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Effect of Building Information Modeling on Construction Projects Design Stage Efficiency

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Keywords:
BIM; Clash detection; Cost estimation; Cost overruns; Design error; Navisworks; Typical school.

Highlights:

- An effective treatment approach by photo-Fenton oxidation method.
- Effects of irradiation time, pH value, hydrogen peroxide, Fe+2 doses, and UV intensity.
- Using of Photo-Fenton, Fenton, and Ultraviolet, Photo-Fenton of removing oil from produced water.

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Abstract: Clash detection in building information modeling (BIM) is gaining significant importance as an enhanced tool for coordinating design schemes. Its primary task is to identify design errors and clashes between design disciplines during the design phase before the start of the project. Problems with such errors and clashes require frequent corrections and revisions of drawings, leading to time delays and cost overruns. For this research, a typical school project consisting of ten two-story buildings was selected as a case study, i.e., only two buildings were implemented. This paper aims to clarify and identify the cost-saving benefits that can be achieved through clash detection that supports the BIM system at the design stage. The research methodology involved gathering building data and independently converting architectural and construction drawings from 2D to 3D, subsequently exporting them to Navisworks for analysis. The findings revealed the presence of multiple design flaws that require rectification before commencing the implementation phase. According to the obtained results, it was observed that the total costs spent on each building exceeded the estimated total costs by approximately 25% due to design errors. Additionally, when considering a group of items in the bill of quantity for each building during the calculation and clash detection analysis, it was found that each item experienced a 10% increase in costs compared to the estimated values. Consequently, the combined total costs for both buildings surpassed 100 million IQD. Utilizing BIM technology has significantly influenced and improved various stages of the construction process and how BIM technology is used to create a model building that closely matches the estimated cost.

تأثير نمذجة معلومات البناء على كفاءة مرحلة تصميم المشاريع الإنشائية

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الخلاصة

ان استخدام تقنية كشف التداخلات مع بعضها في نمذجة معلومات البناء (BIM) لها أهمية كبيرة في قطاع التشييد باعتبارها جانبًا حاسمًا في تنسيق وترابط المخططات. تكمن وظيفتها الأساسية في تحديد أخطاء التصميم وعدم التناسق والترابط بين التخصصات المختلفة أثناء مرحلة التصميم قبل بدء المشروع. تتطلب هذه التعارضات الى تصحيح وتنقيح مستمر للمخططات، مما يؤدي إلى مشاكل في تأخير الوقت وتجاوز الكلف. لغرض اجراء هذا البحث، تم اختيار مشروع مدرسة نموذجية تتكون من عشرة مباني كل مبنى من طابقين، منفذ منها فقط اثنان كدراسة الحالة. يهدف هذا البحث إلى توضيح وقياس فوائد توفير التكاليف التي يمكن تحقيقها من خلال استخدام تقنية كشف الصدام المدعمة بـ BIM في مرحلة التصميم. تضمنت منهجية البحث جمع بيانات البناء وتحويل الرسومات المعمارية والإنشائية بشكل مستقل من 2D إلى 3D، ثم تصديرها لاحقًا إلى برنامج Navisworks لتحليلها. كشفت النتائج عن وجود عيوب تصميمية متعددة تتطلب تصحيحها قبل البدء في مرحلة التنفيذ. وفقًا للنتائج التي تم الحصول عليها، لوحظ أن إجمالي التكاليف التي تم إنفاقها على كل مبنى تجاوزت التكاليف الإجمالية المقدرة بنحو ٢٥٪ بسبب أخطاء التصميم. فضلاً عن عند النظر في مجموعة من الفقرات في جدول الكميات لكل مبنى أثناء تحليل الحساب واكتشاف أخطاء التصميم، وجد أن كل فقرة شهدت زيادة بنسبة ١٠٪ في التكاليف مقارنة بالكلف المقدرة. وبالتالي فإن إجمالي التكاليف الإجمالية لكلا المبنيين تجاوزت ١٠٠ مليون دينار عراقي. أوضحت الدراسة استخدام تقنية BIM وتأثيرها بشكل كبير على مراحل الانشاء وتحسينها وكيف يتم استخدام نموذج بناء متكامل يسهل في تطابق الكلف المخمنة بأكبر قدر ممكن مقارنة بالكلف الحقيقية.

الكلمات الدالة: نمذجة معلومات البناء، كشف الاشتباك، تقدير التكلفة، تجاوزات التكلفة، خطأ في التصميم، المدرسة النموذجية.

