iran for its potential application in the pre-tender cost estimation process in construction projects inside the country. This assessment was conducted in two sequential phases: the initial phase focused on assessing the capabilities necessary for BIM models of Iranian building projects to effectively execute the BIM-based cost estimation process, ensuring precise and dependable outcomes. The subsequent phase evaluated the accuracy and efficiency of the BIM-based cost estimation process. Conducting such studies, which assess the application of a scientific methodology in actual circumstances, can be efficacious in fostering a comprehensive comprehension among managers and decision makers in that domain. Historically, the introduction of novel techniques in the building sector of emerging nations like Iran has consistently been received with scepticism from the local population.

This research stands out for its innovative method of estimating pre-tender costs in Iran's construction industry by utilising building information modelling (BIM) technology. It aims to fill the gap in precise cost estimations during the bidding phase by introducing a novel framework for assessing the quality and functionalities of BIM models. The study's comparative analysis demonstrates the superior accuracy and effectiveness of BIM-based methods over traditional methods. Moreover, the cutting-edge suggestion to incorporate artificial intelligence (AI) for evaluating the quality of BIM models could greatly enhance the accuracy of cost estimation. The research's capacity to establish uniform pre-tender cost estimations in developing countries and its clearly defined future research directions highlight its contributions to the field and its wider applicability.

2. Literature Review

2.1. Cost Estimation Process

Cost estimating involves gathering and evaluating past data and utilising quantitative models, techniques, tools, and databases to forecast the future cost of an item, product, programme, or task [13,14]. This estimation is based on the available information at a specific moment in time [15].

Initially, the act of creating an estimate may seem to be an intricate computational procedure. Nevertheless, in practice, it frequently entails a subjective procedure that relies on the knowledge and expertise of the main players [16].

As portrayed in Figure 1, the Cost Guide outlines the most effective methods and typical process within a 12-step methodology for calculating project costs. The cost estimating process offers essential assistance for commencing, investigating, evaluating, scrutinising, and delivering a cost estimate. Every individual stage within the set of 12 phases holds significance in guaranteeing the timely development and delivery of cost estimates, which are crucial for supporting critical programme choices [17].

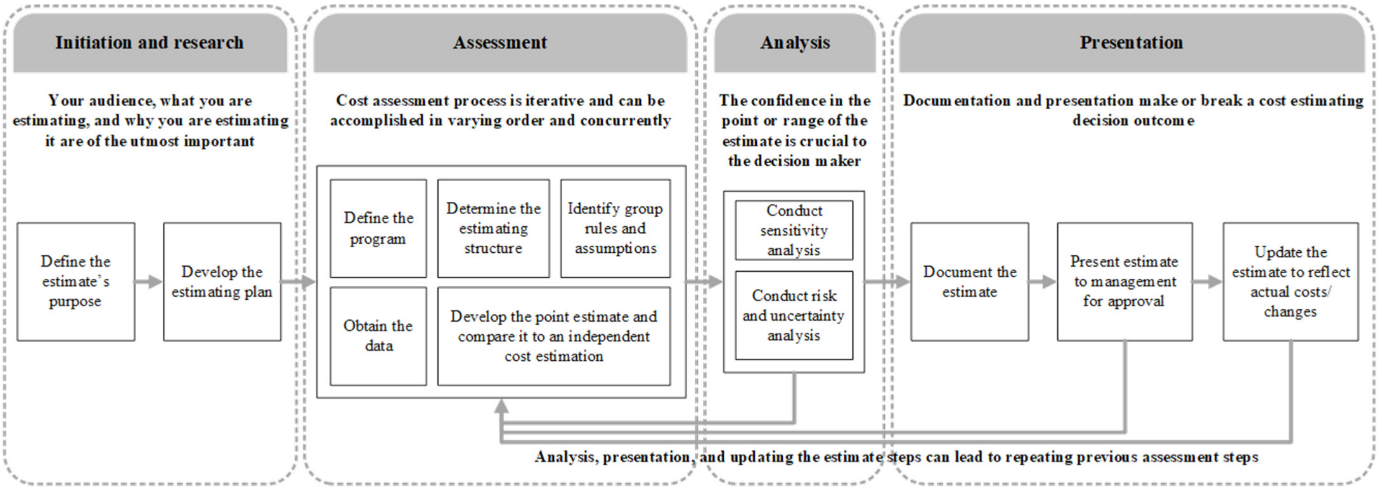


Figure 1. Typical project cost estimating process [17].

More precisely, the steps are as follows: (1) acquire the Statement of Work; (2) perform a quantity take-off: convert the scope of work into measurable quantities; (3) determine the prices for the quantities; and (4) verify the accuracy and validity: verify and implement sagacity.

During the design process, it is utilised to approximate the initial project expenditure for a feasibility analysis. During the preconstruction phase, it is utilised to approximate the project's expenses and create the bill of quantities to bid or tender the project. During the building phase, it is utilised for scheduling, procuring materials, monitoring progress, and determining change orders and additional work payments [5]. In the standard project delivery approach, also known as Design-Bid-Build (DBB), a meticulous quantity take-off is conducted during the bidding process to accurately estimate costs after the design phase [18]. Having a precise cost estimation in the first phases of the design process might assist the team in making well-informed design choices [19]. Hence, it is crucial to conduct accurate quantity take-off at the pre-tender phase [18]. The dependability of the predicted cost relies on the precision of the quantities provided [5].

The amounts of materials have a significant effect on the result of the cost estimation [20]. Quantities take-off is a customary procedure conducted after the design development phase to generate a bill of quantities to tender the project [21]. Historically, the process of quantity take-off has been laborious and susceptible to mistakes due to its reliance on measurements from 2D building plans and human interpretations [21].

2.2. Five-Dimensional (5D) BIM Model and Cost Estimation

BIM is a technological tool that utilises a digital model to accurately depict both the geometric and semantic details of a physical building [22]. Its purpose is to streamline the design, construction, and operation processes, serving as a reliable foundation for decision-making [21]. With the increasing use of BIM in the architecture/engineering/construction/operation (AECO) industry, stakeholders like owners, architects, and general contractors are focusing on methods to minimise time and expenses. This includes utilising BIM for cost estimation [1].

To promote the utilisation of BIM, previous research has identified some activities that serve as links between 3D objects and cost data. These studies have also suggested the integration of data related to cost and time [23,24]. BIM technology has brought about a new method for estimating costs known as BIM-based cost estimation [5]. The utilisation of 5D BIM in cost assessment is revolutionising the approach of professionals in their work. It reduces repetitive chores and enhances expertise, guaranteeing the accuracy of data and materials from the outset, while offering alternative options and analysis of the outcomes [25]. BIM offers a superior approach for performing quantity take-off. A BIM model consists of graphical representations and data properties for each element, allowing for the direct extraction of quantities from the identifiable objects in the model [26].

Studies have demonstrated that the utilisation of BIM for estimating purposes leads to a reduction in both working time and errors [27]. Furthermore, it enhances the performance of estimators in comparison to conventional estimation methods [24]. Bečvarovská and Matějka [28] conducted a comparative analysis of traditional quantity take off and BIM-based quantity take-off methods, utilising a case study. The study showed that employing a BIM-based approach significantly reduces both the amount of time required and the occurrence of inaccuracies, in comparison to the conventional method.

