Potential Cost Savings Analysis of Building Information Modelling-Enabled Clash Detection

Mohamed Abdelrahman Abdalla Bashir[1], *Faridahanim Ahmad[1], Tsu Yian Lee[1], Mohd Nashruddin Mohd Shah[2] and Mariah Awang[3]

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Abstract: Building information modelling (BIM) has an established function in clash detection, yet its full potential remains underutilised in the construction industry. This underutilisation is due to the lack of an easy-to-follow guide for practitioners and a general lack of awareness regarding its cost-saving benefits. This article presents a case study demonstrating the application of BIM for clash detection and cost estimation. Revit was adopted to develop three-dimensional (3D) models for architectural and structural systems, while Navisworks was adopted to integrate these models and conduct clash detection. The Malaysian Standard Method of Measurement for Building Works Second Edition (SMM2) was referred to estimate the costs associated with clashes. As a result, 65 relevant clashes were identified in this case study. Categorising these clashes into major, medium and minor categories enabled the prioritisation of critical issues. The study revealed a substantial additional expenditure of MYR60,323.80 required to resolve all identified clashes. This finding underscores the importance of early clash detection to prevent budget overruns. This study contributes to the industry by providing a straightforward and reliable approach for detecting clashes and estimating costs in real-world projects. It also encourages wider adoption of BIM practices within the construction sector.

Keywords: Building information modelling, Clash detection, Clash avoidance, Cost savings analysis, Cost estimation

INTRODUCTION

In recent years, the world has witnessed an increase in large-scale and complex building projects (Chidambaram, 2020). The traditional method of manually drawing and sketching on paper can no longer keep pace with the architectural revolution required for designing and developing today's buildings (Eldeep, Farag and El-Hafez, 2022). The complexity of modern architecture requires

[1]Faculty of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, MALAYSIA
[2]MFE Formwork Technology Sdn. Bhd., Lot 4 and Lot 6, Jalan Tun Perak 3, Perdana Industrial Park, 42200 Port Klang, Selangor, MALAYSIA
[3]Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Muar, Johor, MALAYSIA
*Corresponding author: faridahanim@utm.my

more sophisticated tools to handle the detailed and dynamic nature of current building requirements (Mehrbod et al., 2019). This necessity has driven the adoption of advanced technologies that offer comprehensive and integrated solutions, enabling architects, engineers and contractors to collaborate more effectively and efficiently (Darwish, Tantawy and Elbeltagi, 2020; Lee, Ahmad and Sarijari, 2023). Building information modelling (BIM) has emerged as a revolutionary solution to address this need (Darwish, Tantawy and Elbeltagi, 2020; Daszczyński, Ostapowski and Szerner, 2022; Eldeep, Farag and Abd El-Hafez, 2022; Machado and Vilela, 2020; Sinoh, Othman and Ibrahim, 2020).

BIM is a sophisticated digital tool that allows architects, engineers and construction professionals to collaboratively design, visualise and manage building projects in a virtual environment (Kjartansdóttir et al., 2017). Unlike traditional two-dimensional (2D) drawings, BIM incorporates three-dimensional models that provide a comprehensive representation of a building's components and attributes (Eldeep, Farag and Abd El-Hafez, 2022; Kjartansdóttir et al., 2017). This three-dimensional (3D) modelling enables the provision of quantitative and verifiable data during the early design phase while predicting outcomes for later construction stages (PwC [PricewaterhouseCoopers LLP], 2018).

Clash detection is an essential part of the BIM process, ensuring the sustainability of the design (Alone, 2020; Chidambaram, 2020; Mehrbod et al., 2019). Clashes between elements in construction projects can lead to unsatisfactory quality of work, disputes and safety risks (Khawaja and Mustapha, 2021; Matejka and Sabart, 2018). With the increase in design complexity, the probability of facing clashes and challenges in design coordination between the elements is also increased (Chidambaram, 2020). Therefore, checking design coordination is a vital process before construction to ensure that a design meets expected safety and functional standards (Mehrbod et al., 2019). To satisfy the specific coordination of the different building elements, BIM facilitates this process by enabling design engineers to visualise the building in a simulated environment and identify potential clashes between components (Akhmetzhanova et al., 2022). While human errors are common in project design, the clash detection functionality within the BIM tool helps identify and resolve these mistakes efficiently before construction begins (Akponeware and Adamu, 2017). Subsequently, this approach reduces the cost required for resolving clashes during the construction phase (Bradley et al., 2016).