1.INTRODUCTION

1.1.Research Background

The construction industry is a substantial, complex, and economically significant sector that plays a significant role in a nation's economy [1]. Construction projects, in practical terms, are the total of an organization's planned activities, whether they involve using materials or not, to transform a concept or a design for engineering or construction work to satisfy human or economic requirements while adhering to quality, cost, and time constraints [2]. In the building process, every phase is generally independent of the others. Each of these processes often has a particular team working on it, as well as needs, information, and tools. Distributing tasks among different teams and their processes for completing each task can increase time requirements for each stage. Moreover, this division of labor also increases the probability of stages clashing or colliding with each other. Also, any changes that must be made at a particular project stage will not seamlessly impact the other stages. Therefore, the work will often not be uniform and smooth [3]. Buildings undergo multiple stages during construction, leading to numerous errors primarily attributed to plan discrepancies. Several factors primarily contribute to time delays and cost overruns in construction projects. These factors include inadequate construction planning, poor estimation, project changes during construction, deficient contract management, and financial and payment issues [4]. Such inconsistencies include differences between architectural and structural designs or a need for more understanding of the plans. Consequently, these errors resulted in project delays, increased costs, and issuing change orders. Rectifying these mistakes required additional efforts, depleted project resources, and adversely impacted the project's overall quality [5]. When implementing construction projects with design information, numerous issues exist, including misaligned specifications and drawings, missing pertinent information, delayed delivery of the design information, and unintended outcomes that contribute to building flaws, schedule delays, and budget overruns [6]. Discrepancies can be found in the quantity and cost bills or project drawings. Various drawings are available in the (AEC) industry to help with project implementation, e.g., architectural, structural, and electrical. The subsequent phases will be impacted if the information is inaccurate and insufficient. Change orders, therefore, frequently occur. Drawing inconsistencies makes disputes costly to resolve, causes delays, and adds to them [3]. During the design stage, using Building Information Modeling (BIM) offers several advantages. Firstly, it clarifies the design concepts, making them easier to understand and simplifying the project conceptualization process. Furthermore, BIM provides the owner with early and more precise visualizations of the design, enabling informed decision-making. Also, it improves simulations and coordination, thereby reducing errors and conflicts in the design phase [7]. Ghaffarianhoseini et al. [8] categorized design errors in multipurpose facility projects into illogical design, discrepancies, and missing items. The design error costs from 139 projects investigated through a questionnaire survey were calculated [9]. The results indicated that direct design error costs accounted for 6.85% of the total contract amount, while indirect design error costs accounted for 7.36%, totaling 14.21%. Most construction projects in Iraq contain numerous issues during the design phase. If these issues are not detected early, they will impact and manifest during the construction phase, exceeding the allocated and estimated costs for specific items and the project, resulting in incorrect estimations. This paper aims to show the effect of BIM, clarify and quantify the cost-saving benefits as much as most closely to the actual cost spent, achieved through the following objectives: employing BIM-enabled clash detection, examining clashes between different disciplines within a contemporary school project, and assessing the influence of design errors. Enhancing design efficiency, reducing change orders, and early detection of design errors before they occur can be achieved through Building Information Modeling (BIM) technology. The first research limitation was during the implementation of the first and second buildings in the central typical School in one of the Iraqi governorates for the academic year 2021-2022, while the second limitation was in the design preparation stage. This study is part of BIM-focused research, offering significant insights into modern clash detection technology's use and influence on Iraqi construction projects to encourage and promote its widespread use.

2.LITERATURE REVIEW

2.1.Building Information Modeling

BIM technology is a typical approach to enter, control, and visualize buildings throughout any project life cycle [10]. Through 3D visualization, real-time display, cost, and comprehensive facilities management, this technology eases analyzing and evaluating buildings and increases building design efficiency [11,12]. It is commonly used in construction because it can quickly fix errors during the early design stage and help with precisely timed construction, construction sequencing, clash detection, and design alternatives that permit simple solutions for challenging projects [13, 14]. BIM is used in many stages of a construction project, such as design validation, computing quantities, preconstruction, and 3D Building Information models at each stage of the construction process [11, 15]. Specifically, a BIM-based clash detection design revision lowers losses that might happen throughout the construction stage, i.e., design issues in the design process, by employing design reviews to identify and remedy issues before implementation [16-18]. This method, known as BIM-based design validation, has gained much popularity [19]. Cost savings and additional costs were calculated using collision detection. If this technique is applied to every collision, its associated costs will be determined. As confirmed by [20], implementing BIM significantly reduced 20% of the overall project value, specifically attributed to identification collisions.

