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Automation of cost control process in construction project building information modeling (BIM)

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ABSTRACT

This research is carried out to investigate the critical role of BIM technology in estimating the construction project cost with higher accuracy than the manual method of budget evaluation. A construction project case study is selected, presenting a commercial complex in Al-Anbar, Al-Ramadi, Iraq. A comparative analysis is conducted to compare the accuracy of the REVIT software (BIM technology) with the manual calculation method. The major research findings revealed that using the BIM technology via the REVIT software provided a more effective approach and practicality than manual calculations of steel, concrete, and other architectural components. In addition, the findings confirmed that the accuracy of cost estimation using BIM technology via REVIT software is better than manual calculations. The reason is the elimination of human errors during the calculations process. Thus, accurate results can be obtained from the REVIT software. Also, the research outputs indicated that using the BIM technology can save much time, effort, and cost needed to calculate the cost of the construction project compared to the manual cost estimation of the construction project.

Keywords: BIM technology, construction project cost, accuracy, manual calculations, comparative analysis, human errors

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1 Introduction

The rapid increase in the global population and the high urbanization rate led to a significant expansion in the construction industry [1] and the pace at which building construction passes worldwide. Digitalization and information technology have provided remarkable innovative methods for helping engineers from different disciplines track and manage their construction projects with less time, effort, and cost [2]. BIM technology, which was developed in 1974 [3], is capable of providing different effective solutions for building and construction via modeling the facility and tracking 3, 4, 5, 6, or 7 variables before, during, and after the projects are executed, which is known as three dimensional (3-D), 4-D, 5-D, 6-D, and 7-D, respectively. BIM technology (Building Information Model-ling) can be defined as "A virtual approach, innovated by research and development (R&D), through which the data of construction projects and their information related to their degree of execution are modeled and tracked through computer software packages for enabling design and planning team, including construction stakeholders, such as civil engineers, architects, owners, designers, suppliers, consultants, contractors, and subcon-tractors to more effectively and easily cooperate and more facilitate their communication in comparison to conventional methods of design, planning using in construction" [4]. Using BIM technology by different engineers and construction stakeholders around the world contributed to a significant shift in the efficiency and performance of the construction industry in comparison to conventional methods used by engineers in managing several construction projects, which has helped save a high level of time, effort, and cost required in traditional ways in managing the projects. In addition, the use of BIM technology led to increased accuracy in the estimation of construction projects' costs, leading to a

remarkable reduction in the losses and errors that occurred when conventional methods were used [5]. Figure 1 presents the key beneficial impacts and contributions of using BIM technology.

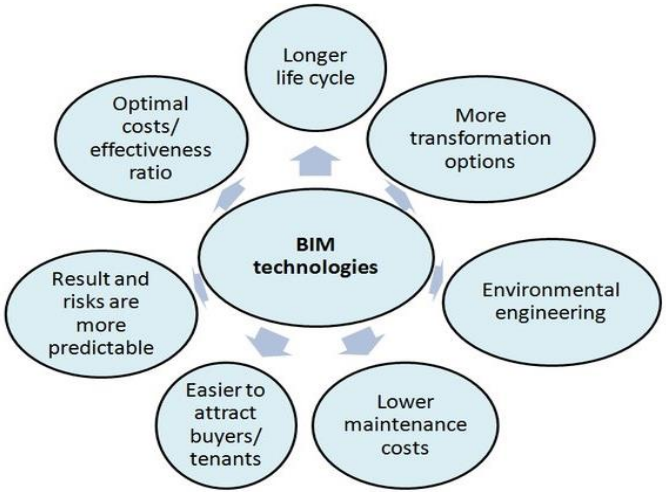

Figure 1. Major contributions and key advantages of BIM technology [6]

2 Literature review

A study has been conducted to review the development related to the BIM technology concept over the last decades. For achieving the study goal, a comprehensive literature re-view is executed. Several ideas and key definitions of BIM technology were addressed and reviewed. Further, the research identified critical aspects and major characteristics of BIM technology between 1975 (since BIM technology was initiated) and 2013. The comprehensive literature review results revealed that BIM technology has been passing through various developments, modifications, and improvements that helped promote performance and effectiveness in managing small-, medium, and large-scale construction projects [7]. Figure 2 presents the key definitions and main concepts related to the BIM technology since 1975.

