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# Cash or Clash: Evaluating the Financial Benefits of BIM Clash Detection

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## Abstract

The construction industry confronts persistent challenges related to inefficiencies, rework, and cost overruns, driving the need for advanced digital solutions like Building Information Modelling (BIM). This research appraises BIM clash detection's financial and operational benefits, emphasizing its pivotal role in improving project performance. Centered on case study projects, the research employs a comprehensive cost-benefit analysis framework, integrating quantitative data from BIM clash reports, project rework logs, and qualitative insights from stakeholder interviews. The analysis evaluates financial indicators such as Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Return on Investment (ROI) to determine the viability of BIM clash detection. Findings reveal that implementing this technology lessens rework frequency, enhances project timelines, and fosters stakeholder communication and coordination. A significant reduction in errors and rework also ensures higher cost savings and more efficient resource utilization. The study utilizes advanced techniques like federated BIM modelling, sensitivity analyses, and scenario-based evaluations to simulate real-world conditions and quantify outcomes. Results confirm a positive NPV, a BCR greater than 1, and a high ROI, underscoring BIM clash detection's economic feasibility and long-term value. The research illustrates how this technology mitigates construction risks, improves stakeholder satisfaction, and ensures superior project delivery quality. Through its rigorous methodological approach and robust analysis, this research demonstrates the transformative potential of BIM in modern construction. It offers actionable insights for stakeholders seeking to enhance efficiency, reduce costs, and adopt innovative technologies to revolutionize project delivery and management processes.

***Keywords***

*Building Information Modelling (BIM); Clash Detection; Cost-Benefit Analysis; Digitalization.*

## 1. Introduction

Building and construction projects have traditionally relied on paper-based communication, often leading to missing information, imprecision, and reduced efficiency in collaborative activities. Ineffective commuaffectn among project teams negatively affects productivity levels. In contrast, BIM's digital integration with parametric data enhances collaboration by improving design accuracy, project coordination, and construction efficiency (Mohamed et al., 2024; Zhairy et al., 2025). Design conflicts can be identified at early stages because BIM generates comprehensive virtual models that reduce errors, rework, and associated costs.

Within the Building Information Modeling (BIM) framework, clash detection plays a critical role in coordinating architectural, structural, and mechanical, electrical, and plumbing (MEP) systems in multidisciplinary construction projects. Models created in Revit—including architectural, structural, and MEP components—are consolidated in Navisworks to perform collision detection analysis (Chahrour et al., 2020). By enabling prescheduled inconsistency checks, BIM helps prevent human errors, scheduling conflicts, and costly design modifications. According to Abdalhameed and Naimi (Abdalhameed and Naimi, 2023), BIM-based clash detection significantly improves project efficiency by resolving conflicts between MEP networks, structural components, and architectural elements, as claimed by Mohamed et al. (2025).

Real-time clash detection and resolution are facilitated by advanced BIM-based software tools such as Navisworks, Revit, BIMcollab, Solibri Model Checker, and Autodesk BIM 360. These tools create a unified project environment where teams can analyze and resolve design discrepancies. Their use improves on-site accuracy, reduces design disputes, and strengthens planning and execution processes. Consistent application of BIM clash detection increases the likelihood of project success by minimizing risks, supporting better decision-making, and preventing costly conflicts (Nabawy et al., 2025).

This study focuses on the cost-benefit analysis of BIM collision detection in construction projects. It investigates whether BIM clash detection technology enhances project performance by mitigating construction hazards, minimizing cost overruns, and reducing rework. By assessing the financial implications of BIM collision detection, the study aims to determine its economic impact through a comparative analysis of intended costs and benefits, such as reduced rework, shorter project timelines, and improved collaboration. The research evaluates the cost-effectiveness of BIM clash detection by considering both tangible benefits—such as cost savings, optimized resource utilization, and minimized change orders—and intangible advantages, including enhanced project quality, improved decision-making, and greater stakeholder satisfaction.

This study examines the cost-benefit implications of BIM clash detection in construction projects. Specifically, it investigates whether the technology improves project performance by reducing hazards, minimizing cost overruns, and limiting rework. By assessing both costs and benefits—including reductions in rework, shorter project timelines, and improved collaboration—the study provides a balanced view of BIM's economic impact. The analysis considers tangible benefits such as cost savings, optimized resource utilization, and minimized change orders, as well as intangible benefits including improved project quality, enhanced decision-making, and greater stakeholder satisfaction.