2.2.Clash Detection Technique

Clash detection is among the most often utilized technologies in the BIM system. The phrase describes the automatic recognition of geometric penetrations (conflicts or clashes) of various 3D model components at the early phase of the design stage. Its goal is to confirm the construction is geometrically feasible [21]. Structure, architecture, and MEP (Mechanical, Engineering, and Plumbing) components compose a project. Involving multiple parties in creating each component, the likelihood of errors increases. Utilizing BIM helps consolidate all the data and construct a simulation model. This approach assists in identifying potential conflicts even before the building begins and identifies required design drawing adjustments, reducing the need for rework, construction costs, and time [22]. As mentioned by [23], the results indicated that in projects without BIM, the cost of rework and design errors accounted for 11% and 14.21% of the total cost, respectively. Additionally, rework represented 0.414-1.216% of the total construction cost in projects designed using BIM technology, while schedule delay accounted for 0.454-0.736%. Considering that the design stage accounts for 70% of the overall construction expenses, combining multidisciplinary skills is essential throughout the whole building construction operation [24]. Controlling cost and time has been a paramount concern in the construction industry from the project's inception [25]. The most crucial factors determining a project's success are the money spent and the required time [22]. Olanrewaju et al. [26] discovered that BIM might reduce the estimated preparation time by 80% and construction costs by 10% through clash detection. This method prevented considerable delays in the project timeline as well as increased expenses for procurement, demolitions, and additional labor due to redesign [20]. Construction project management heavily relies on BIM tools, including clash detection, quantity take-off, design, and simulation. The most frequent reasons for delays and cost overruns include bad designs, incorrect estimates, blunders, and mistakes made during construction because of design conflicts [27]. Therefore, using traditional 2-dimensional drawing on current projects is inaccurate and merely results in time loss, accuracy, and financial loss [22]. In the case of two-dimensional designs, they were conducted sequentially and separately, and each stage depended on the previous stage, so the structural designer could not make his design until completing the architectural design, and so on. In the case of BIM modeling, the design process for different disciplines occurred simultaneously. Therefore, conflicts can be detected through the so-called integrated central model, as seen in Fig.1 [28]. The "Integrated Central Model" developed by the project participants is like that shown in Fig 2. This procedure avoids potential design disputes and confrontations while increasing efficiency. At the same time, the BIM model encourages direct visualization and sharing of the design process. It would eventually raise the model's level of quality [28,29]. Like an "X-ray," the BIM model examines the model to find any flaws and weaknesses in the design, pointing out any elements that clash and ensuring that the model complies with organization standards, construction codes, and other criteria [30, 31]. The conflict types were classified into three types: (i) the hard type is the largest in terms of impact; it changes the physical properties and the shape of the building components, leading to cost overruns and delays in the schedule that need immediate attention, (ii) the soft type is the regular type clashes close some of them are due to the small area that can be remedied and have a medium impact on cost and schedule and need a solution before construction and low minimal impact on cost and schedule that can be resolved on-site [28,32,33]. Pärn et al. [34] propose a third type, which they categorize as "multi-discipline clashes," involving clashes between various disciplines within a building project. Implementing clash detection results in numerous benefits, such as fewer changes, reduced warranty cost claims, time spent on addressing errors, developing designs, documenting, coordinating change orders and rework, and redesigning in the field [35].

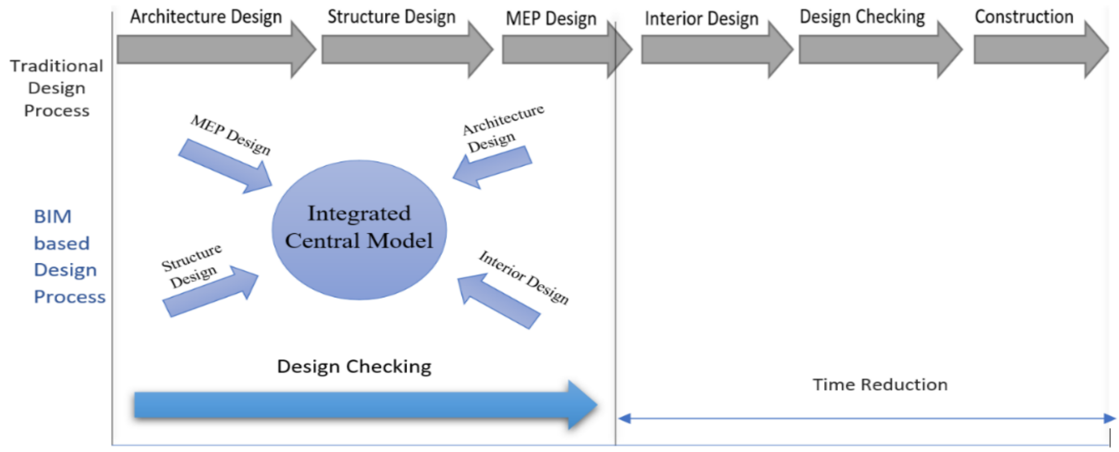


Fig. 1 Traditional Design Methods Compared with BIM Methods (Researcher Based on [28]).