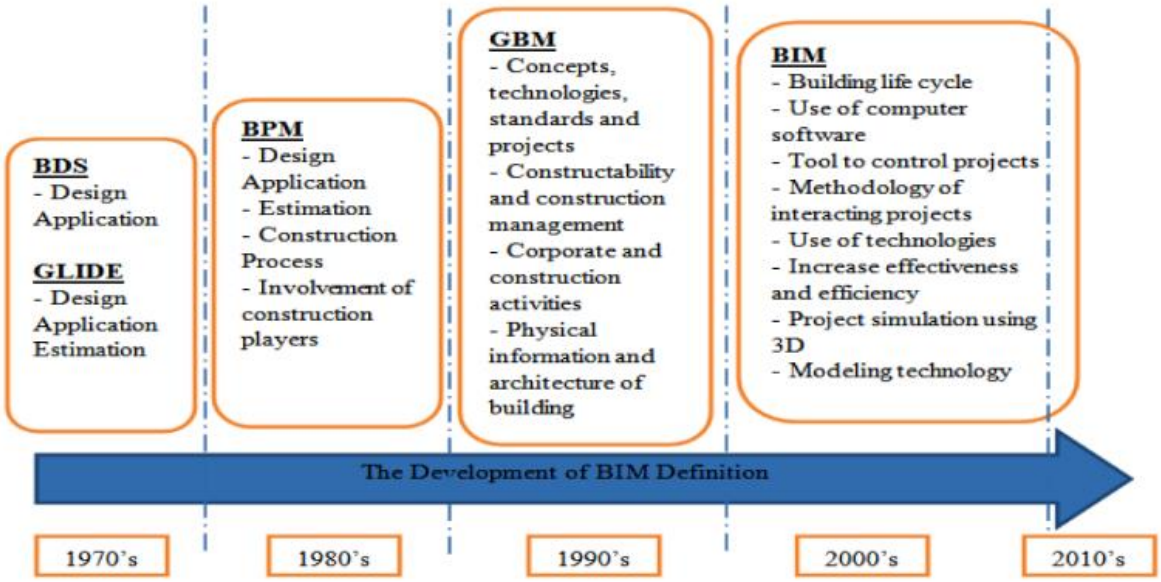

Figure 2. Key concepts and definitions developed for BIM technology over the decades [7]

Research is carried out by investigating the history, stages of development, and future aspects and different innovations implemented for BIM technology over the decades worldwide and in Malaysia. A systematic literature review is implemented to accomplish the study goal. The comprehensive literature analysis reviewed numerous academic publications and peer-reviewed articles, discussing major contributions and key developments conducted on the BIM technology over the latest decades. The literature analysis results confirmed that BIM technology was initiated in 1974 as a building description system (BDS), then developed into graphical language for interactive design in 1977. IT was followed by a building product model (BPM),

through which modeling for different facilities was initiated in 1989. Then, a generic building model (GBM) was implemented in 1995, reaching the BIM concept at the start of the twentieth-first century. Various effective analysis methods and innovative technologies were exploited to increase the BIM technology's critical role and accuracy in estimating projects cost [8]. Figure 3 presents the stages of development that occurred to the BIM technology (References in the figure are cited in the references [9]-[13]).