However, the Royal Institution of Chartered Surveyors (RICS) categorised BIM measurement into three distinct groups: automatic, derived, and manual take-off. The last approach is a conventional estimating method that does not utilise BIM in any way [24]. To ensure accurate BIM-based quantity take-off and cost estimation, it is crucial to clearly establish the LOD for each element of the BIM model. This is because the LOD directly impacts the accuracy of both processes [29]. LOD refers to the level of geometric detail and associated information contained within a BIM model element [30]. LOD of a model element is assessed using a scale ranging from LOD 100 to LOD 500. A model at LOD 100 includes visual depictions of items represented by a generic figure. A model at LOD 500 encompasses elements that possess precise attributes such as size, orientation, shape, quantity, and even particular model numbers. LOD 500 models are utilised for determining unit pricing estimates, whilst LOD 100 models are employed for initial estimations [31]. During the initial phases of the design process, specifically the schematic design phase and design development phase, designers employ a low LOD [18]. The enhanced visualisation of the 3D model enhances satisfaction levels and reduces the level of uncertainty surrounding cost fluctuations for both the quantity surveyor and the client throughout the project's execution [32]. The use of BIM has enhanced the accuracy of estimation by allowing estimators to proactively identify and rectify any flaws or omissions in the design [24].

2.3. Accuracy, Time Spent and Level of Detail

Skitmore [33] defined the accuracy of early stage estimates as consisting of two components: bias and consistency. Bias refers to the difference between the estimate and the contractor accepted tender price, while consistency refers to the reliability of the estimate in relation to the tender price. Bias refers to the mean difference between the actual tender price and the projection, whereas consistency of estimates refers to the level of variation around this mean. The precision of quantity take-off is indicative of the dependability of subsequent tasks, including cost planning during the design phase, cost estimation in the pre-construction phase, schedule planning, material procurement, and progress monitoring during the construction phase [34]. The accuracy range of the estimate is influenced by various variables and hazards. Therefore, the accuracy of the estimate is not just determined by the maturity and quality of the scope definition provided at the time of estimation. To determine accuracy, a risk analysis is necessary [2]. The accuracy of project estimates, particularly in the early stages of project definition, is primarily influenced by systemic risks such as the level of familiarity with technology, the complexity of the project and its execution, the quality of reference data and assumptions used in preparing the estimate, and the time and level of effort budgeted for the estimate [2].

Several research studies have suggested methods to enhance the effectiveness and precision of BIM-driven quantity take-off and cost estimation. Cheung et al. [35] created a system for estimating construction costs in real-time. This approach utilises floor areas from BIM models during the initial design phase. Aram et al. [22] introduced a framework for a knowledge-based system designed to carry out BIM-based quantity take-off. In their study, Cho and Chun [36] integrated a BIM approach for quantity take-off with a data prediction algorithm to accurately determine the amounts of reinforced concrete structures. Lim et al. [37] introduced computational approaches for estimating the amount of rebar in 3D structural models. Ma et al. [38] introduced a semi-automatic system designed to generate bills of quantities from BIM models. The system has the capability to autonomously calculate the quantities of structural elements (such as columns, slabs, and beams) that intersect with each other.

RICS established a BIM guideline specifically for cost managers, along with a corresponding validation mechanism. The guideline outlines a procedure to verify the availability of quantities that adhere to the measurement rule in BIM. This verification is conducted when examining the quantities derived from BIM during the design phase [24]. Extracting data from the model using BIM technique can improve the productivity and accuracy of estimators' work. This is because the traditional quantity take-off method, which typically consumes 50–80% of the overall working time in estimations, can be time-consuming. Therefore, utilising BIM for quantity take-off estimation can be beneficial [23].

The duration necessary for the preparation of a cost estimate will escalate in proportion to the LOD that is either accessible or required for said estimate. According to Hatamleh et al. [3], as more detail is provided, the level of accuracy also increases in direct proportion. BIM models can expedite the process by enabling estimators to directly retrieve measurements and material amounts from the models. According to Olsen and Taylor [31], the time spent on this process can be reduced by up to 80%, while still maintaining accurate quantity take-offs and estimates within a 3% margin. If the collection of illustrations lacks adequate information due to the project being in the schematic or development stages of design, one must rely on knowledge and expertise to deduce the necessary information. Hence, the conventional method of estimating quantities is both laborious and susceptible to mistakes, leading to discrepancies in the outcomes produced by different quantity surveyors [26]. Hence, it is crucial to acknowledge that the accuracy of any cost estimation is contingent upon the quality of information available, which is determined by the current level of project development [39].

Sattineni and Bradford [40] argued that the BIM models provided by design teams to general contractors are insufficient for accurate cost assessment due to the absence of essential information. Olsen and Taylor [31] found that BIM models provided to general contractors often lack up to 50% of the necessary data for quantity take-off. According to Smith [41], the primary obstacles to using BIM for quantity take-off are the subpar quality of BIM models and the challenges associated with verifying them. Firat et al. [42] proposed that BIM models should adhere to the relevant modelling guideline for accurate quantity take-off. In their study, Franco et al. [43] found that the development of BIM models is constrained by both time and cost, which consequently restricts its application in cost estimation.

Hardin and McCool [44] examined the applications of BIM in four project delivery methods: Design-Bid-Build (DBB), Construction Management at Risk (CM-at-Risk), Design-Build (DB), and Integrated Project Delivery (IPD). The DBB technique restricts the potential of BIM due to the absence of information exchange between design teams and contractors during the design phase. In contrast, the utilisation of BIM is highly compatible with the Construction Manager at Risk (CM-at-Risk), Design-Build (DB), and Integrated Project Delivery (IPD) approaches due to the increased level of integration and communication between the design and construction teams right from the beginning stages. Therefore, it is possible to estimate the construction costs during the design process in order to determine if the design aligns with the budget of the projects. The precision of each category of construction cost estimation is likely to improve as the LOD grows, influenced by design choices and the acquisition of increasingly precise construction data. Consequently, each one also necessitates additional time to be precisely generated.

The precision of a project estimate will enhance as the project advances through its life cycle. For example, a project in the commencement phase may have a rough order of magnitude estimate in the range of −25% to +75%. As the project progresses and more information becomes available, precise projections may reduce the margin of error to −5% to +10%. Certain organisations have established rules specifying the appropriate timing and level of confidence or accuracy required for making improvements [15].

Figure 2 depicts the correlation between the level of accuracy and the duration allocated to the four traditional techniques for estimating project costs [39]. The distinction among these four approaches lies in the LOD of the information and the specific phase of the project in which the estimation is conducted. This diagram illustrates the correlation between three crucial factors in cost estimation: precision, time allocation, and LOD of information. Greater specificity in the information leads to a shorter estimation process and more precise outcomes.

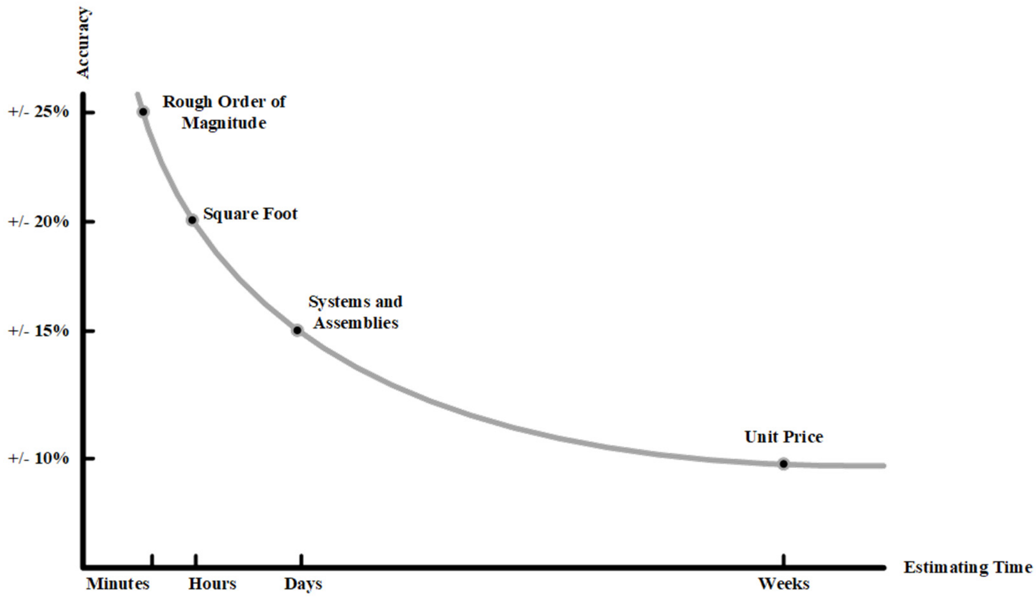


Figure 2. Typical project cost estimation model [39].

