Celal Bayar University Journal of Science

Evaluating the Usability of BIM-Based Quantity and Cost Estimation in Construction Projects

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Received: March 16, 2025
Accepted: December 9, 2025
DOI: 10.18466/cbayarfbe.1659041

Abstract

As in every industry, there are technological developments in the construction industry. One such development is Building Information Modelling (BIM). Two-Dimensional (2D) projects can be interpreted differently by stakeholders and discrepancies can go undetected. Consequently, repetitive and inaccurate quantity and cost calculations may occur. BIM allows the representation of a building in three dimensions (3D) using smart objects instead of traditional lines and enables quantity and cost estimations by assigning area, volume and monetary information to these objects. Even if changes are made to the model designed in BIM, quantity and cost will also change automatically. Thus, BIM accelerates the process by reducing the necessity of repeated calculations. With these features, BIM can overcome the problems of traditional methods by providing fast, practical and realistic estimates. In this study, a building was exported from 2D to a BIM based program and modeled in 3D. Quantity and cost calculations were performed using the same program and the process was explained. To determine the accuracy rate of the BIM system, a comparison was made by calculating the cost over the bill of quantities calculated by the traditional method and the ready-made quantity (RMQ) data included in the project. As a result of the comparison, BIM calculated costs were about 7% higher than RMQ and traditional methods. This proves that the idea BIM reduces costs is inaccurate. Rather than reducing costs, BIM provides realistic results.

Keywords: 3D Modelling, BIM, Building Information Modeling, Cost, Quantity.

1. Introduction

Building projects are designed by technical staff from various disciplines, such as civil engineers, architects, electrical engineers, and mechanical engineers. As a result, many two-dimensional (2D) project files containing sections, plans, and details are created separately for each discipline. Many 2D project files make it difficult to achieve interdisciplinary project coordination. Therefore, defects and errors in the projects and incompatibilities among disciplines may go undetected. Failure to identify project defects and errors can result in underestimation or overestimation of quantities. Unforeseen errors can result in lost time and cost in later phases of construction.

The success of construction projects is contingent upon the timely completion of the structure within the estimated budget limits, with the desired quality and efficient use of resources [1]. Consequently, the Architecture, Engineering and Construction (AEC) sectors are seeking new techniques to reduce project costs and improve efficiency and quality [2]. The "Industry 4.0" revolution has given rise to useful digital technologies. One such innovation, Building Information Modeling (BIM), has influenced the development of the AEC sector worldwide [3].

In the construction industry project designing was done on paper with the classical manual drawing method. Since the design process was long, project production was also delayed. With the transition to Computer-Aided Design (CAD) facilitated more expeditious and cost-effective project design. This transformation signified the initial revolution within the construction industry. The second revolution was Building Information Modeling (BIM) which is widely used today [4]. BIM is defined as a 3D digital representation of the physical and functional attributes of a building that serves as a shared resource for information about that building throughout its

lifecycle [5]. BIM is considered a software because 3D designs, and clash detections are performed in digital environment by using software in BIM. However, BIM is not only software [6]. It is also a technological development and process that allows the project to be modeled and monitored in 3D throughout its lifecycle, including information such as quantity, time, budget, and the sharing and management of this information among teams [7].

The various subsets that comprise BIM are expressed using the term of dimension. These are 3D (building model), 4D (time), 5D (cost), 6D (sustainability), 7D (facility management), and 8D (safety) [8]. It is not possible to impose limits on BIM dimensions because new dimensions can be introduced as the studies progress. Consequently, this multidimensional capacity of BIM is expressed as "nB" [9].

The 4D BIM system is a process that integrates time with building components of 3D model [10]. 4D BIM is a planning process in which the graphical simulation of the progress of the building over time can be monitored in 3D, thus enabling project stakeholders (owner, project manager, project design team, etc.) to effectively visualize and analyze spatial and temporal problems in construction progress. Consequently, this facilitates the creation of a more efficient work schedule [11]. 5D BIM involves the integration of cost-related data into the 4D model. [12]. 5D improves construction cost estimation and accelerates the process [11].