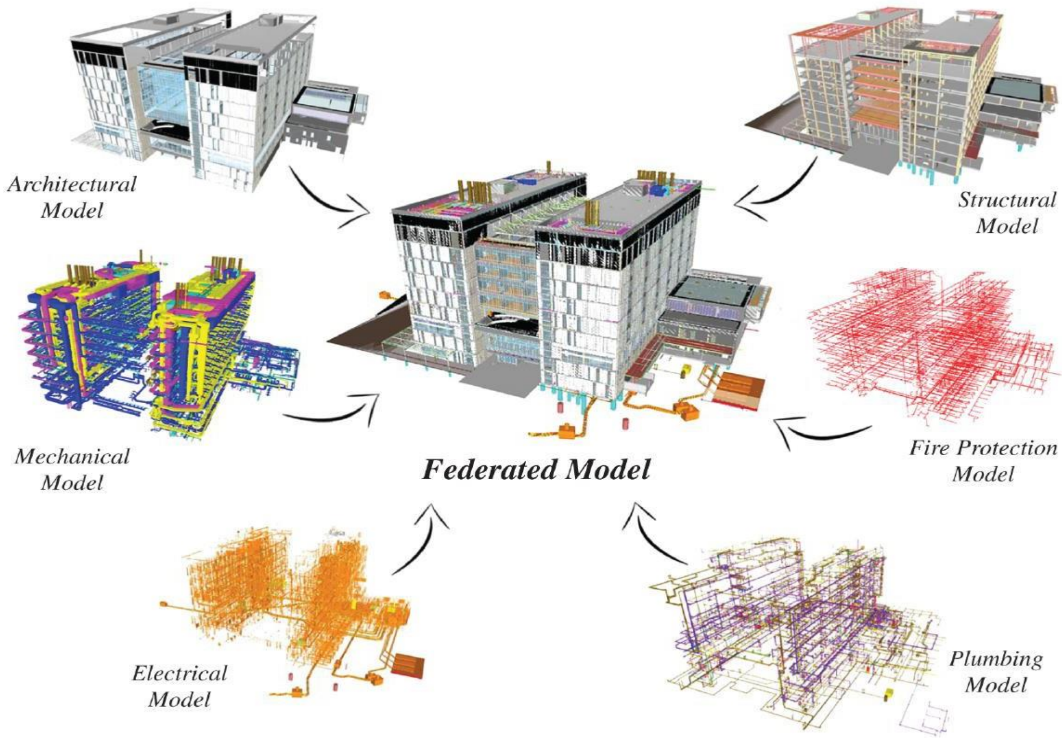


Fig. 2 Example of the Federated Model [30].

3.RESEARCH METHODOLOGY

The research methodology mainly includes studying the selected case study and creating a 3D model using Autodesk Revit 2023 software, followed by individually modeling each building as a structural design and architectural design. After completing the 3D BIM model, create a 3D model using IFC Builder software and export it to Navisworks software to integrate each building with its architectural and structural model for clash detection. Utilizing clash detection to detect the design errors in the building and identify design errors that increase costs.

3.1.Case Study Description

Constructing educational buildings is a major part of the construction industry in Iraq, with a large number under construction and more to be built. To meet the demands of the public and private sectors, many building construction projects have been built. However, defects and errors will arise during the design and construction phases, leading to high construction costs. The Typical School project was chosen because it included several design issues that increased or decreased the bill of quantities, leading to high costs, prompted numerous modification orders, and ultimately caused a delay in the project's execution. During the building phase, a contractor was given charge of this school (2021-continuing until now). The project design is also detailed (slabs, beams, columns, concrete wall, finishing floor, stairs, and so on). As a BIM tool, this study was included in Autodesk Revit and Autodesk Navisworks (version 2023). In Iraq, central school buildings are distributed across every governorate. For this case study, a specific central school building, which had previously been demolished, was selected. It comprises ten buildings: zones (1, 2, 3, 4, 5, 6, 7, 8, 9, and 10). This type of building was considered a typical school project in Iraq. Figure 3 shows the proposal for the rendering of the case study in Revit 2023 after finishing the work. Building B, C, H, I, and J have not started the work yet. So, the case study was conducted on buildings 1 and 2 only because they were about to be completed. Some buildings have two floors: the ground floor and the first floor. The total area of the site work is about (3518 m2). The 3D model was created in Revit based on the 2D drawings provided by the contractor and by visiting the building to observe the missing details and changes not included in the 2D drawings. A summary of project details is outlined in Table 1.

Table 1 Brief Details About the Case Study.

Project Type Details	**Educational Buildings/ Government Contract/ Central Typical School**
Project duration	2021 till now
Project consists of	Ten building
Overall area	3518 m²
Building 1 area	1300 m²
Building 2 area	1,530 m²
Cost of building 1	The expected cost is 492 million IQD Iraqi dinars.
Cost of building 2	Approximately 540 million IQD Iraqi dinars.

Fig. 3 Proposal Rendering at the Project Completion.