This study contributes novel insights to the field by providing an empirical financial analysis of BIM-based clash detection, specifically quantifying the cost implications of rework due to unresolved spatial conflicts in construction projects. Unlike previous studies that primarily focused on the technical or operational benefits of BIM, this research introduces a data-driven cost model that links specific types of clashes and opening sizes to measurable delay penalties and financial losses. Additionally, the work explores the relationship between clash severity, opening dimensions, and rework frequency, offering practical benchmarks for prioritizing clash resolution. By grounding the analysis in real project data and extending it to include cost structures and stakeholder impacts, this study bridges the gap between BIM functionality and financial decision-making, thereby contributing a unique, interdisciplinary perspective to the existing body of knowledge.

## 2. Literature Review

The construction industry has undergone substantial change when BIM is implemented for clash detection because it enhances design precision while reducing construction expenses and making projects more productive (Abdalhameed and Naimi, 2023; Gouda Mohamed and Mousa, 2024; Mohamed et al., 2020). The 2D CAD drawings that were commonly used in construction practice caused numerous design misunderstandings and coordination problems between disciplines such as architecture and structural engineering, and mechanical, electrical, and plumbing (MEP) systems (Silva et al., 2024). BIM-based clash detection establishes a fundamental shift by identifying collisions within digital models ahead of construction startups, thus minimizing errors and improving project expenses and timelines (Juszczyk et al., 2023). Construction clashes occur between building elements, so they do not align correctly in their final positions. Clash detection issues comprise three categories: hard clashes, soft clashes, and workflow clashes, as described by Hasannejad et al. (2022) and Alnaser et al. (2024). Two components creating spatial conflicts constitute hard clashes, whereas soft clashes develop from spatial limitations and operational requirements, such as insufficient maintenance access paths. The execution of projects generates timing differences between planned tasks that result in poor resource management and scheduling (Mamdouh et al., 2024). Construction firms face significant financial expenses because they lack the timely detection of design conflicts. Research reveals that missing project error detection during the project timeline drives costs to thirty percent of project values by implementing more labor work, rework expenses, and additional material waste (Daszczyński et al., 2022). BIM-based clash detection prevents project costs while creating smooth project execution through design-stage conflict resolution (Alqahtani et al., 2023; Mohamed et al., 2023; Mohamed and Marzouk, 2021).

The implementation of BIM raises project cost efficiency through its design coordination capabilities, which utilize software tools like Autodesk Navisworks, Solibri Model Checker, and BIMcollab (Mohamed and Marzouk, 2024). According to Kermanshahi et al. (2020), BIM-enabled clash detection reduces rework expenses between 20% and 40%, thus creating significant monetary benefits. The economic viability of BIM clash detection methods was confirmed when Chahrour et al. (2020) demonstrated that large-scale project contract costs decreased by 20% in such deliveries. BIM increases both financial project sustainability and return on investment throughout construction projects. Project managers who implement time 4D- and cost-based 5D BIM models can use live simulations to optimize construction sequences while predicting cost variations (Rui et al., 2021). Better financial planning, reduced budget overruns, and enhanced cash flow management can be achieved (Savitri et al., 2020). BIM-based clash detection allows construction projects to finish up to 15% faster than traditional coordination practices, thus proving the time-saving benefits of BIM, according to Akhmetzhanova et al. (Akhmetzhanova et al., 2022).

Actual construction projects have demonstrated through real examples how BIM clash detection methods save construction costs. The Malaysian Police Headquarters adopted BIM technology to prevent construction conflicts, resulting in major construction rework reduction and material cost savings of 15% (Kermanshahi et al., 2020). Clash detection in the BIM-based hospital construction project in Vietnam revealed 36 design inconsistencies, enhancing coordination among different teams and avoiding project delays (Hasan et al. 2022). The findings of Hasan et al. (2022) support these results by measuring BIM-based construction waste quantification, which shows that clash detection prevented 40–45% of potential material waste, thus improving environmental sustainability.

Research by Stone (2019) demonstrated how BIM implementation leads project companies toward better operational efficiency while producing satisfied clients. Implementing BIM clash detection for Iraqi construction projects led to improved inter-team communication, according to the findings of (Al-Izzy and Al-Btoush, 2022), which produced a 35% reduction in project errors.