In summary, when comparing this study to previous similar research, the main distinctions can be found in the areas of emphasis and circumstances. This study focuses on the difficulties and possibilities of using BIM-based cost estimation during the pre-tender phase, taking into account the quality and capabilities of BIM models utilised in Iran. Additionally, it assesses the accuracy of BIM-based cost estimation in comparison with traditional methods, a direct comparison that has not been thoroughly examined in the previously mentioned studies. Moreover, this study highlights the reluctance of planning and estimating managers and decision-makers in developing countries such as Iran to adopt new methods. This scepticism is a distinctive socio-cultural characteristic that may not be as prevalent in other research settings. Furthermore, it proposes the utilisation of artificial intelligence (AI) to evaluate the excellence of BIM models, representing a progressive approach that contrasts with the conventional techniques examined in prior research. The current study makes a unique contribution by specifically examining the use of BIM technology for cost estimation in the Iranian context. It stands out by conducting a comparative analysis with traditional methods and proposing the inclusion of artificial intelligence (AI) for the quality assessment of BIM models.

3. Research Methodology

The major body of this research comprises four stages, as outlined in the study objectives:

Stage 1: Identifying the assessment criteria for the capabilities of model estimation: The objective of this research segment is to develop a checklist for assessing the competencies required to accurately estimate the expenses associated with the 3D model of the project within the framework of building information modelling. In order to accomplish this objective, it is necessary to establish the criteria for this assessment, which was achieved by conducting interviews with specialists. As a result of the COVID-19 pandemic era, these interviews were conducted online. The selection criteria for the expert interviewees were determined by the relevance of their knowledge domain and the level of their practical experience in areas such as building information modelling (BIM), construction biddings, and time and cost management of construction projects. To ensure high-quality interview outcomes that were based on a comprehensive approach, attempts were made to interview experts from each field, considering the scarcity of individuals who possess expertise in all of these areas. A total of eight individuals were interviewed, consisting of four BIM modellers, two BIM managers, and two experts involved in project planning and cost management. The discipline of scheduling and cost management was founded upon the principles of building information modelling. Each individual, drawing from their expertise and understanding, established criteria for assessing the necessary skills required to create a suitable and dependable report. The findings from the conducted interviews were compiled as a collection of influential factors, which were subsequently refined and corrected. The evaluation criteria were condensed into a concise list and subsequently transformed into a checklist using Microsoft Office Excel 2021 spreadsheets.

Stage 2: Evaluation of the cost estimation capabilities of existing models: A constraint of this study was the potential unavailability of preexisting project models in Iran. This was mostly owing to the novelty of building information modelling in Iran and the legal disputes between employers and designers, which hindered access to the models in the majority of cases. Hence, a total of five diverse construction project models in Iran, along with their comprehensive files and accessible data, were gathered. The models underwent meticulous scrutiny and assessment according to the predetermined criteria outlined in the checklist acquired during the preceding stage. These five models were selected as representative examples of all the constructed models in the country’s projects. They were evaluated to assess the quality and necessary capabilities required for accurate and reliable cost estimation during the pre-tender stage.

Stage 3: Comparing the accuracy and speed of traditional and automatic cost estimation: The model that received the highest score after being assessed according to the criteria outlined in the checklist is the one that is based on the evaluations determined in the previous stage, specifically regarding the capabilities. Furthermore, it possesses functionalities that can be utilised in the procedure of cost estimating, which relies on building information modelling, to acquire dependable and fitting outcomes. The approved model was utilised in the subsequent phase of the study to conduct the cost estimation procedure employing both manual and automated approaches. The objective of this stage is to assess and contrast the velocity of the process and the precision of the outcomes derived from these two methodologies in a quantitative manner. The two cost estimation approaches employed in this section are as follows: Firstly, the traditional approach is currently prevalent in various nations, including Iran. This approach involves initially scrutinising two-dimensional maps and technical specifications, such as joinery tables and other relevant papers, to precisely ascertain the extent and specific specifics of the tasks. Subsequently, measurements are taken on the two-dimensional maps via Autodesk AutoCAD 2022.1.3 tools. Their findings were recorded in Microsoft Office Excel 2021 spreadsheets. Once the measured values for each work item were determined, the building price list was consulted to itemise and price the work items. At this stage, a specific price was assigned to each work item, allowing for the calculation of the price per unit of work and the total price for each item. To generate a visual insight, the whole process has been drawn in Figure 3 for further illustration.