3.2.Creating 3D BIM Model for Case Study

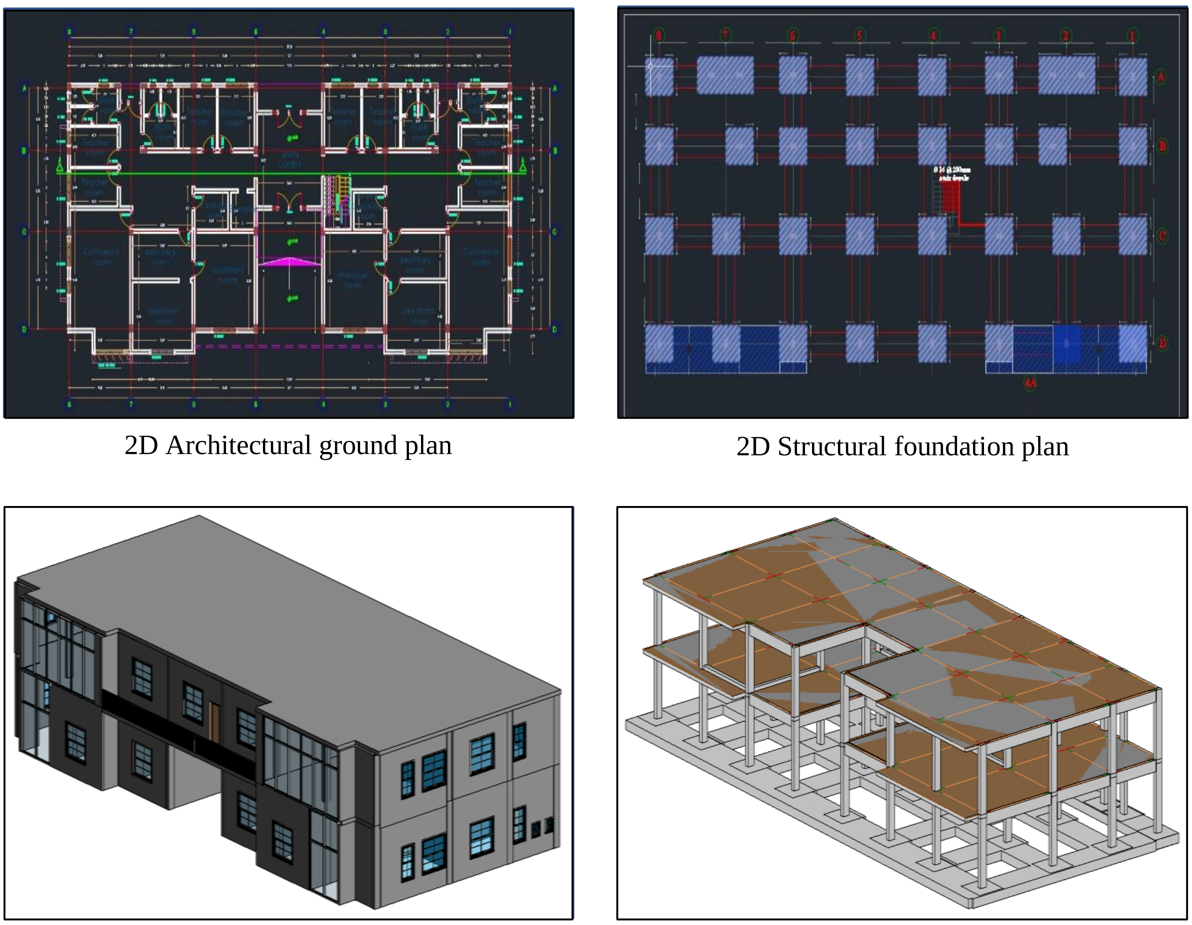
Revit 2023 was used to achieve this study's purpose instead of other programs for several reasons. The main reason for selecting the Revit software is that it allows the export of the model in various languages (such as gbXML) for software and tools to evaluate and analyze the building performance; not all buildings were considered; only 1 and 2, and as there were two implemented buildings. As with Revit, Navisworks is an Autodesk product that may be used for various analysis and verification tasks that adhere to the 3D design for a construction project. One benefit of the Navisworks software is that it integrates models from other disciplines more easily. Clash detection, time modeling(4D), and cost planning (5D) may also be done using some of the program's features.

3.2.1.Case Study 1 (Building 1)

The building's location is crucial to the project since it is the primary structure for the school's administrative functions, faculty offices, and lab spaces. The structure has a 1300 square meter area and is expected to cost 492 million Iraqi dinars. Only the interior and exterior finishing is yet to be done, and the building is currently 90% complete. Figure 4 illustrates the modeling of the building for the architectural and structural components.

3.2.2.Case Study 2 (Building 2)

Building 2, as shown in Fig. 5, comprising two parts and spanning an area of around 1,530 square meters, is one of the largest structures within the school. With two floors and 20 classrooms, it is strategically positioned in the center of the school to facilitate the convenient movement of students between various facilities. The estimated cost of constructing this building is approximately 540 million IQD Iraqi dinars. Currently, only the interior and exterior finishing works remain, as depicted in Fig. 5. The construction progress of the building stands at approximately 90%.



2D Architectural ground plan

2D Structural foundation plan

3D Architectural model by Revit

3D Structural model by Revit

Fig. 4 The 2D Plans and the 3D BIM Model for Building 2.