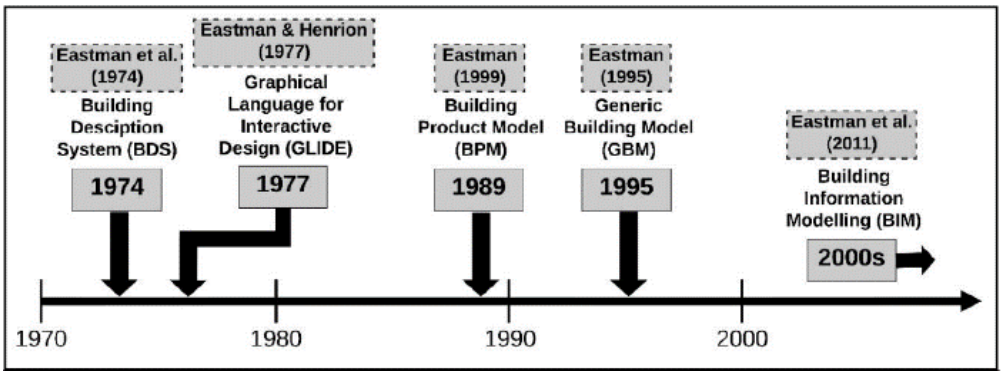

Figure 3. Stages of development occurred to the BIM technology over the time [8]

A published manuscript investigates and determines key elements and significant features of BIM technology. The research implemented a comprehensive literature review by which the BIM technology's key features and critical characteristics were classified. The literature analysis findings affirmed that BIM technology is characterized by its higher accuracy in evaluating construction projects' costs than manual calculations, which contain many human errors. Furthermore, BIM technology utilizes software packages and information technology tools that help engineers, architects, and designers manage construction projects effectively and flexibly. Additionally, one of the major BIM technology features is its capability to design and monitor several construction projects via advanced technical approaches that implement green and environmental principles and energy conservation methods to save the building's energy consumption and make it remarkably energy-efficient [14]. A study is performed to assess the BIM technology's main characteristics and significant features. The study conducted a comprehensive literature review. Several recent publications were analyzed to address the leading BIM technology's features, principles, and characteristics. The research findings indicated that BIM technology is featured with higher reliance on 2-D, 3-D, 4-D, and 5-D modeling using CAD software tools that enable the tracking of the entire construction project, starting from design and planning until the complete execution of the construction project. In addition, the results confirmed that BIM technology principles pass through three levels, initiating from paper design, and ending with overall modeling of the facility via different CAD software packages [15], as indicated in Figure 4.