A review of the literature reveals an increase in the importance and applications of BIM systems [8]. Xu [4] examined the application principle of the BIM system and the 5D modelling process through a sample project, concluding that the integration of BIM technology into construction projects increases the quality of the structure and reduces the cost. Lee et al. [13] aimed to assess the applicability of 5D BIM in their study. The BIM process, initiated by the conversion of a 2D drawing of a bungalow type building into a 3D model, was concluded in 5D with the integration of cost data. The focus of the study was on the factors that would affect the applicability of 5D BIM in the modelling process, and it was determined that 5D BIM does certainly have a high level of applicability. Finally, they concluded that even if it is possible more than five dimensions in the BIM process, excessive information may increase complexity in terms of BIM implementation. Zhang et al. [14] developed a building information system that includes budget information and monitoring dimension. Hardin, described the use of BIM for effective cost management [15].
In this paper, a building was modeled in 3D with the BIM system, the quantity and cost of the building was calculated, and the process was presented. At the same time, the quantity take-off and cost calculations prepared using the BIM system were compared with those calculated using the traditional method and the ready-made quantities (RMQ) included in the project. The comparisons were made to determine the level of accuracy of the quantity take-off and cost calculations using BIM in construction. This study differs from prior works in that it compares the costs of BIM the system with that of traditional and RMQ.

2. Materials and Methods

In the Republic of Türkiye, all public institutions that are subject to the Public Procurement Law conduct tenders for goods, services, consultancy, and construction works through the Elektronik Kamu Alımları Platformu (EKAP) [16]. All tenders announced on EKAP, as well as the documents related to these tenders are open to public access. In this study, one of the constructions announced on EKAP was selected and analyzed. The project of this construction is a 2D CAD project. To leverage the BIM system, it is necessary to convert this 2D CAD project into 3D model using BIM-based software.

2.1 BIM 3D

To utilize the 3D function of BIM, options include 3D based BIM software such as Autodesk Revit, Tekla Structures and ArchiCAD. For this study Autodesk Revit was chosen. Compared to the other options, Revit has a free, one-year student version that can be renewed, and there various resources available to learn the program. Additionally, Revit works in high compatibility with AutoCAD. Revit is a BIM application that uses a singular parametric 3D model to generate plans, sections, elevations, perspectives, details and schedules [3]. In 2D CAD projects, building elements are expressed with lines, while in Revit program, modeling is done with families and smart objects [17]. Thus, the building elements modeled as objects in the Revit program have information such as width, length, height, and, depending on these parameters, area and volume, as in reality. By adjusting the parameters of measure in the Revit program, thereby building projects can be modeled 3D by creating different types of structural elements such as columns and beams.

In the Revit software, 3D modelling can be designed from the beginning, or an existing 2D AutoCAD file can be exported to the Revit environment [2]. Consequently, 3D modelling can be designed on a 2D project [18]. In this study, the AutoCAD file in the selected project was exported to the Revit environment and modeling was designed.

2.2.1 Quantity Take-off Using BIM

The utilization of BIM tools facilitates accurate and clear quantitative data. The accuracy of this data supports a

correct feasibility study. Accurate quantities lead to accurate cost estimates [19]. The Revit program, which is used in 3D modelling in BIM, is also used for quantity take-off [20]. In the Revit program, the category, area, and volume information of the elements can be accessed from the "Schedules/Quantities" in the "Create" panel in the "View" tab. Additionally, this menu can generate automatically schedules of the quantities [21]. A modification made to the structural elements of the model is reflected in the quantity data immediately, thereby accelerating the quantity take-off process with the Revit [22].

2.2.2 Quantity Take-off Using Traditional Method

Traditional quantity take-off estimates are manual progress performed by measuring floor plans, sections and other drawings contained in 2D projects [23]. As the traditional method is based on human interpretation, it is difficult to obtain an accurate calculation and avoid errors [24]. In addition, it is also difficult to interpret and process the connection among structural elements (e.g. cross-section of beam, column, wall and slab connection) in 2D environment in 2D project. For this reason, manual quantity take-off based on 2D projects is both challenging and error prone [25].

2.2.3 Ready-Made Quantity (RMQ) in Project

Designers attach ready-made quantity (RMQ) schedules to some 2D CAD architectural and structural design projects. Although it varies according to the designer's preferences, there are RMQ lists for concrete, formwork and rebar in structural design projects. In architectural design projects the quantity of materials such as floor (ceramic, parquet, etc.) can be calculated based on the square meters of associated rooms. Although this provides quick access to quantity data, its accuracy should be questioned. The aim of this study was to compare the quantity of materials data using the traditional method between BIM. However, when the RMQ data in structural and architectural AutoCAD project of the building that is the subject of the study was examined, it was found that there were differences between the quantity data calculated using BIM and the traditional method. Therefore, the RMQ data in the AutoCAD project was also included in the comparison.