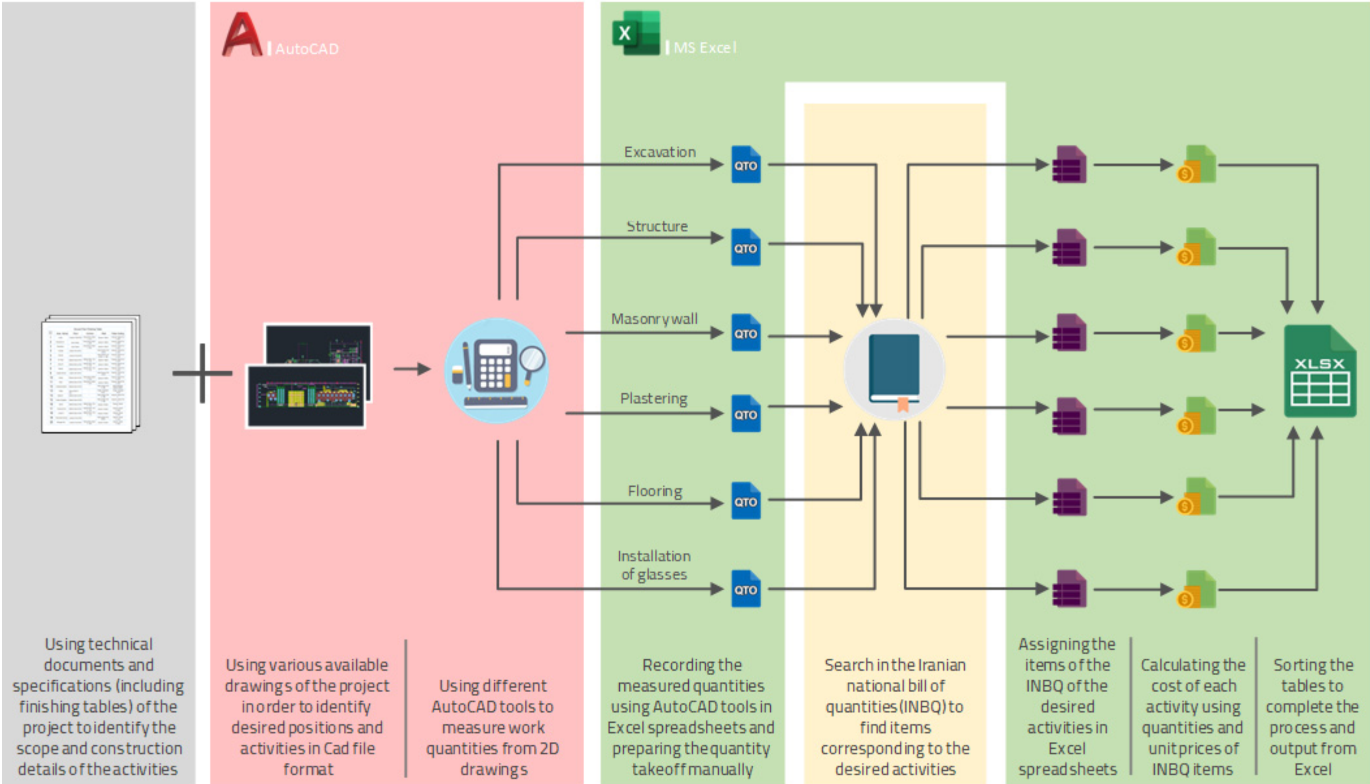


Figure 3. Stages of measurement and estimation in the traditional method.

In the BIM-based method, the desired building information model is first produced using modelling software like Autodesk Revit 2022. Then, the model is moved to model management software where fifth-dimension tools are utilised. The study utilised the Autodesk Navisworks 2022, which is a component of the Autodesk software suite, to supervise the administration of the building model generated by Autodesk Revit 2022. The quantification module of the software includes various tools such as Take-off, Item and Resource Catalogue, Quantification Workbook with Navigation Pane, Property Mapping, and Selection Tree. These tools help in the cost estimation process by calculating the expenses of the desired job items. Thus, with this tool, the initial step involved identifying the needed work items and assessing their respective work values and volumes. Subsequently, the results were refined and edited, resulting in the compilation of a comprehensive list of values. An advantage of the quantification tool is its ability to input the price list of the construction sector. This allows for the identification and allocation of products to certain work tasks, enabling the programme to itemise and compute the cost of each item. This skill has the potential to enhance the integration among various operations during the cost assessment process. After designating the price list as a catalogue in the quantification tool, the individual items from the price list were allocated to each work item. By specifying the unit price of the items for the work items and utilising the values listed, the total price for each item was computed. Ultimately, the outcomes of these computations were retrieved and presented as tables within Excel files. Despite the potential advantages of utilising cloud-based systems like the Common Data Environment (CDE) in this context, their implementation has been postponed in this study due to the absence of uniformity in the workplace and inadequate familiarity with such systems among project-oriented organisations in Iran. Figure 4 presents the flowchart of this procedure.

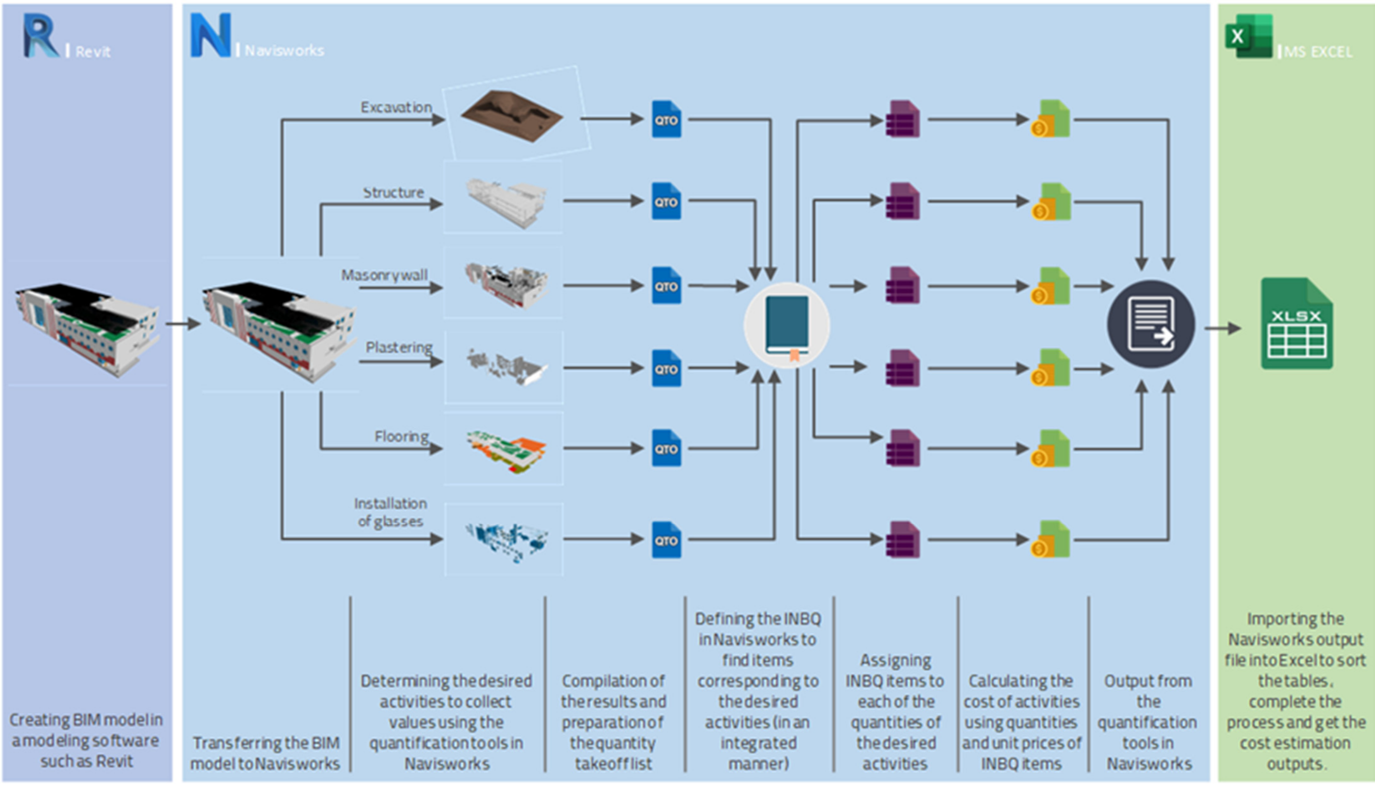


Figure 4. Stages of measurement and estimation based on BIM models.

Following the completion of the cost estimation process using both methodologies, a comparison was made to evaluate the correctness of the results. The discrepancy between the results obtained from each of these two methods was calculated based on the actual values of the project. This discrepancy was then compared for each method. The method with a smaller deviation from the actual values is considered more accurate.

In the subsequent phase, the duration required to acquire each value was documented in order to evaluate the efficiency of each cost estimation approach. The recorded time for each method was then compared to determine which method yielded the intended outcomes in a shorter timeframe, indicating a higher speed.

Stage 4: Determining the shortcomings of the models and proposing improvement solutions: The models that failed to meet the minimum requirements during the evaluation phase, as determined by the criteria outlined in the checklist, were thoroughly reviewed to identify their deficiencies. These models are not suitable for cost estimation based on building information modelling. These models have exhibited flaws that have resulted in their rejection during the control and evaluation phase. This process allows for the identification of deficiencies, limitations, and challenges in the models, and facilitates the development of solutions based on implementation approaches. The construction business suggested repairing them. The Figure 5 depicts a flowchart illustrating the overall process and main components of the research study, based on the aforementioned steps.