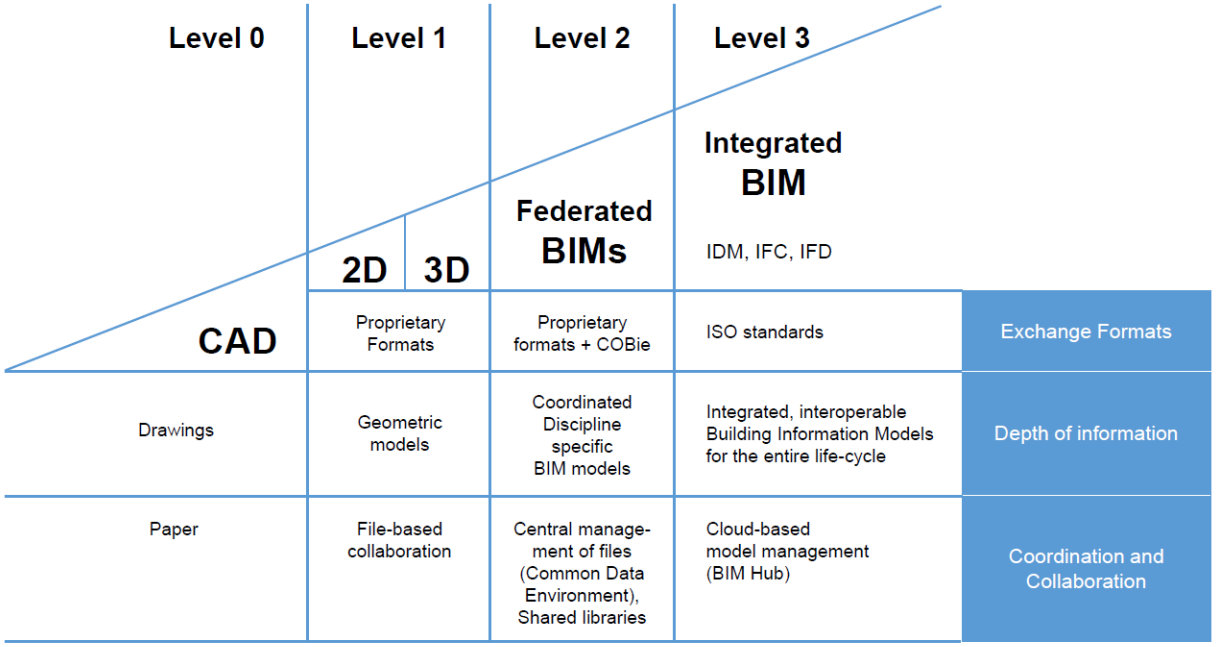

Figure 4. Main levels of BIM integration for buildings design and management [15]

A study is executed to locate key benefits and critical advantages of BIM technology in providing an effective and accurate estimation of the budget for different construction projects. The research relied on a case study analysis to accomplish its research goal. A typical construction project in the Czech Republic was selected, and the project's cost estimation was carried on. The case study results revealed that implementing BIM technology is greatly helpful and functional, as it provides a cost estimation process with a higher degree of accuracy. Furthermore, the case study findings indicated that BIM technology could offer an effective method for cost calculations of different construction projects, saving much time and effort compared to manual cost estimation [16]. Research is executed by exploring and identifying major contributions of BIM technology in predicting the cost accurately and managing the budget of construction projects effectively. A comprehensive literature review is implemented to accomplish the study goal. Additionally, descriptive research via interviews collected primary data from civil engineering experts and project management professionals in BIM technology. The analysis results confirmed that implementing BIM technology in the construction industry helps achieve effective prediction and estimation of construction project budgets. Besides, findings revealed that BIM technology provides accurate cost estimation results, saving a higher amount of time than conventional methods of cost estimation [17].

3 Materials and methods

3.1 Methods

Initially, a comprehensive literature review analysis is conducted to address critical principles and significant concepts of BIM technology. The literature is vital to shedding light on major BIM technology's role in predicting the cost (project budget) with higher accuracy. Following the first step associated with the literature analysis, the researcher selects a case study of a typical medium-scale project in Iraq (a commercial complex) and analyzes the cost required for its construction. Then, the BIM system is implemented to predict the project's cost via the REVIT software, which is well-known for BIM technology. Finally, the results will be validated and verified by comparing the resulting values of the project budget from the BIM system with the manual calculations of the same project. Following this step, major work's conclusions and recommendations are drawn. Figure 5 presents the research methodology flowchart.