Despite the recognised advantages that BIM offers to the construction industry, its utilisation remains limited, particularly in developing countries (Akhmetzhanova et al., 2022; Othman et al., 2021). In Malaysia, up to 72% of both private and public construction sectors do not utilise BIM in their projects

(Othman et al., 2021). In Indonesia, 60% of contractors and consultants from the infrastructure sector are unfamiliar with BIM implementation (Roy and Firdaus, 2020). In Kazakhstan, only 50% of contractors adopt BIM in clash detection (Akhmetzhanova et al., 2022). Challenges hindering BIM adoption include low client demand and a limited understanding and expertise in BIM implementation (Monejo and Makinde, 2020). To increase client interest, it is crucial to demonstrate BIM's tangible benefits, particularly in terms of cost savings (Sinoh, Othman and Ibrahim, 2020). Furthermore, providing easily accessible guidelines is essential to enhance industry practitioners' proficiency in utilising BIM effectively (Monejo and Makinde, 2020). However, there is a lack of empirical research providing a detailed, step-by-step demonstration of how to identify clashes and accurately calculate cost savings using BIM in real-world case studies.

Therefore, this study aimed to demonstrate the steps involved in clash detection using BIM and calculating cost savings. To achieve this, 3D architectural and structural models of a building project were developed in Revit. Revit is a software primarily used for creating and designing BIM models (Eldeep, Farag and Abd El-Hafez, 2022; Sampaio et al., 2022). Subsequently, Navisworks was utilised for model integration and clash detection. Navisworks is a popular software platform designed for the integration and visualisation of 3D models (Jiang et al., 2022; Sampaio et al., 2022). It offers a variety of tools for reviewing, analysing and simulating 3D models, including its clash detection application (Jiang et al., 2022; Sampaio et al., 2022). The expected cost savings resulting from resolving clashes were calculated based on the Malaysian Standard Method of Measurement for Building Works Second Edition (SMM2). The findings of this study can serve as a valuable guide for industry practitioners to perform clash detection and cost analysis.

LITERATURE REVIEW

Background of Building Information Modelling

BIM is a process of using 3D modelling tools to generate a 3D virtual building model while integrating with the building's details (Eldeep, Farag and Abd El-Hafez, 2022; Kjartansdóttir et al., 2017). Several functions within these modelling tools enable cohesive workflows across the design, construction and operation stages of a building project (Kjartansdóttir et al., 2017). The 3D model, integrated with the multidisciplinary information of a building project, allows stakeholders to collaborate effectively and make informed decisions at every stage of the project (Chiu and Lai, 2020; PwC, 2018; Sinoh, Othman and Ibrahim, 2020). During the design phase, BIM enables collaboration between architects, engineers and contractors to visualise the design and detect any issues at the early stage (Akhmetzhanova et al., 2022; Lee et al., 2017). This approach is far more efficient than relying on traditional 2D drawings (PwC, 2018). In the construction phase, the 3D model serves as a shared platform for different parties to perform material and cost estimation, schedule planning and monitoring, safety management and clash detection and resolution (Anna et al., 2021; Hasannejad, Sardrud and Shirzadi Javid, 2022; Lee, Ahmad and Sarijari, 2023). During the operation phase, the model continues to provide value by supporting facility management and monitoring the building's energy performance (Bapat, Sarkar and Gujar, 2021; Eleftheriadis, Mumovic and Greening, 2017; Jiang et al., 2022). Therefore, BIM delivers significant benefits throughout a project's lifecycle (Eleftheriadis, Mumovic and Greening, 2017).

However, the implementation of BIM in the industry faces several challenges. A lack of client demand for using BIM has limited industry awareness and implementation (Monejo and Makinde, 2020; Saka and Chan, 2023). This reluctance is often due to clients not fully understanding how BIM can benefit their projects (Monejo and Makinde, 2020). Introducing BIM's benefits to clients, such as demonstrating cost savings through clash detection, can help overcome this barrier. Even when BIM is utilised in projects, a lack of collaboration and coordination among stakeholders can limit its effectiveness (Chidambaram, 2020; Darwish, Tantawy and Elbeltagi, 2020). Although BIM is more actively adopted during the design stage by architects and consultants, contractors often show less interest in using BIM for project monitoring (Doan et al., 2021). They prefer to rely on traditional and manual methods to monitor site conditions and progress (Doan et al., 2021). This is because they have limited knowledge and technical expertise with BIM (Monejo and Makinde, 2020; Roy and Firdaus, 2020; Saka and Chan, 2023). Additionally, previous studies indicated that the absence of standardised guidelines and legal frameworks for BIM implementation can confuse industry practitioners and discourage further exploration (Doan et al., 2021; Monejo and Makinde, 2020; Sinoh, Othman and Ibrahim, 2020). Therefore, contractors require guidance and training to enhance their competency and fully appreciate BIM's benefits (Monejo and Makinde, 2020; Olugboyega, 2019).