2.3 Cost

In Türkiye, approximate construction cost is commonly determined by "unit price method" and "unit area cost method" of the Ministry of Environment, Urbanization and Climate Change. In the unit price method, the Ministry has defined item no and unit price for each of the materials, labor, machinery and equipment required for construction. The approximate cost of construction is calculated by multiplying the quantity required for each construction work by the unit price determined separately for each work and summing the resulting costs [26].
BIM based software has built-in cost estimation features. When any change is made in the model, cost data changes automatically [2]. Revit software also functions on this principle. Total cost calculations can be made by defining budget information for the building elements modelled within the Revit.

3. Results and Discussion

The tender document received from EKAP contains AutoCAD files (dwg) with architectural and structural projects. According to the data in the AutoCAD files, the total upper elevation of normal floor is +12.30 meters and elevation of the roof floor, where there are 2 elevators and 1 staircase, is +16.30 meters (Figure 1.). The entrance elevation is +0.30 meters, and the lower elevation of basement is -3.70 meters. There are also 2 lift shafts under the raft foundation with a lower elevation of -5.80 meters.

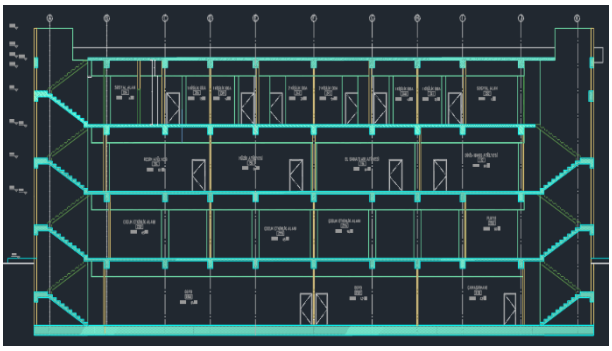


Figure 1. Architectural view of the project.

The building has 770 m² floor and 3080 m² construction area (Figure 2.). The building is a 4-storey reinforced concrete building with a basement + ground + 2 floors. Each floor of the building is 4 meters high. There is also a roof floor with stairs and elevator buckets.

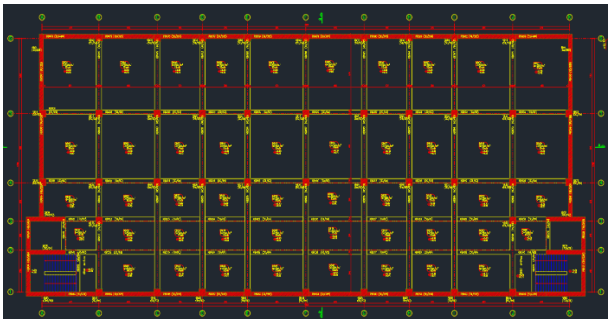


Figure 2. Structural plan of the project.

All structural elements in the AutoCAD project modelled using smart objects (family) in Revit software. In Revit, building elements also include material information and changes can be made. Revit program includes ready-made materials as well as allowing the user to create the desired material. For example, a wall whose material is

Celal Bayar University Journal of Science
Volume 22, Issue 1, 2026, p 106-112
Doi: 10.18466/cbayarfbe.1659041

brick is ready in the program, but by changing the material of the wall, we can obtain an aerated concrete wall. This method has been used to model ceramic, parquet, levelling concrete, suspended ceiling, 10 cm and 20 cm aerated concrete were modelled.

In Revit, structural and architectural projects can be modelled and combined in different Revit files. In this study, these two projects were modelled together in a single file, which allowed the clashes and overlaps to be detected and rectified during the modelling process. In the model, architectural floor and structural floor may overlap each other or the wall may intersect with the column. Such situations are undesirable incompatibilities, and the Revit shows warnings to the user about these situations. These warnings must be taken into consideration and rectified, as they have a direct impact on the quantity of the model. In addition, shafts in the model must also be modelled. For example, in this study, the elevators shafts in the foundation, ventilation shafts for the floors, and door-window shafts in the walls were left. Consequently, the 3D modelling process was completed and made suitable for quantity take-off (Figure 3.).