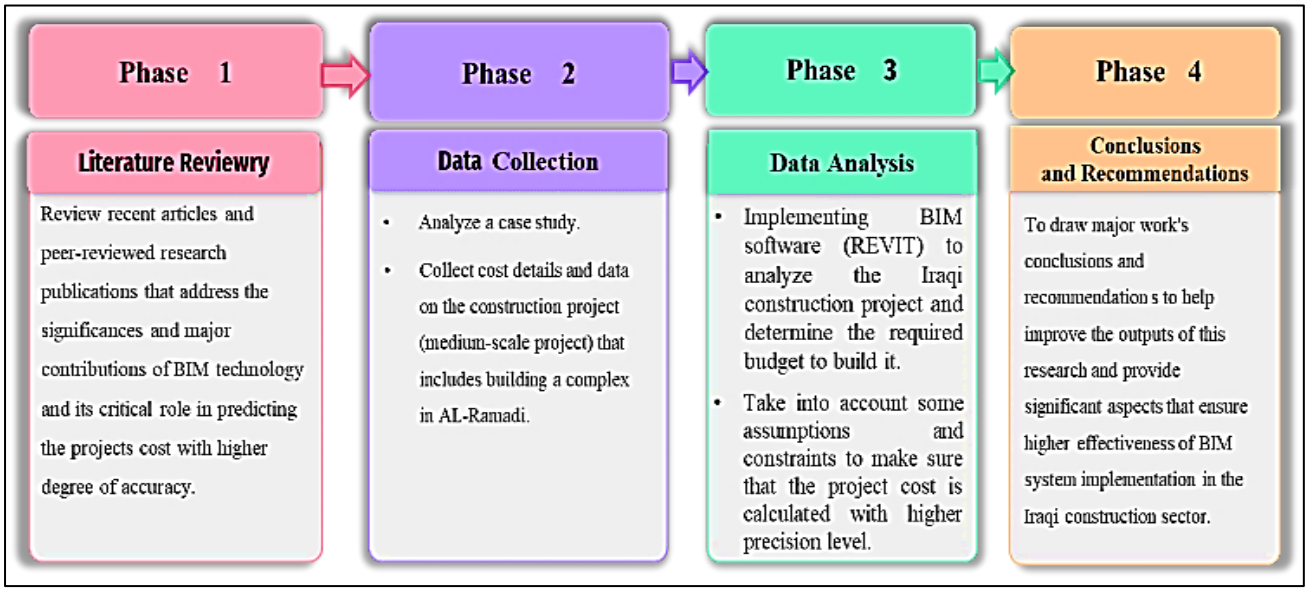

Figure 5. The thesis methodology flowchart

3.2 BIM software package

Major BIM technology tools include AutoCAD, SketchUp, Navisworks, Aurora, REVIT, and ArchiCAD. However, not all software tools from those are capable of integrating the construction project budget, schedule (achievement time), and resources (activities) during the execution of the project. One of these software tools that can achieve these aspects is the REVIT software. REVIT is greatly popular among engineers, architects, and designers due to its potential in modeling the building to plan, design, execute, and operate the facility before, during, and after its construction process. One of the major advantages of REVIT software is its benefits

in providing 3D, 4D, 5D, 6D, and 7D modeling [18], as illustrated in Table 1. REVIT was founded in 1997, and its name was Charles River software®. Neverthe-less, it was renamed REVIT software in 2000. Then, it was acquired by AutoDesk® in 2002 [19]. REVIT needs to select the materials and define the dataset of the construction project. These datasets include the cost of elements used in constructing the building, such as concrete, windows, doors, and other parts. Then, REVIT makes 5D modeling to estimate the cost and build an intelligent 3D model of the project to enable engineers and designers to understand the construction process and track the building phases of the facility [20]. Major stages of the REVIT software package are presented in Figure 6.

Table 1. Types of Modeling in REVIT software package [18]

Type of Modeling	Categories Modeled and Investigated	Major Features
3D	Three geographical dimensions (x, y, and z) of the structure.	Most common modeling used by designers. It helps visualize and observe the realistic building before it is built.
4D	Three geographical dimensions (x, y, and z) of the structure, plus the duration (time of activities).	It is greatly helpful to let stakeholders prepare the next phases and resources and track the construction process.
5D	Three geographical dimensions (x, y, and z) of the structure, the duration (time of activities), and the budget required (project's cost).	5D is essential to let owners and engineers optimize the cost required for construction, provide a higher accuracy level, and reduce financial losses during construction.
6D	Three geographical dimensions (x, y, and z) are the structure, the duration (time of activities), the budget required (project's cost), and environmental sustainability.	6D modeling helps project managers to make their construction process more sustainable and environmentally friendly by completing the project green and producing less harmful waste, plus making it an energy-efficient facility.
7D	Three geographical dimensions (x, y, and z) of the structure, the duration (time of activities), the budget required (project's cost), environmental sustainability, and operation and maintenance.	7D modeling is vital to make the project effective in the long term. It is associated with maintenance and operation guidelines, operation status, warranty specifications, and technical information.

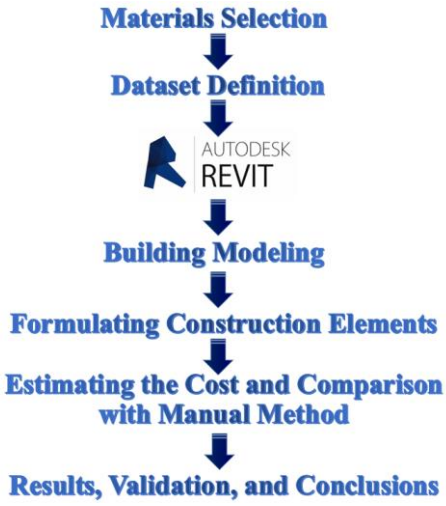

Figure 6. Major REVIT phases in estimating the project cost

In this work, the 5D modeling of the investigated building is implemented to help determine the facility's budget with a higher level of accuracy. The manual method for estimating the same project's cost is used to compare the degree of accuracy between the traditional way and the BIM technology.