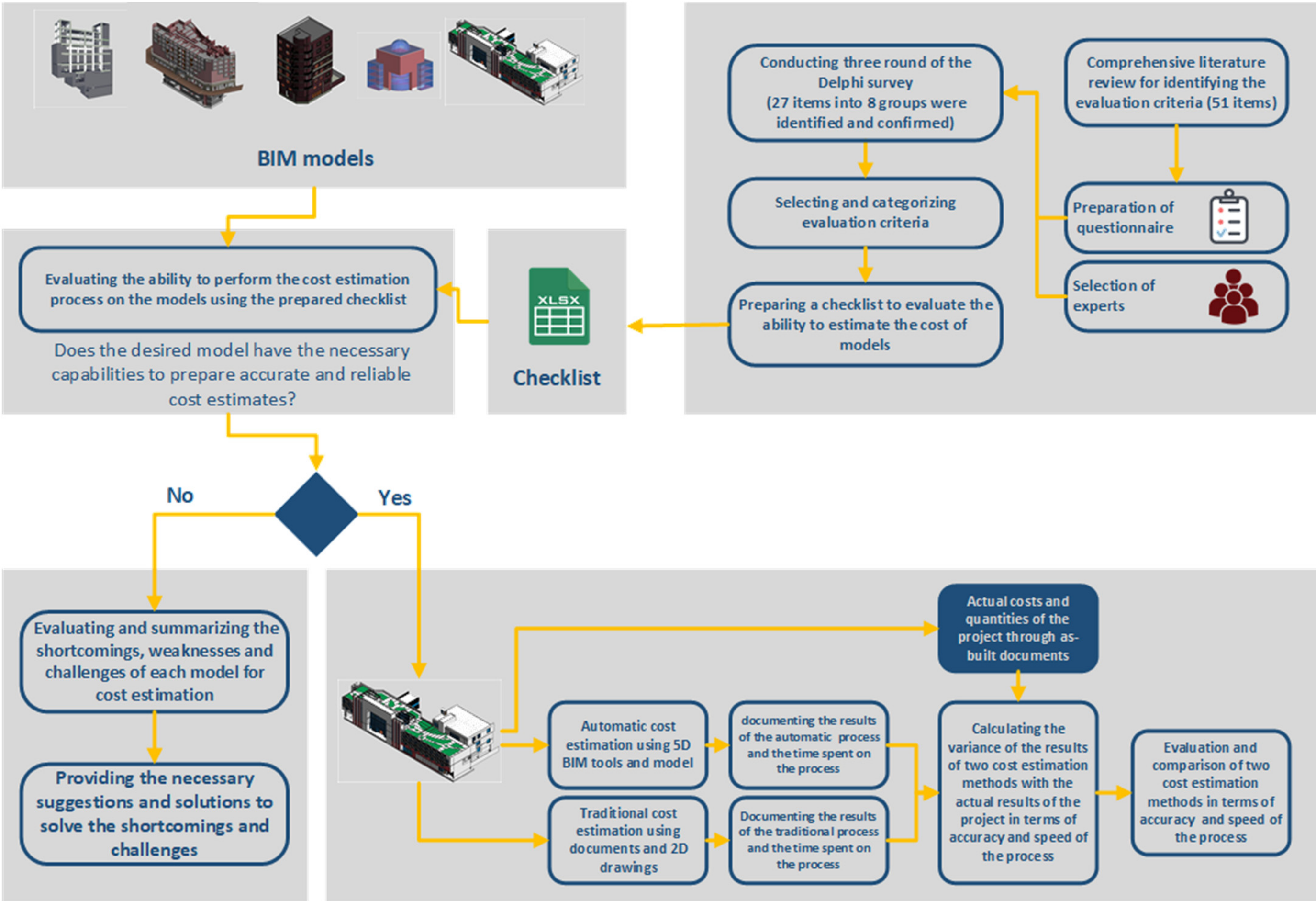


Figure 5. Research process of the study.

4. Presentation of Research Findings

The research community comprised specialists and researchers in the field of building information modelling, specifically those involved in modelling, model management, and the fourth (scheduling) and fifth (cost management) dimensions of construction projects in Iran. The initial step involved identifying and studying the research background, which included prior journal publications. The purpose was to gather evaluation criteria that could be used to analyse the capabilities of the cost estimations related to the models. The outcome of this stage was the identification of 51 assessment criteria. Subsequently, the respondents were provided with a questionnaire consisting of a list of these criteria. The utilisation of expert viewpoints facilitated the process of refining and ultimately selecting evaluation criteria that are tailored to the specific requirements of the building industry in Iran. Ultimately, a total of 27 evaluation criteria were categorised into 6 distinct groups. The result of this procedure, which takes the form of a checklist, is displayed in Table 1 for further illustration.

Table 1. Checklist consisting of evaluation criteria for cost estimation capabilities of BIM models.

Code	Checklist Items	References
	1. Drawing and modelling	
1.1	Correct use of tools	[12,20,45]
1.2	Accuracy in drawing details	[8,12,45,46]
1.3	Insertion point and orientation	[45]

Table 1. *Cont.*

Code	Checklist Items	References
1.4	Checking the interferences in the model and fixing them through the clash detection tool	[22,45]
1.5	Compliance with modelling standards	[25,45]
1.6	Modelling based on execution plan (BEP)	[8,12,45]
1.7	Appropriate adjustment of the model's level of detail (LOD)	[47]
	2. Geometric information	
2.1	Greater LOD in a product model	[12,24,46]
2.2	Display additional icons	[8,24]
2.3	Style and visibility	[8,11]
2.4	Appropriate adjustment of the geometry level of the model (LOG)	[46]
2.5	Correct classification of used families	[47]
	3. Semantic information	
3.1	Appropriate level of information (LOI)	[12,24]
3.2	Defining the technical specifications of materials and equipment with appropriate accuracy	[20,24]
3.3	Proper classification of specifications and non-geometric information in the model	[22,25]
	4. Parameters	
4.1	Proper definition of parameter names	[8,27]
4.2	Group or category of parameters	[27]
4.3	Correct definition of dimensions or size parameters	[24,27]
4.4	Correct definition of engineering parameters	[20,27]
4.5	Correct definition of user-specific parameters	[22,24,27]
	5. Classification	
5.1	Classification mapping	[25,48]
5.2	Accurate definition and appropriate matching of the catalogue for the model	[20,48]
5.3	Determining the details of the execution method and the specifications of the materials based on the catalogue items	[5,18]
5.4	Correct and complete definition of the resources used	[18,22]
	6. Documentation	
6.1	Correct categorization and organization of each discipline in Project Browser	[49]
6.2	Management of sheets of each discipline	[11]
6.3	Organization of modelled item estimation lists	[11]

Multiple studies have assessed the cost estimation capabilities of building information modelling (BIM) technology [50]. A study conducted by the Czech Technical University examined the utilization of data from information models for cost estimation and the necessary process modifications to fully implement BIM in this context [51]. A separate study examined the utilization of building information modelling (BIM) in the context of quantity take-offs and cost estimation. The study emphasized the difficulties and possibilities for estimators, specifically in the automation of measurements and the integration of different software programs [52]. These studies offer valuable perspectives on the efficacy of BIM for cost estimation and the necessary criteria for its implementation. These studies frequently employed some common criteria such as accuracy, efficiency, and compatibility with existing workflows to assess the cost estimation capabilities of BIM models.

The aim was to choose and assess BIM models obtained from construction projects with diverse attributes, distinct components, and varying geographical locations within the country. Model number (1) corresponds to a museum, project (2) serves as a control and management facility for a power plant, project number (3) entails a hotel development, project number (4) involves a residential apartment block and project number (5) encompasses a multi-purpose complex for residential and educational purposes. Furthermore, it is of an administrative nature. The findings from the study and evaluation of the models are depicted in Table 2 for perusal.