Definitions and Types of Clashes

Construction projects require the involvement of various parties, such as architects, civil, mechanical, electrical, plumbing consultants and engineers. Failure to manage their designs can result in clashes between different construction elements (Alone, 2020). Clashes refer to conflicts or interferences between building elements that are unacceptable in actual construction (Chidambaram, 2020; Daszczyński, Ostapowski and Szerner, 2022; Mehrbod et al., 2019). They are considered wasteful in construction projects, negatively impacting cost, time and effort (Mehrbod et al., 2019; Sampaio et al., 2022). They can arise due to design errors, a lack of coordination among disciplines, changes in design and human error in preparing information (Mehrbod et al., 2019; Nasuha, Rahman and Haron, 2023). In general, clashes can be classified into three categories, which are hard clash, soft clash and workflow clash (Daszczyński, Ostapowski and Szerner, 2022) (as shown in Table 1).

Table 1. Description of hard, soft and workflow clashes

Types	Description
Hard clash	A hard clash occurs when two or more objects inhabit the same physical area or overlap in the model (Bockstael, Candidate and Issa, 2016; Kermanshahi et al., 2020). This type of clash commonly occurs when combining architecture, engineering and construction works (Chidambaram, 2020).
Soft clash	A soft clash is also known as an indirect clash. It occurs when the distance between objects is less than designed (Bockstael, Candidate and Issa, 2016). When designing for mechanical, electrical and plumbing (MEP) works, spatial tolerance for maintenance at later stages always needs to be considered. Hence, soft clashes commonly happen in MEP works (Nasuha, Rahman and Haron, 2023).
Workflow clash	A workflow clash is also known as a time clash. This type of clash does not involve conflicts between objects (Sampaio et al., 2022). It refers to the conflict in the project timeline due to inaccurate information (Kermanshahi et al., 2020). For example, the delivery time of materials does not match the scheduled activity time (Kermanshahi et al., 2020).

Among the three types of clashes, hard clashes are typically the first to be addressed due to their potentially significant impact on the project schedule and cost (Akponeware and Adamu, 2017). Hard clashes involve objects that should not overlap but have overlapped in the model, with varying degrees of severity (Bockstael, Candidate and Issa, 2016). Resolving hard clashes often involves different scenarios, requiring different actions and involving different parties. Subsequently, it impacts the required stakeholders, actions and costs to address the clashes (Kermanshahi et al., 2020). Therefore, hard clashes can be further classified based on severity into minor, medium and major clashes, as described in Table 2, adapted from Chahrour et al. (2020).

Table 2. Categorisation of clashes

Category of Clashes	Required stakeholders			Required Action		
	Contractor	Designer	Client	Rectification	Rebuild	Redesign
Major	✓	✓	✓	✓	✓	✓
Medium	✓	✓		✓	✓	
Minor	✓			✓		

Source: Adapted from Chahrour et al. (2020)

Major clashes are significant conflicts between building elements that can substantially impact project quality, timeline and budget (Chahrour et al., 2020; Daszczyński, Ostapowski and Szerner, 2022). Consequently, designers must undertake redesign efforts, contractors need to rectify and rebuild affected areas, and client approval is essential for implementing necessary solutions. Medium clashes are less critical than major clashes but still require attention to ensure smooth project progression (Chahrour et al., 2020; Daszczyński, Ostapowski and Szerner, 2022). In this context, designers may need to revise the design of elements to resolve clashes with existing construction, while contractors must rectify and rebuild based on the revised design. Minor clashes are relatively minor conflicts that can generally be addressed by contractors alone (Chahrour et al., 2020; Daszczyński, Ostapowski and Szerner, 2022). Although these clashes may not significantly impact project timelines, resolving them may incur costs, especially if they affect aesthetic aspects (Chahrour et al., 2020). Understanding the clashes of classification is important because it helps project teams to prioritise issues based on their severity and impact on the project (Akhmetzhanova et al., 2022). This prioritisation is particularly crucial in large and complex projects, where numerous elements and interactions between different building systems can lead to a high number of clashes (Sampaio et al., 2022).

Building Information Modelling-Based Clash Detection

Traditionally, clashes in construction projects were detected by manually reviewing overlaid drawings by consultants (Daszczyński, Ostapowski and Szerner, 2022; Eldeep, Farag and Abd El-Hafez, 2022). This method is time-consuming and overlooked mistakes can easily occur (Daszczyński, Ostapowski and Szerner, 2022). On the other hand, with the implementation of 3D modelling from the designing stage to the execution stage, clashes can be identified earlier (Eldeep, Farag and Abd El-Hafez, 2022). Clash avoidance during the design phase can avoid rework during construction, which subsequently saves cost and time (Eldeep, Farag and Abd El-Hafez, 2022). Additionally, 3D modelling provides better visualisation, enabling more accurate decision-making compared to traditional 2D drawings (PwC, 2018). Several case studies can be found in the existing literature.