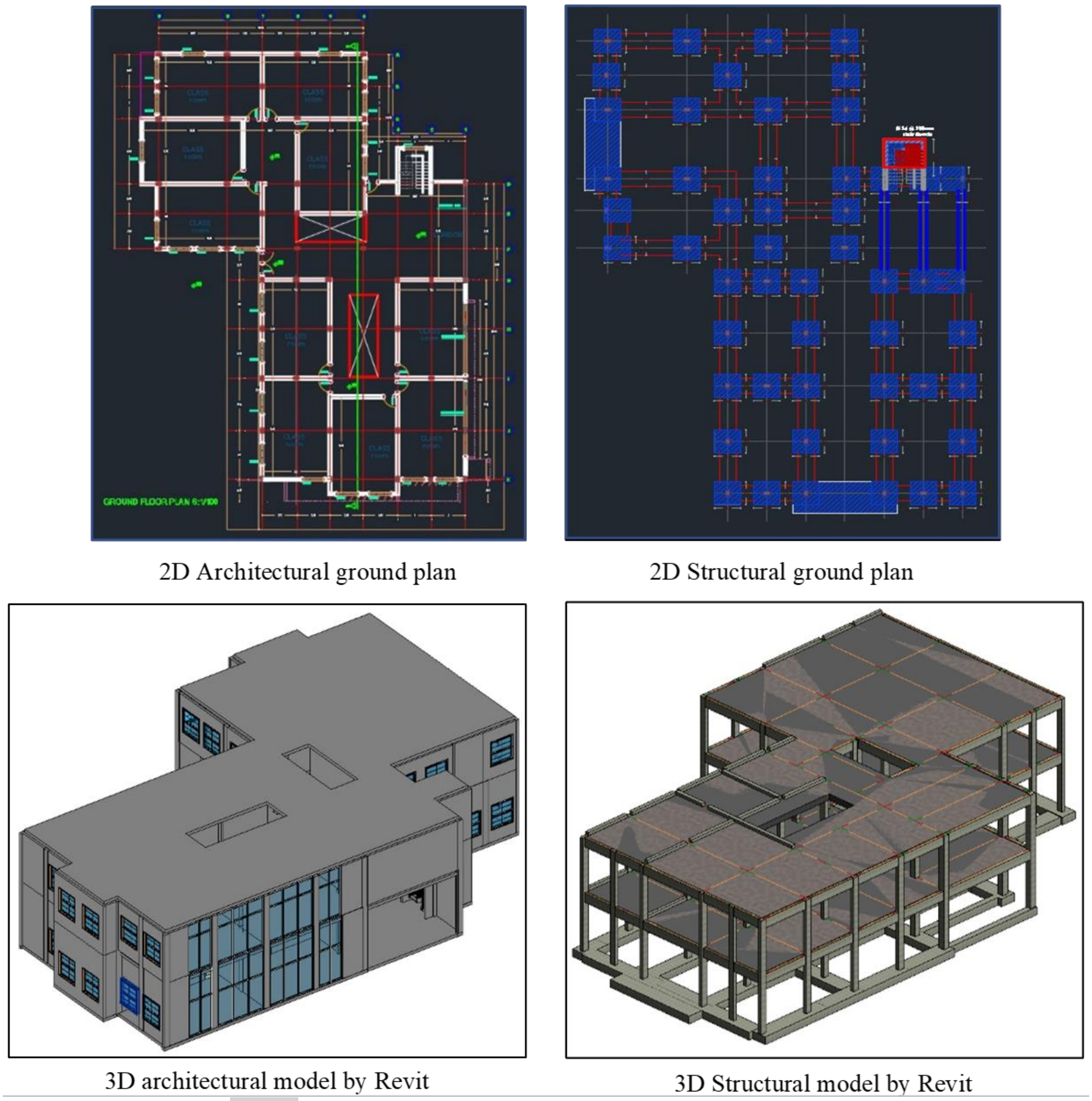
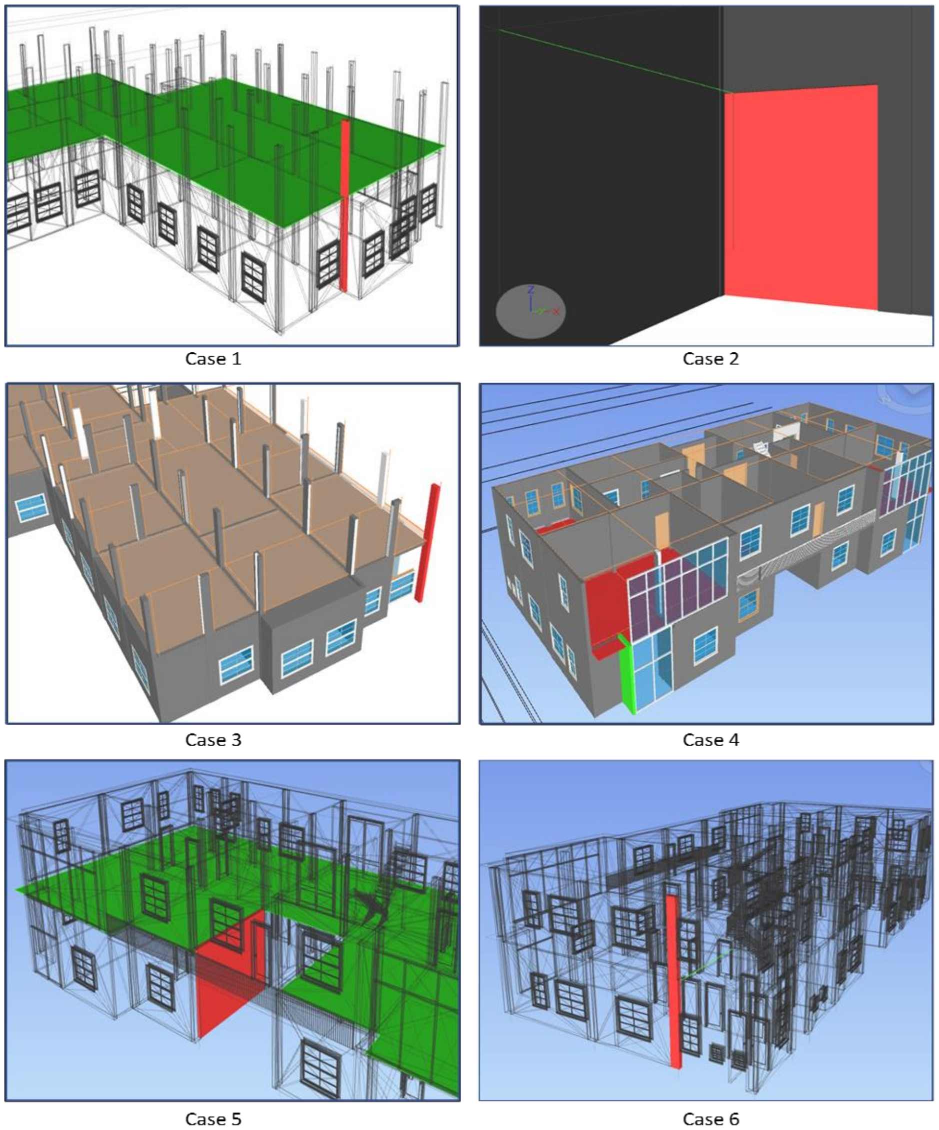