The evaluations indicate that all five models met the specified criteria. Initial inquiries indicate that the primary factors contributing to the deficiencies in models for BIM-based cost estimating are drawing and modelling, semantic information, and classification. The models can be graded according to the number of criteria that they incorporate.

1. Project number (5) with 19 criteria out of 27 criteria (70.37%)
2. Project number (3) with 14 criteria out of 27 criteria (51.85%)
3. Project number (2) with 11 criteria out of 27 criteria (40.74%)
4. Project number (4) with 9 criteria out of 27 criteria (33.33%)
5. Project number (1) with 6 criteria out of 27 criteria (22.22%)

Model number (5) has been found as the most optimal model among the existing models for estimating the cost based on building information modelling. It satisfies around 70% of the established requirements. This model is recommended for gathering values and estimating the cost for the stage. Subsequently, the research is chosen. The model number (5) associated with the Dar al-Warath project is a versatile building that serves administrative, educational, and residential purposes. It spans an approximate area of 14,000 square metres.

This section of the study assessed the efficiency and accuracy of the one-time cost estimation process using both the conventional manual approach and the method based on building information modelling. The results produced from each method were then compared. Thus, initially, the conventional cost estimation procedure was implemented using the prevailing standard method. The chosen tasks in this procedure were randomly selected from all stages of implementation, such as excavation, framework, reinforcement, and carpentry, in order to provide a comprehensive representation of all project tasks. The outcomes of this phase are presented in Table 3 for further illustration.

Subsequently, the values were extracted, and the cost calculation was conducted utilising a methodology grounded in building information modelling. This approach utilised the tools of the fifth dimension of building information modelling to autonomously derive values from the information model. Table 4 provides a concise overview of the results generated by this procedure.

By utilising records related to construction and extracting the outcomes of two cost estimation techniques, the precision of each approach was determined by calculating the deviation of the actual numbers found in the construction documents. Table 5 displays the triple values (real-traditional method-fear-based method) for each item, as well as the deviation of the values derived from each technique compared to the actual values, and the corresponding percentage of divergence for each method. Upon analysing the table, it is evident that the cost estimation method utilising building information modelling yields values that are more closely aligned with the actual values found in construction documents, in comparison to the traditional cost estimation method. The average deviation percentage for the traditional method is approximately twice as high as that of the building information modelling method.

Table 2. Results of the evaluation of the capabilities of estimation of models.

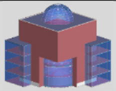
	Drawing and Modelling							**Geometric Information**					**Semantic Information**			**Parameters**					**Classification**				**Documentation**		
	1.1	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**3.1**	**3.2**	**3.3**	**4.1**	**4.2**	**4.3**	**4.4**	**4.5**	**5.1**	**5.2**	**5.3**	**5.4**	**6.1**	**6.2**	**6.3**
	✓							✓		✓						✓	✓									✓	
			✓						✓		✓	✓		✓			✓	✓		✓	✓				✓	✓	
	✓		✓				✓	✓	✓		✓		✓			✓	✓		✓		✓				✓	✓	✓
	✓			✓				✓			✓					✓	✓			✓					✓	✓	
	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			✓	✓			✓	✓	

Table 3. The results of traditional cost estimation.

No.	Sector		Code	Quantity	Unit	Unit Cost (IRR)	Total Cost (IRR)
1	8	In-situ concrete	08.01.02	164.06	m^3	3,797,000	622,918,734
2			08.01.06	468.56	m^3	4,349,000	2,037,784,836
3			08.01.07	762.74	m^3	4,470,000	3,409,464,160
4	9	steel structure	09.01.01	85,030.20	kg	170,000	14,455,134,170
5			09.02.20	16,238.25	kg	143,000	2,322,069,250
6	12		12.05.03	3654.57	m^2	802,000	2,930,967,406
7			12.05.05	5102.68	m^2	605,500	3,089,672,013
8	18	coating and plastering concrete blocks	18.02.02	1894.75	m^2	206,000	390,319,365
9			18.02.10	1894.75	m^2	181,000	342,950,510
10	19	woodwork	19.15.02	51.66	m^2	1,890,000	97,637,400
11	20	ceramics and tiles	20.03.21	326.47	m^2	1,215,000	396,662,265
12			20.03.22	263.65	m^2	1,313,000	346,176,783
13			20.03.24	951.05	m^2	1,401,000	1,332,425,253
14	22	stonework	22.03.20	753.67	m^2	2,589,000	1,951,261,454
15	23	plastic and polymer	23.02.05	449.06	m^2	3,236,000	1,453,145,216
16			23.03.50	26.08	m^2	2,403,000	62,666,996
17	24	glass	24.01.05	364.86	m^2	1,000,000	364,856,000
18			24.01.08	3.28	m^2	1,733,000	5,680,774

Table 4. The results of cost estimation based on BIM models.

No.	Sector		Code	Quantity	Unit	Unit Cost (IRR)	Total Cost (IRR)
1	8	In-situ concrete	08.01.02	166.23	m^3	3,797,000	631,171,572
2			08.01.06	460.15	m^3	4,349,000	2,001,174,084
3			08.01.07	754.77	m^3	4,470,000	3,373,810,271
4	9	steel structure	09.01.01	84,767.40	kg	170,000	14,410,458,000
5			09.02.20	15,281.78	kg	143,000	2,185,294,126
6	12	concrete blocks	12.05.03	3654.57	m^2	802,000	2,930,967,406
7			12.05.05	5167.94	m^2	605,500	3,129,189,802
8	18	coating and plastering	18.02.02	1884.74	m^2	206,000	388,256,585
9			18.02.10	1884.74	m^2	181,000	341,138,068
10	19	woodwork	19.15.02	60.34	m^2	1,890,000	114,044,303
11	20	ceramics and tiles	20.03.21	305.60	m^2	1,215,000	371,309,261
12			20.03.22	248.78	m^2	1,313,000	326,646,643
13			20.03.24	997.41	m^2	1,401,000	1,397,374,290
14	22	stonework	22.03.20	823.67	m^2	2,589,000	2,132,491,454
15	23	plastic and polymer	23.02.05	441.97	m^2	3,236,000	1,430,208,537
16			23.03.50	31.19	m^2	2,403,000	74,937,571
17	24	glass	24.01.05	403.31	m^2	1,000,000	403,308,866
18			24.01.08	3.87	m^2	1,733,000	6,701,511

Table 5. Calculation of the deviation of the values and the accuracy of each of the cost estimation methods.