Eldeep, Farag and Abd El-Hafez (2022) compared the conventional 2D computer-aided design (CAD) method with a BIM-based model in a building construction project at the University of Damman. This comparison revealed that many clashes were identified during construction when the design team relied solely on 2D CAD drawings. For example, using the 2D CAD method, a significant clash between mechanical and air conditioning ducts occurred due to insufficient detail and the inability to visualise overlapping systems. On the other hand, BIM models enabled multidisciplinary teams to concurrently develop and visualise designs during the design phase. By using Revit and Navisworks, more than 100 clashes were identified and resolved during the design phase, demonstrating the effectiveness of BIM in saving costs for clashes.

Sampaio et al. (2022) integrated multidisciplinary systems into a 3D model, identified clashes between systems and linked the project schedule with the 3D model. Their study demonstrated that Revit was effective for developing 3D models, while Navisworks was a user-friendly tool for performing clash detection and simulating construction flow based on the schedule. Thus, conducting clash analysis before schedule integration ensures that contractors can adhere to the planned project timeline with minimal deviation. Meanwhile, Akhmetzhanova et al. (2022) acknowledged the importance of prioritising clash avoidance over clash detection. Their study, which investigated BIM-based clash detection in a construction project in Kazakhstan, advocated for a proactive approach to clash avoidance. While approximately half of the contractors incorporated BIM models for clash detection during the construction phase, transitioning to clash avoidance was proven challenging. This difficulty stemmed from the lack of standardised protocols and regulatory support to guide the BIM process. Challenges such as varying file formats and insufficient object information created additional burdens for BIM coordinators. To optimise BIM usage, stakeholders must receive adequate training to enhance their competence in handling BIM tools.

Although BIM-based clash detection is an established function and widely adopted, contractors still find it challenging to implement it in projects, especially in highly complex projects (Akhmetzhanova et al., 2022; Mehrbod et al., 2019). A highly complex project may detect several different types of clashes in the system (Bockstael, Candidate and Issa, 2016). Without proper knowledge of model integration, clash examination and issue documentation, the process can become overwhelming (Mehrbod et al., 2019). Therefore, researchers play a significant role in developing clash detection guidelines that can be easily understood and followed by industry practitioners to encourage BIM implementation.

Cost Analysis for Building Information Modelling-based Clash Detection

BIM has significant financial benefits for construction projects by reducing staff quantity, detecting clashes, saving time, improving information quality and enhancing coordination (Bradley et al., 2016; European Union, 2021; PwC, 2018). However, limited studies have detailed the steps required to quantify cost savings by performing clash detection using BIM. Addressing this gap is crucial to validating the practicality of BIM in clash detection and underscores the financial benefits for construction projects.

A handbook providing cost-benefit analysis methodologies was prepared for the European Commission (European Union, 2021). It helps clients assess the financial performance of their projects through the implementation of BIM (European Union, 2021). This handbook uses indicators such as benefit-cost ratio, net present value, economic benefit-cost ratio and economic net present value to evaluate financial benefits (European Union, 2021). While it highlights metrics for analysing the economic impact of BIM adoption, it does not specifically address methods for quantifying cost savings from clash detection. Return on investment (ROI) is another metric used to evaluate the cost-benefits of BIM. For example, Neelamkavil and Ahamed (2012) adopted BIM to identify potential clashes during the design stage, resulting in cost savings of USD84,500 by avoiding clashes. This achievement yielded a remarkable ROI of over 200%. This indicates that cost savings from clash detection can significantly offset the initial investment for BIM implementation (Daszczyński, Ostapowski and Szerner, 2022; Neelamkavil and Ahamed, 2012). While ROI provides a straightforward measure of financial benefits derived from BIM implementation. It can be meaningful for clients to review, but it does not provide step-by-step guidance to the industry practitioners, especially contractors, on how to quantify cost for clashes. Daszczyński, Ostapowski and Szerner (2022) developed a mathematical model that incorporates several clash resolution factors to calculate cost savings from clash detection. This paper demonstrated the significance of considering additional resources, such as workforce and materials, to resolve clashes during cost analysis. However, this model was specifically designed for clashes occurring in electrical installation scenarios. Clashes that occurred in complex building projects may require different resources to resolve. Therefore, this study provided a step-by-step guide on how to quantify clashes and calculate the cost savings in a building project.

METHODOLOGY

This study used a case study method to evaluate the applicability of BIM for clash detection and cost savings. The case study focused on a multi-story building project. This study was divided into three stages, which are (1) the development and integration of 3D architectural and structural models, (2) clash detection and (3) cost estimation.

Case Study Description

The case study focused on an ongoing residential building project. The project encompasses a 3,000m² area, featuring multiple rooms, lounge areas, living halls, a gym and other facilities. The structural components of the building were nearly complete, while the architectural elements were still in progress. These components made the project ideal for the study, as they allowed the identification and resolution of clashes before the completion of the architectural phase. Addressing clashes early helps prevent potential delays and contributes to significant cost savings by avoiding expensive rectifications later in the project.