Fig. 5 The 2D Plans and the 3D BIM Model for Building 2.

4.RESULTS

The design errors and clashes between different disciplines were observed to manifest as recurring instances across each building. Therefore, selecting representative samples encompassing most of these errors was considered for further analysis. Depending on the Navisworks program's features for examining the location and reason for the conflict, a particular group of conflict images was chosen to detect the first and second parts. As shown in Fig. 6, the building can be shown with high accuracy, and the Navisworks simulation program can provide an illustration that visualizes the conflicts among other elements. As indicated in Tables 1 and 2, the costs were significantly exceeded due to design errors caused by the differences in quantities of most work items. As shown in Table 2, in terms of columns, the initial plans showed that the columns did not match the roof level in the architectural plans and in more than one place on the first and second floors, where the column conflicts and design errors caused an increase in the number of columns increasing costs by 20% over the costs estimated for this item. The increase in costs of 8% of the estimated costs was caused by the conflict represented by axial beams in conflict with ceilings and walls, as well as at the level of the two floors. Constructing the building's roof marks the final stage of implementing reinforced concrete for the floor. Any changes in the number of columns and beams significantly impact the roof size. The last changes to the columns and beams of the first and second floors caused an increase of 16% in the estimated costs for this item. The walls, essential components of the building, are attributed with a significant weight in the cost ratios compared to other items. The quantity of bricks in this building is influenced by beams and columns, along with their height, resulting in a 25% increase in their estimated cost. That is for items that caused an increase in costs associated with the conflicts, design errors, and the influence of some of them on each other. Regarding the remainder of tables items 5 and 6, there was an increase of 46 percent from the estimated costs, which was not evident in the conflicts or collisions in the simulation model. This increase is attributed to the conflicts of the previous items, resulting in higher costs for internal and external finishes. When the estimated costs for the six items are aggregated and compared with the total costs based on actual quantity, the expenses escalate from 218 to 270 million IQD. As for the costs and results obtained from the analysis conducted, shown in Table 3 below for the second case and as was stated in terms of information and results in the first case, the change in quantities has been included and exceeded in additional items on the items related to conflicts. In this case, four images from a group of conflict images were shown according to the conflict in the building. One of the advantages of the Navisworks simulation is that it shows the building with high accuracy and an illustration that can easily imagine the clashes and remediate them before their implementation. The columns are started with, and as explained regarding the cases of clashes, the columns and their effect in the first case are the same as what occurred in the second case, where the increase in the number of columns was caused by conflicting designs, resulting in a 7% increase in costs over the estimated costs for this item. Additionally, a kind two classification of conflicts represented in the beams and their conflicts with the ceilings, walls, and at the level of the two floors caused the costs to exceed 9% of the estimated costs.



In Case 1, there is an interference between one of the structural columns and the roof of the architect. Case 2 demonstrates a clash between the beam and the wall. Case 3 reveals a mismatch between the structural and architectural ceiling, resulting in a clash with one of the columns. Case 4 showcases the overlapping of the wall with the ceiling. Case 5 highlights the overlap of one of the walls with the architectural ceiling. Lastly, in Case 6, there is an incorrect overlap between one of the thresholds and the columns.

Fig. 6 A Collection of Clashes Observed in Each Study.

Table 2 The Effect of Quantity Clashes for Building 1 (Case Study 1).