No.		Sector	Code	Actual Condition		BIM-Based Estimation		Manual Estimation	
				Quantity	Unit	Variance	%	Variance	%
1	8	In-situ concrete	08.01.02	175.11	m^3	8.877	5.069	11.050	6.311
2			08.01.06	448.13	m^3	12.019	2.682	20.437	4.561
3			08.01.07	752.90	m^3	1.871	0.248	9.847	1.308
4	9	steel structure	09.01.01	83,923.27	kg	844.134	1.006	1106.935	1.319
5			09.02.20	15,603.76	kg	321.980	2.063	634.490	4.066
6	12	concrete blocks	12.05.03	3698.68	m^2	44.103	1.192	44.103	1.192
7			12.05.05	5253.14	m^2	85.193	1.622	150.458	2.864
8	18	coating and plastering	18.02.02	1873.56	m^2	11.177	0.597	21.190	1.131
9			18.02.10	1873.56	m^2	11.177	0.597	21.190	1.131
10	19	woodwork	19.15.02	66.45	m^2	6.109	9.194	14.790	22.257
11	20	ceramics and tiles	20.03.21	285.46	m^2	20.148	7.058	41.015	14.368
12			20.03.22	233.27	m^2	15.510	6.649	30.385	13.026
13			20.03.24	1153.53	m^2	156.120	13.534	202.480	17.553
14	22	stonework	22.03.20	871.86	m^2	48.186	5.527	118.186	13.556
15	23	plastic and polymer	23.02.05	439.76	m^2	2.212	0.503	9.300	2.115
16			23.03.50	34.95	m^2	3.768	10.780	8.874	25.389
17	24	glass	24.01.05	425.37	m^2	22.060	5.186	60.513	14.226
18			24.01.08	4.08	m^2	0.213	5.221	0.802	19.657
		Total variance (%)					4.374		9.224

The speed of the process between the two techniques was compared by calculating and displaying the difference in time spent to execute the cost estimation process using the recorded cost estimation methods as indicated in Table 6. The duration of each work item has been precisely measured and documented, considering the specific cost estimation method used, starting from the initial phase up to the final step, which involves computing the overall price of the item. The recorded data indicates that the cost estimation procedure using the old method has used much more time compared to the method based on building information modelling.

Table 6. Calculation of the difference in the time spent and the speed of cost estimation methods.

No.		Sector	Code	BIM-Based Estimation	Manual Estimation	Variance	
				Time Spent	Time Spent	Hours	(%)
1	8	In-situ concrete	08.01.02	0:04	0:11	0:07	63.64
2			08.01.06	0:07	0:35	0:28	80.00
3			08.01.07	0:06	0:12	0:06	50.00
4	9	steel structure	09.01.01	0:18	1:14	0:56	75.68
5			09.02.20	0:14	1:36	1:22	85.42

Table 6. *Cont.*

No.	Sector		Code	BIM-Based Estimation	Manual Estimation	Variance	
				Time Spent	Time Spent	Hours	(%)
6	12	concrete blocks	12.05.03	0:04	0:35	0:31	88.57
7			12.05.05	0:06	0:56	0:50	89.29
8	18	coating and plastering	18.02.02	0:08	1:45	1:23	79.05
9			18.02.10	0:14			
10	19	woodwork	19.15.02	0:08	0:25	0:17	68.00
11	20	ceramics and tiles	20.03.21	0:08	1:11	1:03	88.73
12			20.03.22	0:10	0:20	0:10	50.00
13			20.03.24	0:07	0:13	0:06	46.15
14	22	stonework	22.03.20	0:06	0:10	0:04	40.00
15	23	plastic and polymer	23.02.05	0:09	0:27	0:18	66.67
16			23.03.50	0:10	0:10	0:00	0.00
17	24	glass	24.01.05	0:06	1:12	1:06	91.67
18			24.01.08	0:09	0:43	0:34	79.07
Total				2:34	11:55	9:21	78.46

5. Discussion of Research Findings

The primary objective of this research is to assess and appraise the present state of building information modelling in Iran, with the aim of incorporating it into the pre-tender cost estimation process for construction projects in the nation. This assessment was conducted in two sequential phases: the initial phase examined the quality and necessary functionalities of BIM models in Iranian construction projects for conducting cost estimation using BIM and obtaining accurate and dependable outcomes. The subsequent phase evaluated the precision of the results and the efficiency of the BIM-based cost estimation process. The anticipated outcome of this research is that it will enhance the efficacy of implementing the BIM approach in the pre-tender cost estimation process in Iran. This novel methodology, through the eradication of flaws and deficiencies and the enhancement of precision and excellence in designs, along with the augmentation of accuracy and swiftness in cost estimation, enables the recipients to gain a deeper comprehension of the workload and expenses associated with the project in the pre-tender phase and throughout the tender process.

The quality evaluation criteria for cost estimation of BIM models consist of 27 specified criteria, organised into 6 subject groups: (1) drawing and modelling, (2) geometric information, (3) semantic information, (4) parameters, (5) classification, and (6) documentation, and they were classified and illustrated in the format of a checklist. The statements made solely pertain to the characteristics of the BIM model. However, it is crucial to consider other significant aspects in the cost estimation process that are influenced by BIM and its outcomes. The procedure is significantly influenced by two crucial factors: manpower and software platform [25]. The accuracy and quality of the findings are closely correlated with the amount of skill and proficiency of the individuals engaged in this process, such as modellers, estimators, financial managers, and others. For this role, individuals with proficiency in 5D BIM concepts and BIM model management software, as well as extensive expertise and understanding in management, cost estimating, and construction implementation methodologies, are required. BIM-based software tools enable the consolidation of visual representation and the integration of both geometric and non-geometric project data into a single model. This facilitates the analysis of information in areas such as time and cost management. The software's modelling and model management capabilities directly impact the quality of the analysis output generated by the model. The platform possesses various features, including its level of complexity or ease of training and mastery, user-friendliness, ability to interact with other software platforms through facilities such as IFC, efficient tools for collecting values and estimating costs, integration with the schedule, and the ability to discover interferences. The precision and quality of the cost analysis results are influenced by the software utilised in this procedure.

The evaluation criteria were systematically regulated on the models, and the outcomes were meticulously documented. Upon examining the specifics of model number (5), it became apparent that it possesses a substantial quantity of geometric and semantic data that is systematically organised and described. This attribute can be regarded as the model's most significant strength. Regarding modelling, while there is room for improvement in the precision of modelling composite elements, overall, the model has an acceptable quality. The use of BIM-based cost estimation is feasible, although it should be noted that the main weakness of model number (5) lies in the classification and coding of work items. This issue was observed consistently across all the collected models. Ultimately, this model met 19 out of the 27 checklist requirements, demonstrating the highest level of alignment with the evaluation criteria. As a result, it was employed to calculate the cost in the subsequent phase. The primary deficiencies of BIM models used in construction projects in Iran for cost estimation during the pre-tendering process can be classified into three categories: (1) The inadequate standard of drawing and geometric modelling. (2) The insufficient level of quality and quantity of specifications and semantic information. (3) Issues arising from the discrepancy between the model and the catalogue in the classification and itemization of work items.

With respect to item number (1), using skilled and seasoned designers and modellers, who possess ample expertise and strategic foresight in projects, enables them to generate models which closely align with actual situations and are more practicable. Moreover, establishing modelling rules and guidelines that define the minimum acceptable quality range helps promote the standardisation of the BIM drawing and modelling process, resulting in enhanced output quality. Other studies have recognised that although BIM has been extensively utilised worldwide for some years, the modelling has lacked the requisite precision and does not possess the essential quality to accurately estimate costs and yield credible conclusions based on BIM (2). Concerning the limitation of number (2) pertaining to insufficient information in the model, prior studies have utilised a comprehensive database containing all the necessary information for the construction of a three-dimensional model, specifically aimed at enhancing its quality. It is crucial to gather the values and make an accurate estimation of the project's cost [5,25]. Leicht and Messner [50] state that the key features that set BIM apart from traditional documents like 2D maps and technical specifications are the ability to visually represent spatial information, the provision of data for additional analysis, and the presence of information [5]. A robust database is essential for accurately defining, coding, and systematically categorising building parts during project modelling. This integrated 3D model encompasses all the necessary information for quantitative measurement, including measurements and costs, ultimately resulting in high-quality outcomes. Improvement occurs. Item number (3) pertains to the deficiency of BIM models in categorising job items. This research aimed to establish a standardised pricing list that may be used to categorise and code work items in Iran. The price list was created using a quantification tool in the form of a catalogue, allowing for semi-automatic classification. A previous study in this sector examined the utilisation of the base price list during the classification phase of work items in the BIM-based cost estimating process. The study also showed the practical viability of this approach [9]. However, it is important to recognise that the Yindi category in Iran's basic price list differs significantly from the standard classification and coding structures used in BIM. These structures, such as uniformat and masterformat, have been established and utilised in recent years. These distinctions are typically evident in the execution techniques, technical specifications of equipment and materials, classifications of work items, and size of work item units, among other factors. Hence, if the government aims to promote the growth of BIM in the construction sector in the future, it should also strategize extensively on substituting the rudimentary price list with conventional classification and coding frameworks within BIM. Alternatively, it should make significant modifications to the existing price list to ensure better compatibility with these frameworks.