The Development and Integration of 3D Architectural and Structural Models

This study identified the applicability of BIM for clash detection and cost savings using a case study. The case study focused on identifying and resolving hard clash between structural and architectural systems in a multi-storied building project. This stage describes the steps involved in the development and integration of 3D models.

The dimensions and details of the structural and architectural systems were obtained from 2D drawings generated by AutoCAD software. These drawings, created by different consultancy firms, often increased the likelihood of clashes due to variations in design standards and communication practices (Eldeep, Farag and El-Hafez, 2022). The structural system consisted of beams, columns and slabs, whereas the architectural system comprised walls, doors, windows, floors and stairs. Based on the 2D drawings, the research team collaborated to develop individual 3D models for the structural and architectural systems using Revit.

After both models were developed, they were imported into Navisworks for integration. The integration process ensured that the structural and architectural elements were accurately aligned and coordinated for subsequent clash detection analysis.

Clash Detection

Following model integration, the study conducted clash detection analysis using the built-in clash detection application on Navisworks. Clash detection involves identifying and resolving spatial conflicts or clashes between structural and architectural elements within the integrated model (Alone, 2020; Chidambaram, 2020). For example, walls penetrating beams and columns intersecting with windows. Navisworks provides visual representations of clashes and generates detailed clash reports (Kermanshahi et al., 2020). The details include locations, severity and the nature of each clash. This enables researchers to identify potential design inconsistencies, propose solutions and implement necessary amendments at an earlier stage in the project timeline (Nasuha, Rahman and Haron, 2023).

However, it is important to note that not all clashes detected by the software are relevant (Hu, Castro-Lacouture and Eastman, 2019; Leite et al., 2011). Relevant clashes are clashes that are accurately identified by the software, while irrelevant clashes are those identified by the software but do not correspond to actual clashes in reality (Hu, Castro-Lacouture and Eastman, 2019; Leite et al., 2011). To ensure accuracy, the detected clashes were manually reviewed and filtered, with only relevant clashes considered for cost estimation (Leite et al., 2011).

Following the filtration, the relevant clashes were categorised into three levels, which are major, medium and minor, based on stakeholder involvement and the action required, as shown in Table 2 (Chahrour et al., 2020). This classification helps researchers and industry practitioners in prioritising clashes for efficient rectification, rebuild and redesign (Daszczyński, Ostapowski and Szerner, 2022).

Cost Estimation

This study relied on the SMM2 to determine the cost of resolving clashes (Akbar et al., 2023). SMM2 is a widely recognised set of guidelines and standards within the Malaysian construction industry, used to estimate construction costs accurately (Akbar et al., 2015; 2023). It enables industry practitioners to prepare accurate and detailed bills of quantities by offering standardised rates and methodologies for quantifying works (Akbar et al., 2023).

In this study, the researcher consulted an engineer to identify solutions for resolving the identified clashes. Then, the researchers referred to SMM2 to detail the equipment, materials, labour and overhead required to resolve each clash and calculate the required costs. The process was divided into the following steps:

Step 1: Clash resolution consultation

An engineer was consulted to propose solutions for the identified clashes. This step involved assessing the nature of each clash and determining the necessary corrective actions.

Step 2: Cost calculation

For each relevant clash, resolution activities, such as rectification, demolition and reconstruction, were specified (Chahrour et al., 2020; Daszczyński, Ostapowski and Szerner, 2022). The associated costs for labour, materials, equipment and overhead were then calculated using SMM2 rates (Akbar et al., 2015; 2023).

Step 3: Total cost savings analysis

The total costs for resolving all relevant clashes were summarised to determine the potential expenditure if the clashes were addressed during the construction stage.

RESULTS AND DISCUSSIONS

Combining 3D Structural and Architectural Models

Based on 2D CAD drawings, 3D structural and architectural models were created using Revit, as illustrated in Figure 1. The architectural model encompasses detailed elements such as walls, doors, windows, stairs and floors, while the structural model incorporates features like beams, slabs and columns. Data entry errors can result in discrepancies (Nasuha, Rahman and Haron, 2023). Therefore, throughout the design phase, the researcher paid close attention to the dimensions of each component by performing double-checks.

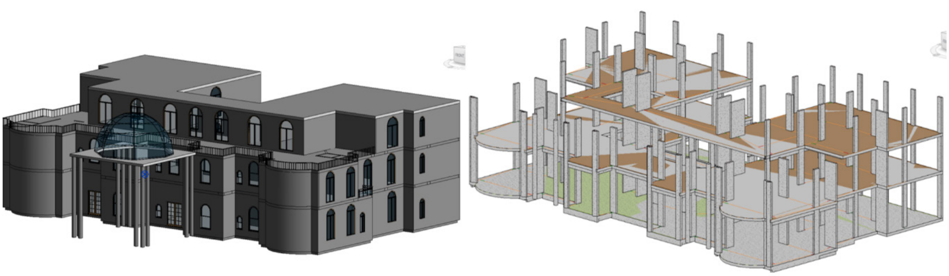

Figure 1. Architectural and structural models

After completing the 3D modelling in Revit, the architectural and structural models were exported to a standard Navisworks file set (.nwf). Upon opening the files in Navisworks, both structural and architectural models can be combined, aligning with the project's base point and survey point. This integration enabled viewing and analysing the models as a unified building model (as shown in Figure 2).