No	Items	As-Built Cost (IQD)	Estimation Cost (IQD)	Error (%)
1	Columns (m3)	13,600,000	10,800,000	20
2	Beams (m3)	25,200,000	23,000,000	8
3	Concrete slabs (m3)	105,000,000	87,500,000	16
4	Wall	80,000,000	60,000,000	25
5	Interior finishing	37,000,000	30,000,000	18
6	Exterior finishing	9,800,000	7,000,000	28
	Total cost	270,600,000	218,300,000	19

Table 3 The Effect of Quantity Clashes for Building 2 (Case Study 2).

No	Items	As-Built Cost (IQD)	Estimation Cost (IQD)	Error (%)
1	Columns (m3)	21,600,000	19,920,000	7
2	Beams (m3)	33,250,000	30,030,000	9
3	Concrete slabs (m3)	127,750,00٠	115,150,000	9
4	Wall	82,500,000	73,250,000	11
5	Interior finishing	50,250,000	44,286,000	11
٦	Exterior finishing	16,800,000	14,733,600	12
7	Interior wall painting	16,750,000	14,762,000	11
8	Exterior wall painting	12,000,000	10,524,000	12
	Total cost	360,900,000	322,655,600	10.5

Furthermore, in addition to the points above, it should be recognized that the successful completion of the building's slab depends on the presence of columns and beams. Consequently, the additional costs incurred have resulted in a 49% increase in the overall implementation costs of the roof. Additionally, the walls are regarded as one of the crucial components of the building, and their implementation cost escalated to 82 million IQD ID. Regarding the remaining numbers, attention should be given to selected project items, specifically No. 5, 6, 7, and 8 in Table 3, as they exhibit a significant cost increase of approximately 94 million IQD compared to the estimated costs of 36 million IQD, attributed to the previous errors.

5.DISCUSSION

The following conclusions can be derived from examining conflict detection through Building Information Modeling (BIM) technology: Incorporating 3D models into construction planning is crucial for enhancing visualization, thereby reducing the likelihood of errors and mitigating the risk of cost overruns during the building phase. The successful accomplishment of the study was facilitated by utilizing relevant literature, leveraging findings from prior research, and the investigation conducted by experts at the work site in a unique study case. A benefit of this particular case is that it was studied post-implementation, meaning that implementing case 1 and case 2 has been approximately completed, and the finalization stage has been reached; therefore, design errors, conflicts, and the amount of difference in estimating quantities were remedied and resolved during implementation, which caused an increase in implementation time and an increase in spent costs. Therefore, this study revealed the massive cost increase in the project and the delay in the project time that if were remedied before implementation to make it more economical and its implementation became in record time. A small group of 6, 7, or 8 items (according to each Table and each case) was chosen from the original bill of quantity for the items executed and the costs spent. The cost increase that appeared in this paper's results is part of the total increase in the project. According to the first case table, each item experienced an increase of over 10% in the estimated costs. When the proportion of the total costs expended on the selected items in the case study was applied to the total estimated costs on the same items, the result indicated an approximate increase of 20%, equating to 52 million IQD. The second case study pertains to a building adjacent to the first one, wherein each of the chosen items from the original bill of quantity witnessed a surge of over 10%. By comparing the estimated costs for the eight items to the actual costs expended on the same items, the increase amounted to approximately 39 million IQD. The cost overruns identified in this study are constrained to the specific elements selected based on the clash detection technique system. The impact of clash detection-associated elements is observed in terms of increased quantity and cost and their influence on the subsequent building elements. As a result, it is anticipated that the total cost of all building elements will exceed 120 million IQD for each building following implementation, and an approximate 18% increase in its estimated total cost was observed for building 1, while building 2 reached approximately 23% of its estimated total cost.

6.CONCLUSION

Traditionally, construction plans are created separately for each discipline, causing inconsistencies and misalignments with other plans. The study highlights the transformative power of fully utilized BIM technology in building preparation, leading to benefits like reduced project timelines and predictive resolution of construction-phase issues through 3D visualization. BIM technology has notably impacted and enhanced different phases of the construction procedure. As a result, the research sought to incorporate collision detection via BIM and furnish evidence and projections regarding the possible financial savings attainable during the construction period in standard school building projects in Iraq. Design schemes of various disciplines require a three-dimensional graphical interface to visualize the building before its implementation, which is required to mitigate many problems, such as change orders, cost overruns, project duration delays, and other challenges and problems that may arise during the implementation of the building. To explain the importance of BIM in this context, a school project was used to demonstrate the importance of this technique and its ability to avoid problems prevailing in construction projects. BIM is useful in avoiding cost problems, causing a 25% reduction in cost overruns attributed to design errors. Moreover, this positively affects the reduction of change orders, reducing the likelihood of a 10% increase for each item in the quantity table. Thus, it is important to consider adopting BIM because of its effective effect, as confirmed by the results of this research. Experts should share the results of the studied case studies, presenting their benefits to encourage the widespread use of building information modeling (BIM) in construction, involving raising awareness, promoting investment, and strengthening implementation throughout the country, ultimately leading to significant time and cost savings and improving work quality.

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