3.3 Case study

This project is located in Iraq, Al-Anbar, Al-Ramadi, the western region of Iraq. It is posited 110 km far from Baghdad. This building presents a commercial complex. It is a multi-story facility containing five floors. The overall surface area of the complex amounts to approximately 1,567 square meters. Table 2 illustrates more details on the building's components and the surface area of each floor. The author conducted a cross-sectional qualitative study to achieve the study goals. An interview with the complex owner pro-vides more data and technical details on the cost of building the complex, the duration required, and some technical information that helps analyze the case study. The manual calculations implemented to evaluate the complex cost will depend on calculating the concrete material, steel, and other complex components.

Table 2. More details on the building's components and the surface area of each floor.

No.	Floor	Area	Use
1	Ground floor	307 sqm	Staircase with elevators, office with bathroom, kitchen, electrical room, two WCs, and gallery and shaft.
2	First floor	315 sqm	One office with bathroom, staircase with elevator, big shaft, bathroom, and gallery.
3	Second floor	315 sqm	One big storage with a bathroom.
4	Third floor	315 sqm	One big storage with a bathroom.
5	Roof floor	315 sqm	Service room with staircase area and roof.
Total		**1,567 sqm**	

Figure 7 presents a photo of this complex.

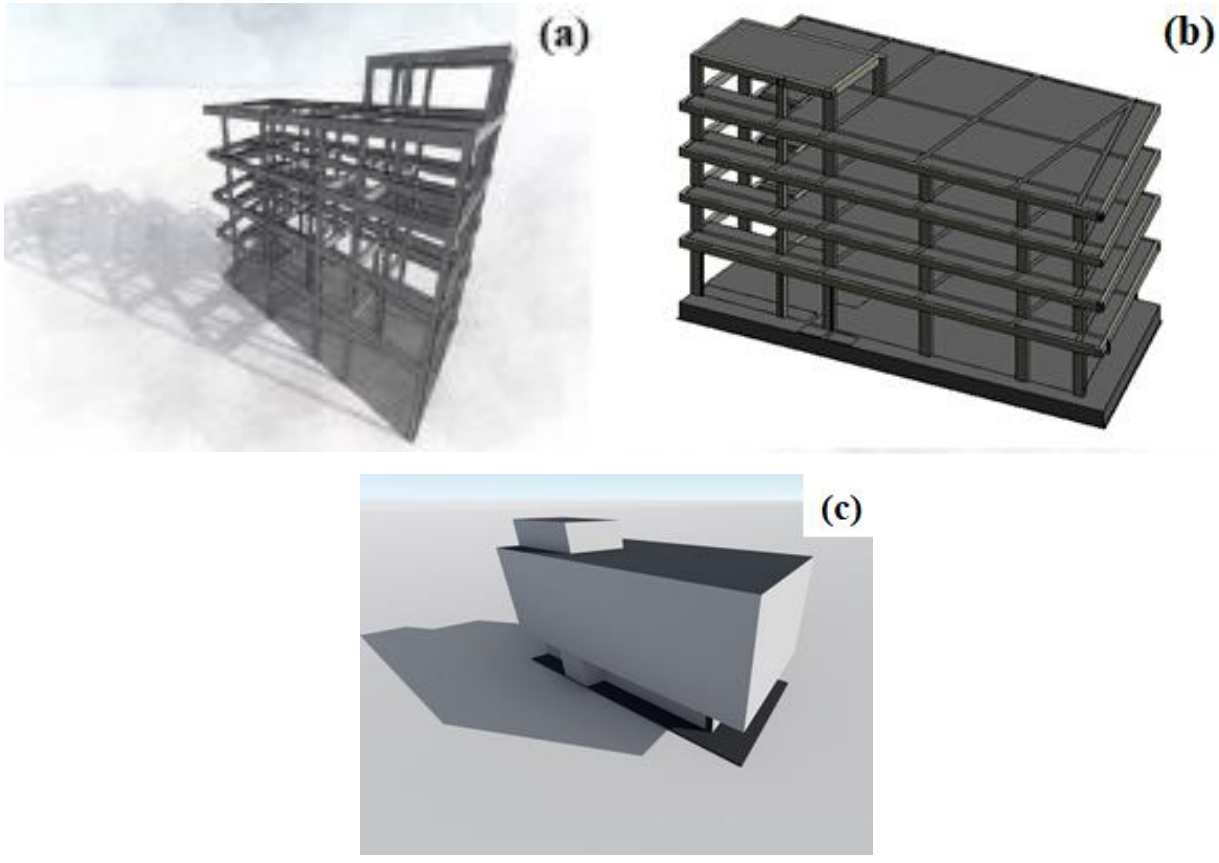

Figure 7. The commercial complex in Al-Ramadi, Iraq: (a) the raft foundation, columns, and beams, (b) the building after adding the solid slabs, and (c) the outside view of the building with concrete.

3.4 Theory and mathematical modeling

Firstly, the amount of cut (or cut volume), CV, is computed via the formula:

$$CV = RA \times RH \quad (1)$$

Where:

RA	Raft area
RH	Raft height

The blinding area, BA, can be computed via the relation:

$$BA = [(L_1 + L_2)/2] \times H \quad (2)$$

Where:

L_1	Length of the site
L_2	The site width
H	Blinding Height

To evaluate the reinforced concrete volume, RCV, for the raft foundation, the following relation is used:

$$RCV = [(L_{1,c} + L_{2,c})/2] \times H \quad (3)$$

Where:

$L_{1,c}$	Length of the foundation
$L_{2,c}$	Width of the foundation
H_c	Height of the foundation