The BIM tool Navisworks AI Assistant employs AI capabilities to evaluate design patterns and produce suggestions for multiple solutions, shortening human involvement and improving decision tempo (Datta et al., 2023; Gouda Mohamed et al., 2024). Implementing cloud-based BIM collaboration platforms enables smooth data-sharing functions and remote project coordination capabilities. Research demonstrates that cloud-based clash detection enables teams to resolve conflicts in real-time 30% faster because it facilitates response speeds among teams operating from distant locations (Hasannejad et al., 2022). Design coordination in megaprojects and multinational construction ventures benefits strongly from this trend due to the multi-regional involvement of stakeholders (Mamdouh et al., 2024).

Studies in artificial intelligence applications for clash detection must be conducted to develop predictive capabilities that resolve conflicts in real time (Silva et al., 2024). Research must examine BIM's cost efficiency across construction projects, both big and small, because currently, there is limited information regarding its effectiveness in medium and smaller-scale projects (Mamdouh et al., 2024). The industry needs research into specific educational approaches for preparing engineers, architects, and project managers to utilize BIM-based coordination methods to improve BIM acceptance across the sector (Datta et al., 2023).

## 3. Research Methodology

This study adopts an investigative and explanatory methodology, applying a case study approach to examine the relationship between technology implementation and operational outcomes in construction projects. The analysis focuses specifically on the costs and benefits of applying clash detection within BIM. By drawing on real-life case studies, the research explores both the challenges and the opportunities associated with BIM clash detection. The objective is to evaluate not only the quantifiable expenses and savings but also the non-quantifiable benefits, such as improved coordination and stakeholder satisfaction. Given its exploratory nature, the study provides a comprehensive assessment of BIM clash detection's impact on project efficiency, cost reduction, and error mitigation. The overall research methodology is illustrated in Figure 1.

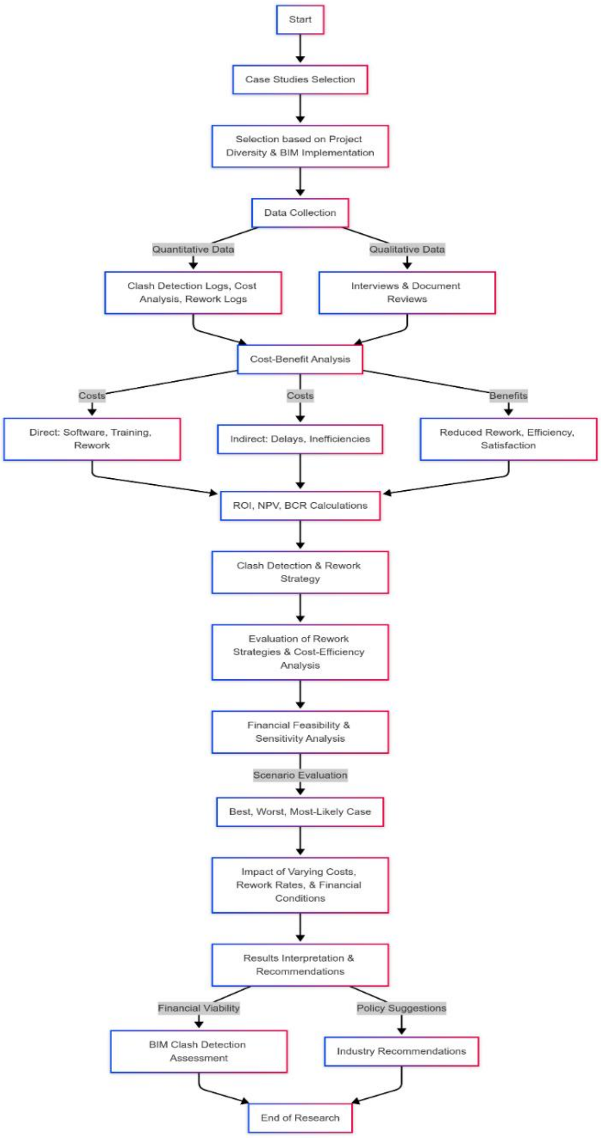


Figure 1. Proposed research methodology (by authors).