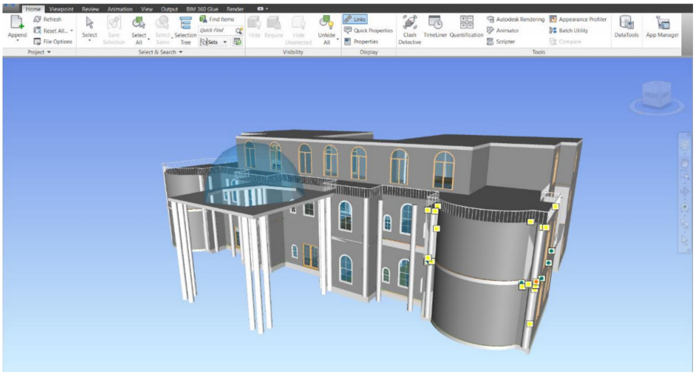

Figure 2. A building model combining architectural and structural components

Clash Detection Results

Clash detection between architectural and structural elements was conducted on Navisworks. The analysis identified a total of 555 clashes between architectural and structural elements. Each clash was detailed with information such as its location, the elements involved and the overlapping distance. Then, the researcher filtered the detected clashes into relevant or irrelevant clashes (as shown in Table 3).

Table 3. Clash filtration

Clash Types	Relevant	Irrelevant	Total
Number of clashes	65	490	555

Table 3 displays the results of the clash filtration. Of the 555 clashes detected, only 65 (12.7%) were considered relevant. Relevant clashes occur due to design errors by engineers that require follow-up action. On the other hand, irrelevant clashes are detected because the software is programmed to consider any intersection as a clash, even though it is a usual intersection (Hasannejad, Sardrud and Shirzadi Javid, 2022). For example, a column passing through a floor was incorrectly detected as a clash by the software, as shown in Figure 3. To manage this, the researcher classified relevant clashes as "reviewed" and irrelevant clashes as "resolved" in the software.

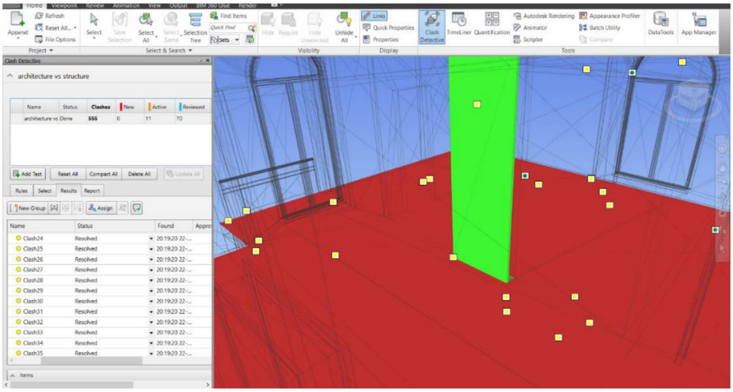

Figure 3. Example of an irrelevant clash

After the filtration process, relevant clashes were further categorised into major, medium and minor clashes based on the stakeholder involvement and clash complexity. Table 4 and Figure 4 show the results and examples of clash categorisation, respectively.

Table 4. Clash groups summary

Category of Clashes	Required Stakeholders			Instances
	Contractor	Designer	Client	
Major	✓	✓	✓	25
Medium	✓	✓		15
Minor	✓			25
Total of clashes				65