The steel reinforcement, SR, can be estimated using the equation:

$$SR = BW \times L \times NSB \quad (4)$$

Where:

BW	Bar weight
L	Length of the steel bar
NSB	Number of the steel bars

BW is expressed as:

$$BW = {BD^2}/{162} \quad (5)$$

Where BD is the bar diameter. It is considered in mm.

4 Results

A comparison analysis is conducted to predict the accuracy of the REVIT software that relies on the BIM technology to estimate the construction project cost of the case study in this research with the manual calculation method to determine the project's cost. From the manual calculation method and the REVIT software evaluation results of steel weight and concrete volume in the project, a comparison between the two approaches can be concluded and illustrated in Table 3.

Table 3. A comparison between manual quantity surveying and Revit results of steel and concrete amount estimation.

Comparison		**Manual Result**	**Revit Results**
Concrete (m^3)	Cut	415.26	427.95
	Blinding	315.02	317.00
	Raft Concrete	384.50	396.25
	Slabs Concrete	562.22	573.15
	Columns Concrete	43.60	47.84
	Beams Concrete	138.34	127.46
	Walls	49.74	42.24
Steel (kg)	Raft Steel	32,439.04	32,611.88
	Slabs Steel	14,797.5	14,797.5
	Columns Steel	8,013.78	9,360.13
	Beams Steel	19,168,48	18,533.98
	Walls Steel	5,122.66	5,099.20

Furthermore, depending on the quantity survey of the project's architectural components, another comparison between the manual method and the REVIT software can be expressed in Table 4.

Table 4. A comparison between manual quantity surveying and Revit results of quantity surveying of project's architectural components.

Comparison	**Manual Result**	**Revit Results**
Blocks (m^2)	1,530.75	1,584
External Plaster (m^2)	1,092.18	1,176
Internal Plaster (m^2)	2,029.81	2,826
Paint (m^2)	2,029.81	2,220
Floor Tiles (m^2)	1,140.83	1,045

It can be concluded from Tables 3 and 4 that the results obtained from the manual calculations are greatly closer to the findings obtained from the REVIT software. However, the REVIT program provided more accurate outputs due to the accuracy in modeling and fewer human mistakes in manual quantity surveying. Thus, it can be observed that the BIM technology principles using the Revit software are considered the future of modern building control that starts from design to the end of construction and beyond.