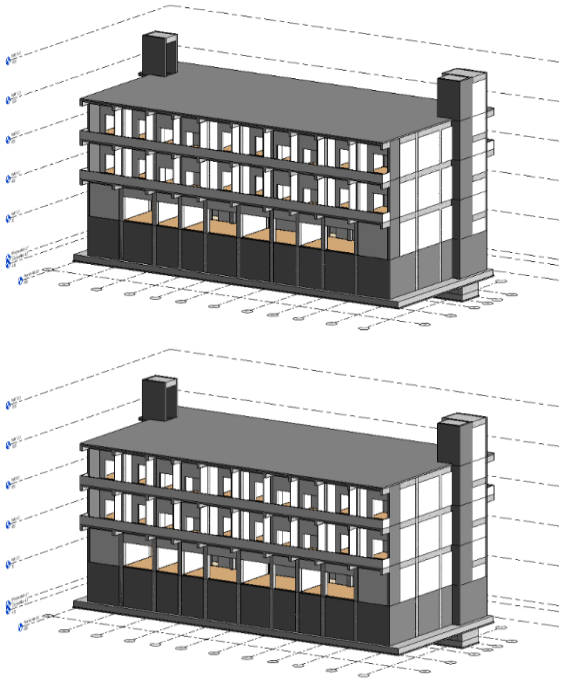


Figure 3. 3D model view in Revit.

Reinforced concrete elements can be modelled by Revit so that the quantity of concrete can be calculated automatically. However, the quantity of formwork required reinforced concrete elements cannot be calculated automatically. For this reason, formwork was modelled on the surfaces of reinforced concrete units and formwork quantities were taken-off. In Figure 4., the brown surfaces surrounding the reinforced concrete represents to formwork unit.

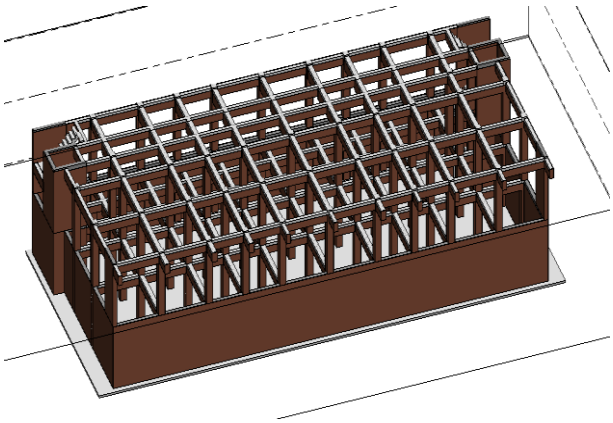


Figure 4. Formwork model in Revit.

Using the "Schedules/Quantity" command in Revit, quantity sheets were created for each of the following productions: lean concrete, concrete, formwork, 10 cm and 20 cm thick aerated walls, leveling and sloping concrete, ceramics, parquets, and suspended ceilings. Subsequently the total quantity was calculated.

The second calculation method in the study, the traditional method, was used to calculate quantity of the building with the width, length and height parameters on the 2D structural and architectural project. It was recalculated several times against the possibility of error. While the wall heights in the project are 4 meters, the wall heights corresponding to the bottom of the beam are 3.80 meters. In the traditional method, in order to determine this situation, it is necessary to examine and calculate the architectural and structural 2D projects separately. However, since the architectural and structural models are together in Revit, this situation can be easily detected, and Revit even calculates it automatically instead of the user.



Figure 5. Ready-made quantity (RMQ) data in project file.

In chapter 2.4, it was explained that some construction projects have ready-made quantity (RMQ) data. In the structural project of this building, there are RMQ data for concrete, formwork and rebar products (Figure 5.). Although there is no RMQ data in the architectural project, the designer provided the area of the rooms. Based on the room areas the building's production of ceramics, parquets, levelling and sloping concrete, and suspended ceiling was calculated and included in the

Table 1. Quantities and differences.

ITEMS						
Name	**Unit**	**Quantity**			**Difference**	
		Revit(R)	**Traditional (G)**	**RMQ**	**R-T**	**R-RMQ**
Lean Concrete	m³	87.70	86.63	86.63	1.07	1.07
Concrete	m³	1,701.00	1,685.03	1,694.08	15.97	6.92
Formwork	m²	7,975.00	7,564.28	7,737.22	410.72	237.78
Aerated 10 cm	m²	2,580.00	2,653.77	-	-73.77	-
Aerated 20 cm	m²	814.00	874.89	-	-60.89	-
Ceramic Floor	m²	1,576.00	1,589.34	1,609.40	-13.34	-33.40
Parquet Floor	m²	1,303.00	1,293.56	1,149.00	9.44	154.00
Levelling Concrete	m²	2,879.00	2,882.90	2,758.40	-3.90	120.60
Sloping Concrete	m²	864.00	892.80	-	-28.80	-
Suspended Ceiling	m²	2,583.00	2,571.90	2,460.40	11.10	122.60

RMQ data. For example, the room area in Figure 6. is 60 m². In other words, it calculated that 60 m² of ceramics, parquets, leveling concrete, and suspended ceilings are produced in this room. Since there is no RMQ data of 10 cm and 20 cm thick aerated wall and sloping concrete production in the project, that is, it would require manual calculation, the quantity of these products is not included in the calculation.