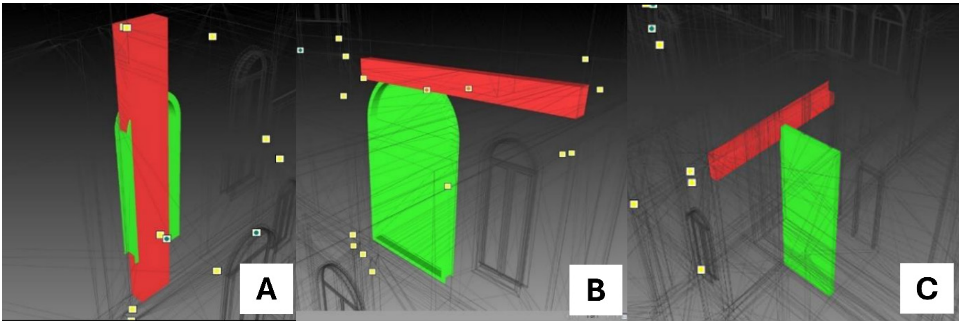

Figure 4. (a) Major clashes (b) Medium clashes and (c) Minor clashes

Figure 4(a) shows a clash between a door and a column, categorised as a major clash. The door shared the same space as the column, requiring corrective action. After discussing with an expert engineer, it was determined that resolving this clash involved demolishing and rebuilding the nearby wall to create space for relocating the door. This solution entailed additional steps, such as renting equipment for wall demolition, rebuilding the wall, obtaining new wall materials and waste clearance. Since this decision affected the building layout, it had to be approved by the client. Therefore, this clash was categorised as major.

Figure 4(b) shows a medium clash between a window and a beam. The window head protruded through the concrete and reinforcement of the beam at a sharing distance of 0.038 m. Addressing this clash required a discussion between the designer and contractor to adjust the window's elevation and modify the beam's size. Therefore, this clash was categorised as medium.

Figure 4(c) depicts a minor clash between a beam and a wall. The clash adversely affected the building's aesthetic design, which might not fulfil the client's satisfaction. The contractor could resolve this issue by covering the intersection part with finishing materials, without needing input from the architect and client.

Cost Estimation for Resolving Clashes

This case study identified 65 clashes, requiring action that could potentially increase project costs. This study employed SMM2 to calculate the costs of workforce, materials and equipment required to address these clashes (Akbar et al., 2015; 2023). The elements considered in the calculation were based on solutions suggested by the expert engineer. Tables 5, 6 and 7 show the cost estimation process for three instances of major, medium and minor clashes, respectively.

Table 5. Cost of solving a major clash

Description	Price Rate (MYR)	Unit	Factor of Activity	Total Cost of Activity (MYR)
Cost of workers	85.00	Day	3.000	255.00
The required equipment for wall demolition	120.00	Day	1.000	120.00
Scaffolding	94.00	Day	2.000	188.00
Brick wall in cement bricks in cement mortar	80.00	m^2	9.630	770.00

(Continued on next page)

Table 5. *Continued*

Description	Price Rate (MYR)	Unit	Factor of Activity	Total Cost of Activity (MYR)
Finishes (plasterwork)	18.40	m^2	9.625	177.10
Lorry with driver for taking the waste	400.00	Day	1.000	400.00
Total cost for door and column clash component				1,910.10

Table 6. Cost of solving a medium clash

Description	Price Rate (MYR)	Unit	Factor of Activity	Total Cost of Activity (MYR)
Cost of workers	85.00	Day	2.000	170.00
The required equipment for wall demolition	120.00	Day	1.000	120.00
Brick wall in cement bricks in cement mortar	80.00	m^2	2.760	220.80
Finishes (plasterwork)	18.40	m^2	2.760	50.78
Total cost for window and beam clash component				561.60

Table 7. Cost of solving a minor clash

Description	Price Rate (MYR)	Unit	Factor of Activity	Total Cost of Activity (MYR)
Cost of workers	85.00	Day	1.000	85.00
Scaffolding	94.00	Day	1.000	94.00
Total cost for beam and wall clash component				179.00

The calculation included factors such as workforce requirements, material, equipment, price rate, affected area and duration required for rectification to ensure accurate cost estimation. This evaluation process applied to all identified clashes. Table 8 summarises the estimated costs for resolving all relevant clashes in the project.

Table 8. Total estimated cost for resolving all clashes in the project

Category of Clashes	Required Stakeholders			Instances	Total Cost for Resolving (MYR)
	Contractor	Designer	Client		
Major	✓	✓	✓	25	47,425.00
Medium	✓	✓		15	8,423.80
Minor	✓			25	4,475.00
Total of clashes				65	60,323.80

The results indicate that if all clashes were detected during the construction phase, the total cost required for resolving the clashes reached MYR60,323.80. In this case study, approximately 78% of this cost was spent on major clashes. This was because extensive actions might be required to resolve major clashes, which involved demolition, rebuilding and architectural layout alteration (Chahrour et al., 2020). This finding aligns with previous studies emphasising the significant impact of major clashes on project timelines and budgets (Chahrour et al., 2020; Daszczyński, Ostapowski and Szerner, 2022). Besides the high-cost involvement, discussions among the client, designer and contractor could also adversely impact the project timeline (Matejka and Sabart, 2018). However, medium and minor clashes should not be neglected. The total cost for resolving medium and minor clashes resulted in an additional expenditure of MYR12,898.80.