5 Discussion

This work indicates that using the BIM technology via the REVIT software provided a more effective approach and practicality than manual calculations of steel, concrete, and other architectural components. This result is consistent with the findings of Namlı et al. (2019), who analyzed the BIM technology's major contributions and found that implementing BIM technology can improve productivity, reduce errors, and achieve a higher level of coordination between stakeholders than traditional methods. This result is consistent with the results of Vitásek S. and Zak J. (2018), who conducted a study for locating and determining key benefits of BIM

technology and found that using BIM technology is greatly effective in offering an active and practical approach to construction project budget estimation. This result is also compatible with Xu et al. (2013), who performed a study to explore and examine the key contribution and beneficial role of BIM technology and found that BIM technology can offer higher work effectiveness in project costs estimation. How-ever, this result is not fully consistent with the results of Tulenheimo R. (2015), who carried out a study for investigating and locating the main challenges of implementing BIM technology for modeling and managing different construction projects in Finland and found twenty-three aspects of BIM technology challenges that hinder its development and implementation in the construction industry, including customers challenges, obstacles in companies, social elements, issues in the technology, and difficulties in supporting de-tails. In addition, the findings of this research reveal that the accuracy of cost estimation using BIM technology via REVIT software is better than manual calculations. The reason is the elimination of human errors during the calculations process. Thus, accurate results can be obtained from the REVIT software. This result is consistent with the results of McCuen, (2015), who carried out an investigation for identifying the main contributions of BIM technology in estimating the cost of different construction projects and found that using BIM technology and REVIT software is greatly beneficial in providing a higher degree of accuracy in evaluating project's budget. This result is also consistent with Vitásek S. and Zak J. (2018). They executed a study for locating and determining the key benefits of BIM technology and found that using BIM technology is greatly beneficial. It helps calculate the construction project with higher accuracy and eliminates human errors. This result is also similar to the findings of Xu et al. (2013), who performed a study for exploring and examining the key contribution and beneficial role of BIM technology and found that BIM technology can offer precise evaluation of construction projects' budget via building modeling of activities and time, thus, estimating budget cost with higher accuracy. More-over, the findings of this study confirm that using BIM technology can save much time, effort, and cost needed to calculate the cost of the construction project. This result is consistent with the results of McCuen, (2015), who carried out an investigation for identifying the main contributions of BIM technology in estimating the cost of different construction projects and found that using BIM technology and REVIT software can save a significant amount of time and effort in evaluating the construction projects' costs.

6 Conclusions

This research is carried out to investigate the critical role of BIM technology in estimating the construction project cost with higher accuracy than the manual method of budget evaluation. A construction project case study is selected, presenting a commercial complex in Al-Anbar, Al-Ramadi, Iraq. A comparative analysis is conducted to compare the accuracy of the REVIT software (BIM technology) with the manual calculation method. The major research findings can be classified into the following paragraphs:

- Using the BIM technology via the REVIT software provided a more effective approach and practicality than manual calculations of steel, concrete, and other architectural components.
- Using BIM technology via REVIT software offered better cost estimation accuracy than manual calculations. The reason is the elimination of human errors during the calculations process. Thus, accurate results can be obtained from the REVIT software.
- Using BIM technology can save much time, effort, and cost needed to calculate the cost of the construction project compared to the manual cost estimation of the construction project.

Abbreviations

RA	Raft area
RH	Raft height
L_1	Length of the site
L_2	The site width
H	Blinding Height
$L_{1,c}$	Length of the foundation
$L_{2,c}$	Width of the foundation
H_c	Height of the foundation
BW	Bar weight
L	Length of the steel bar
NSB	Number of the steel bars
BD	The bar diameter

Competing Interest Declaration

The authors declare that they have no recognized non-financial or financial competing interests in any materials conversed in the current work.

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