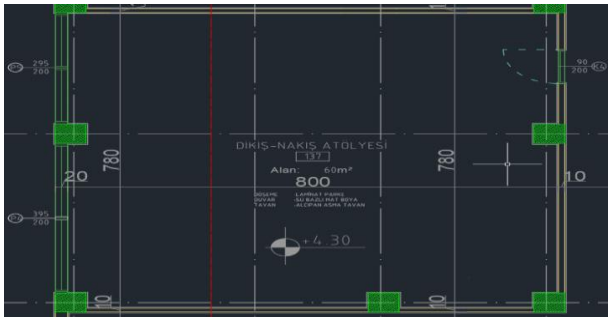


Figure 6. A room area in 2D AutoCAD project.

3.1 Comparison of Quantity Data

Comparing the quantity data obtained from the Revit with the quantity data calculated by the traditional method and RMQ data in the project, it is seen that there are differences (Table 1.). As a result of the comparison of the quantity data obtained from Revit with other methods, it is seen that the 10 cm aerated walls are 73.77 m² less than that calculated by the traditional method, the 20 cm aerated walls are 60.89 m² less, and the sloping concrete is 28.80 m² less. Ceramic product is 13.34 m² less than calculated by the traditional method and 33.40 m² less than the RMQ data. The production of leveling concrete is 3.90 m² less than calculated by the traditional method and 120.60 m² more than the RMQ data. For other products, the quantities obtained from Revit are higher than other methods.

3.2 Comparison of Cost Data

The quantities (Q) obtained from the three different methods were multiplied by the construction unit price (C) of the Ministry of Environment, Urbanization and Climate Change (Equation 1.). The results were summarized, and the total cost was calculated (Table 3.). The deviation rate of Revit's cost results (R) compared to the cost results obtained using the traditional method (T) and the cost results obtained from the ready-made quantity (RMQ) data in the project calculated Equation 2 and 3.

$$\text{Quantities x Unit Price} = \text{Cost} \quad (1)$$

$$((\text{Revit} - \text{Traditional})/\text{Traditional}) \text{ x } 100\% = \text{Deviation} \quad (2)$$

$$((\text{Revit} - \text{RMQ})/\text{RMQ}) \text{x } 100\% = \text{Deviation} \quad (3)$$

Table 2. Unit price of products.

İtems			
No	**Name**	**Unit**	**Unit Price (TL)**
15.150.1002	Lean Concrete	m³	1,409.26
15.150.1006	Concrete	m³	1,616.01
15.180.1003	Formwork	m²	254.33
15.160.1003	Thin Rebar	t	19,696.93
15.160.1004	Thick Rebar	t	19,448.18
15.225.1004	Aerated 10 cm	m²	244.38
15.225.1010	Aerated 20 cm	m²	409.26
15.390.1028	Ceramic	m²	493.38
15.485.1001	Parquet	m²	654.74
15.250.1001	Sloping Concrete	m²	86.31
15.250.1001	Leveling Concrete	m²	86.31
15.530.1901	Suspended Ceiling	m²	330.26

The item numbers of the products in the study were selected from the item numbers defined by the Ministry of Environment, Urbanization and Climate Change, and the unit price of the products for 2022 years was determined (Table 2). Thin and thick rebars were not included in the comparison of quantities. The rebar

quantities are included in RMQ in the project but calculated by Revit and traditional method. RMQ However, to make the total cost comparison more realistic, the RMQ data in the project were included in the cost table of the Revit and traditional method.

When comparing Revit and the traditional method, it is seen that the highest positive value is for formwork with 104,458.42 TL and the highest negative value is for 20 cm aerated wall with 24,919.84 TL. Comparing Revit and RMQ reveals that the highest difference is parquet, with a surplus of 100,829.96 TL (Table 3.). When the cost deviation rates are analyzed, the highest negative deviation rate between Revit and other methods is in 20 cm aerated wall with 6.96% and the highest positive deviation rate is in formwork with 5.43%.