Discussion

The clash detection process revealed several significant clashes between architectural and structural elements. These clashes were identified, categorised and subsequently resolved. The results underscore the importance of integrating various disciplines early in the design phase to mitigate potential clashes (Sampaio et al., 2022). Moreover, it underscored the critical role of BIM in facilitating coordinated design efforts and reducing the risk of costly construction delays (Chidambaram, 2020; Hu et al., 2021; Kermanshahi et al., 2020). While this study focused on architectural and structural work, future research could apply the same methods to additional scopes, such as mechanical, electrical and plumbing systems, to observe a broader impact.

In this study, SMM2 emerges as a reliable reference for quantity take-off in clash cost estimation. SMM2 is widely recognised in Malaysia as it provides detailed measurement rules for various building elements, enabling precise quantification of clash costs (Akbar et al., 2015; 2023). This study demonstrates how to adopt and integrate SMM2 into BIM-based clash detection, quantity take-off and cost estimation processes. The integration of SMM2 with BIM practices not only streamlines the cost estimation process but also provides a structured approach that can be replicated in future BIM projects.

Furthermore, the findings indicate that additional costs for materials, equipment and workforce required for rework can significantly increase the risk of exceeding the budget (Akbar et al., 2015). This aligns with previous research showing significant cost savings when BIM is employed (Daszczyński, Ostapowski and Szerner, 2022; Neelamkavil and Ahamed, 2012). By detecting clashes during the design phase, engineers and management teams can proactively suggest design modifications before construction begins (Akponeware and Adamu, 2017). This proactive approach prevents costly clash resolutions during the construction phase, underscoring the significant financial benefits of early clash detection and resolution using BIM (Akponeware and Adamu, 2017). However, this study is limited to direct cost calculations, focusing on practical approaches that directly benefit BIM practitioners and learners. Future research could further validate its economic benefits by incorporating ROI calculation (Neelamkavil and Ahamed, 2012). Such analyses could offer a detailed understanding of the long-term financial impacts of BIM adoption in the construction industry (Daszczyński, Ostapowski and Szerner, 2022; Neelamkavil and Ahamed, 2012).

In short, this study offers both academic and practical contributions. Theoretically, the study integrates the traditional SMM2-based cost estimation method with modern BIM practices, providing a structured approach to quantify the financial benefits of BIM-based clash resolution. This framework enhances the theoretical understanding of BIM's impact on cost management and offers valuable insights for future research, particularly in estimating BIM-based clash cost savings. Practically, this study addresses common challenges in BIM adoption, such as insufficient training and limited client interest (Monejo and Makinde, 2020; Saka and Chan, 2023). The findings not only provide a practical reference for industry professionals but also serve as a resource for developing training programmes. By highlighting BIM's cost-saving benefits, the study demonstrates its tangible advantages, which can help boost client interest and promote broader BIM adoption. BIM can save costs and enhance coordination between multidisciplinary teams, reducing misunderstandings and conflicts (Matejka and Sabart, 2018). It improves overall project quality, reduces construction delays and consequently increases customer satisfaction (Darwish, Tantawy and Elbeltagi, 2020).

Despite the advantages of BIM, several challenges highlighted in the literature should be addressed. This study addressed these challenges by providing clear guidelines for conducting clash detection and cost analysis (Monejo and Makinde, 2020). Such guidelines can increase contractors' knowledge and skills in handling BIM. However, efforts from other parties are essential to encourage BIM implementation. For example, policymakers can establish a legal framework, provide incentives and organise workshops and training programmes (Akhmetzhanova et al., 2022; Matejka and Sabart, 2018; Othman et al., 2021). Clients can also encourage BIM adoption by demanding BIM in contracts and providing financial and technical support to the team (Monejo and Makinde, 2020).

CONCLUSIONS

This paper presented a case study demonstrating clash detection using BIM, the classification of clashes and cost estimation. The case study focused on a multi-storied building, extracting details from 2D architectural and structural drawings to develop 3D models in Revit. These models were integrated into Navisworks for clash detection among their elements. Following the identification of clashes, they were classified based on severity and the costs associated with resolving them were estimated using the SMM2 method. A visual representation of the integrated model was generated to facilitate clash detection and review. The study identified a total of 65 relevant clashes in the project, categorised into "Major" (25 instances), "Medium" (15 instances) and "Minor" (25 instances) types. It was observed that major clashes incurred the highest costs compared to other types, due to their impact on project quality, requiring rectification, reconstruction and redesign. While medium and minor clashes may seem less critical, their implications on project costs should not be underestimated. The total estimated cost for resolving all clashes is MYR60,323.80. This figure underscores the potential savings achievable through early clash detection during the design phase, thereby preventing additional expenses incurred from addressing issues later in construction. The methods and findings showcased in this study contribute valuable insights to the practical industry by providing an accessible approach to clash detection and cost estimation. The use of widely recognised software tools, such as Revit and Navisworks, ensures the findings' broad applicability. Furthermore, the cost estimation is grounded in the established quantity surveying reference, specifically SMM2, enhancing its reliability and relevance in real-world scenarios.

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