Cost estimation was conducted on the chosen model, and a comparison was made between the accuracy and speed of cost estimation using manual methods and BIM-based methods. The discrepancy between the values obtained in the manual technique was more than twice as large as that of the BIM-based method. Hence, it can be concluded that the BIM-based method exhibits significantly higher accuracy than the manual method. Prior studies have cited other factors contributing to this rise in accuracy, however, two factors stood out as particularly significant: (1) Minimising the likelihood of human mistake during the process of data collection and cost estimating; and (2) enhancing the depth of project information by developing an integrated model.

Nevertheless, it cannot be asserted that the likelihood of inaccuracy in BIM-based cost estimation is non-existent; within the context of BIM, humans are responsible for the modelling and input of primary data. However, the BIM process itself minimises human involvement in tasks such as measuring, recording values, and calculating cost estimations. This reduction in human intervention significantly decreases the likelihood of errors occurring during the data collection and cost estimation process. Another intrinsic characteristic of BIM is its ability to establish integration between geometric and non-geometric (semantic) model data. This integration enhances the precision of model analysis outcomes, particularly in the extraction of values and estimation of project costs. By establishing a connection between cost management (the fifth dimension) and scheduling (the fourth dimension) of the project, it becomes feasible to account for the impact of scheduling conditions and programme limitations accurately and continuously on resource availability and productivity rate calculations. Additionally, this integration allows for the estimation of costs and can enhance the project's alignment with the actual conditions of construction and implementation. Furthermore, incorporating integration during the design phase by merging maps from various disciplines enhances the precision of the project's design and modelling. This integration aids in identifying and resolving interferences, minimising design errors, and facilitating more accurate cost estimation during the initial stages of the project.

Furthermore, the duration required for the manual technique is approximately 4.64 times longer than that of the BIM-based method. This indicates that the cost estimation process is substantially faster in the BIM-based method compared to the manual method. It is important to acknowledge that the recorded timings for each item are precisely calculated and encompass all necessary procedures, including preparation. The efficacy and velocity of the process are directly correlated with the model's access to well-organized and encoded data from the initial stages when the involvement of the estimator is important. Hence, it is evident that an inadequately detailed and classified dataset in the model developed throughout the preceding stages will result in a reduction in speed and an escalation in time.

The research revealed that implementing BIM technology in Iran's construction industry can result in more accurate and expedited pre-tender cost estimations. The analysis identifies significant deficiencies in the existing BIM models, specifically in terms of their geometric and semantic accuracy, as well as their adherence to industry standards. The study highlights the significance of demonstrating the tangible advantages of BIM technology to professionals in the construction industry in order to promote the acceptance of innovative approaches. Additionally, it suggests potential areas for future research, such as the integration of building information modelling (BIM) with advanced data analytics like AI and the assessment of how BIM maturity affects the accuracy of cost estimation. For example, establishing the relative weightings of the essential criteria provided in Table 1 can be a possible future research direction in order to generate a cost estimation maturity index of a construction project for reference during the bidding process. These endeavours have the potential to promote the uniformity of procedures in the worldwide construction sector and facilitate the improvement of more precise bidding procedures in developing countries. This research specifically examined the process of construction bidding in Iran. However, the difficult circumstances outlined in the literature review for Iran's construction industry are also prevalent in numerous Middle Eastern countries and other developing nations across the globe [53–56]. The evaluation framework suggested in this study can be applied and advantageous to other countries encountered with similar comparable challenges, with some adjustments and contextualization based on the specific laws and conditions of their respective construction industries.

A significant constraint encountered in this research was the restricted availability of BIM models and construction project documentation in Iran. This is mostly due to project owners' reluctance to share information and technical documents pertaining to their projects, despite researchers' requests for access. This information typically encounters opposition from project owners or project-focused organisations unless the request is made by an academic institution or a government organisation. As a result, the researcher's objective of assessing a substantial quantity of BIM models for building projects (a minimum of 10 projects) was hindered, and he was inevitably constrained to reviewing only 5 projects' data. The validity of the evaluation results may be impacted by this shortcoming. It is indisputable that the greater the number of actual samples used for evaluation, the more closely the evaluation conclusions will align with real-world conditions.

6. Conclusions

This study conducted an analysis and evaluation of the existing status of building information modelling in Iran, specifically in relation to its applicability in the pre-tender cost estimation process. This assessment was conducted in two sequential phases. The initial phase involved evaluating the quality and necessary functionalities of BIM models used in Iran's construction projects for cost estimation purposes, with the aim of obtaining accurate and reliable results. The subsequent phase focused on assessing the precision of the results and the efficiency of the BIM-based cost estimation process in terms of speed. Conducting studies that assess the practical application of scientific methods in real-world conditions can effectively enhance the comprehension of managers and decision makers in their respective fields. This is particularly important as past experiences have demonstrated that the adoption of new methods in the construction industry of developing nations, such as Iran, often raises scepticism among these individuals. Through interviews with experts, the quality evaluation criteria for BIM models of construction projects in Iran were determined. These criteria are used to estimate the cost of projects based on BIM at the pre-tender stage. The criteria were categorised into six groups: (1) drawing and modelling, (2) geometric information, (3) semantic information, (4) parameters, (5) classification, and (6) documentation. The fifth step involves categorization, whereas the sixth step involves the creation of written records. Furthermore, according to the assessments, the primary deficiencies of BIM models for utilisation in this procedure were concentrated in three principal components: (1) Insufficient precision in drawing and geometric modelling; (2) insufficient quality and quantity of specifications and semantic information; and (3) deviation from established norms or standards. The catalogue model is used for the systematic classification and itemization of work items. Another aspect of the study involved performing a comparison analysis between the existing manual cost estimation methods and the methods based on BIM. The findings revealed that the BIM-based approach yielded more precise cost estimations and required less time to obtain them. Subsequent investigations in this domain can advance the creation of a system capable of assessing the calibre of BIM models to determine cost estimates based on BIM, employing artificial intelligence techniques. This would effectively prevent subpar models from entering the workflow. By effectively managing the models and enhancing the accuracy of cost estimating outcomes, it simultaneously avoids time wastage during this phase. The study encountered limited access to BIM models in Iran as a result of owners' confidentiality concerns. This limitation resulted in a reduction of the sample size from the originally intended 10 projects to only 5 projects. Consequently, the representativeness of the research may be compromised. To further investigate the potential benefits of integrating BIM with advanced data analytics, it is recommended to explore its application in enhancing pre-tender cost estimations in Iran. An examination of the influence of BIM maturity levels on the precision of cost estimation and the capacity of BIM to simplify other aspects of the tendering process could yield valuable knowledge for the construction sector. Furthermore, conducting this study in other developing nations could provide further insights into the widespread applicability of BIM models for pre-tender cost estimations and its ability to establish a consistent level of accuracy in the international construction sector for application.

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