Investigation of the total cost (Table 3.) reveals that Revit results are 89,293.22 TL higher than the traditional method and 162,981.73 TL higher than RMQ in the project. The deviation rate of Revit results compared to the traditional method is 0.700% and compared to the RMQ is 0.704%.

A comparison of Revit and RMQ reveals cost differences in suspended ceiling and parquet. RMQ underestimated the cost of the suspended ceiling and parquet because the designer incorrectly determined the room areas. Since the suspended ceiling and parquet were more detail in Revit, the result was more accurate. For this reason, Revit calculated the cost more than RMQ. RMQ is prepared by the designer and provides ease and convenience in estimate cost. However, as this comparison demonstrates, it may be misleading.

Table 3. Cost comparison and deviation rate (%).

	Cost (TL)			Difference (TL)		Deviation Rate (%)	
Item Name	**Revit (R)**	**Traditional (G)**	**RMQ**	**R-T**	**R-RMQ**	**R-T**	**R-P**
Lean Concrete	123,592.10	122,089.83	122,084.19	1,502.27	1,507.91	1.23	1.24
Concrete	2,748,833.01	2,723,025.33	2,737,650.22	25,807.68	11,182.79	0.95	0.41
Formwork	2,028,281.75	1,923,823.33	1,967,807.16	104,458.42	60,474.59	5.43	3.07
Thin Rebar	2,258,056.06	2,258,056.06	2,258,056.06	0.00	0.00	0.00	0.00
Thick Rebar	1,905,727.16	1,905,727.16	1,905,727.16	0.00	0.00	0.00	0.00
Aerated 10 cm	630,500.40	648,528.31	648,528.31	-18,027.91	-18,027.91	-2.78	0.00
Aerated 20 cm	333,137.64	358,057.48	358,057.48	-24,919.84	-24,919.84	-6.96	0.00
Ceramic	777,566.88	784,148.57	794,045.77	-6,581.69	-16,478.89	-0.84	-2.08
Parquet	853,126.22	846,945.47	752,296.26	6,180.75	100,829.96	0.73	13.40
Sloping Concrete	74,571.84	77,057.57	77,057.57	-2,485.73	-2,485.73	-0.14	4.37
Leveling Concrete	248,486.49	248,823.10	238,077.50	-336.61	10,408.99	-3.23	0.00
Suspended Ceiling	853,061.58	849,395.69	812,571.70	3,665.89	40,489.88	0.43	4.98
Total	12,834,941.13	12,745,677.91	12,671,959.39	89,263.22	162,981.73	0.700	0.704

4. Conclusion

The 3D BIM system provides a more comprehensive, detailed and understandable view of the building. Elevations, floor plans, details and cross-section of building can be created instantly. These features allow the designer to increase working efficiency by not getting lost in details compared to traditional methods. In BIM, there is information such as size, location, material type, cost of structure, so the BIM system is very useful in quantity and cost estimations.

The traditional calculations method of manual quantity surveying is a complex and time-consuming process. Revit, a BIM based program, facilitates this process. Even if there is a revision in the project, this change is automatically reflected in the quantity take-off, and it is not necessary to calculate quantity and cost again and again. Revit allows the user to quickly create detailed schedule of quantities and cost information, with the feature to separate schedules for each floor and each building element. These functions minimize the possibility of errors in quantity and cost estimates and provide realistic results. However, as errors in modelling will lead to inaccurate quantities and therefore misleading cost estimates, attention should be paid to these errors during modelling.

In this study, the cost data calculated with BIM revealed that lean concrete, concrete, formwork, parquet, and suspended ceilings productions has higher prices than other methods. Therefore, the idea that BIM reduces costs is incorrect. BIM method determines higher costs does not mean that the method is wrong. The expectation from the BIM method should be to obtain results close to reality. Because low or high expectations due to incorrect calculations of construction costs can lead to undesirable results during the implementation phase.

The limitations of this study are that only construction and some architectural elements were modelled in BIM and cost estimates were made, not all engineering was included. As the number of units included in the model increases, the efficiency of BIM use will increase, and more accurate results will be obtained. The use of BIM will be more effective by adding details from architecture and other engineering (mechanical, electrical) disciplines. In addition, utilizing 4D and 5D BIM systems with quantity and cost information obtained from this study will add value to the construction sector.

Author's Contributions

Şahin Tolga Güvel: Assisted in analytical analysis on the structure, supervised the experiment's progress, result interpretation and helped in manuscript preparation

Burak Karakurumer: Drafted and wrote the manuscript, performed the experiment and result analysis.

Ethics

There are no ethical issues after the publication of this manuscript.

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