### 3.1. Case studies selection

The site selection for this research was guided by specific criteria to ensure a comprehensive and meaningful analysis. Considerations included the diversity of project locations, variation in project scales, and the extent of BIM implementation. Multiple case studies were chosen to provide a broad perspective on BIM clash detection, spanning different contexts to enhance the applicability of the findings. The projects were selected not only for their diversity but also for their well-documented BIM implementation, which enabled a detailed comparison of construction processes before and after the adoption of clash detection technology. Through this analysis, the study evaluates BIM's role in enhancing operational efficiency, reducing errors, and optimizing costs, thereby reinforcing its exploratory and explanatory foundations.

## 3.2. Data collection methods

This study employs a mixed-methods approach, integrating both quantitative and qualitative data collection techniques to evaluate the impact of BIM clash detection on construction efficiency, cost reduction, and project outcomes. The combination of numerical data and qualitative insights provides a comprehensive understanding of BIM's effectiveness in minimizing rework and related expenses.

To assess the financial impact of BIM, cost data will be collected to compare BIM-integrated projects with non-BIM projects. This analysis will include both direct costs—such as labor, materials, and equipment associated with rework—and indirect costs, including delays, disruptions, and project inefficiencies. A comparative cost analysis will highlight the economic benefits of proactive clash detection in reducing rework and optimizing construction budgets.

In parallel, semi-structured interviews will be conducted with project managers, engineers, on-site workers, and BIM specialists. These interviews will capture practical insights into the effectiveness, challenges, and real-world implementation of BIM clash detection. Their open-ended format allows for an in-depth exploration of how BIM influences workflow efficiency, collaboration, and decision-making. Participants will also be encouraged to share their perspectives on the benefits of BIM and identify potential areas for improvement.

Additionally, a document review will be undertaken to analyze project reports, BIM clash detection logs, and rework records. This step will help validate the interview findings by cross-referencing qualitative perspectives with quantitative evidence. By examining documented clashes, resolutions, and modifications, the study will establish an evidence-based understanding of BIM's effect on project outcomes. Combining cost analysis, interviews, and document review ensures a robust and triangulated research design, thereby enhancing the validity and reliability of the findings.

## 3.3. Data analysis methods

Descriptive statistical analysis will be employed for the quantitative data to quantify BIM's contributions to clash detection and rework reduction. Key statistical measures, including mean, median, standard deviation, and frequency distributions, will be used to identify trends in clash detection efficiency and cost reduction. Additionally, regression analysis will be applied to control for confounding variables such as project size, complexity, and duration, ensuring that BIM's direct impact on rework costs is accurately measured. By isolating BIM's effect on construction cost savings, the study aims to establish a clear link between clash detection efficiency and project financial performance.

A cost analysis will also be conducted to compare pre-and post-BIM implementation expenses, focusing on both direct costs, including labor, materials, and equipment, and indirect costs, such as project delays and inefficiencies. This financial assessment will provide tangible evidence of BIM's potential to enhance project efficiency, minimize waste, and optimize resource allocation.

The qualitative data from interviews and document reviews will be analyzed using thematic content analysis to identify recurring themes related to BIM adoption. This method will highlight key aspects such as BIM's impact on workflow efficiency, collaboration, communication, and project quality. Thematic coding will be applied to categorize data into meaningful insights that reveal BIM implementation's perceived benefits and challenges of BIM implementation. The qualitative findings will be integrated with the quantitative results to provide a holistic understanding of how BIM affects construction projects from an operational and financial perspective.

## 3.4. Cost-benefit analysis framework

Descriptive statistical analysis will be employed to quantify BIM's contribution to clash detection and rework reduction. Key measures such as the mean, median, standard deviation, and frequency distributions will be used to identify patterns in clash detection efficiency and cost savings. In addition, regression analysis will be applied to control for confounding variables such as project size, complexity, and duration, ensuring that BIM's direct impact on rework costs is accurately isolated. By doing so, the study seeks to establish a clear link between clash detection efficiency and overall financial performance.

A cost analysis will also be carried out to compare expenses before and after BIM implementation. This assessment will consider both direct costs—labor, materials, and equipment—and indirect costs such as project delays and inefficiencies. The results will provide tangible evidence of BIM's capacity to improve efficiency, minimize waste, and optimize resource allocation.

The qualitative data gathered from interviews and document reviews will be analyzed using thematic content analysis. This approach will identify recurring themes related to BIM adoption, with particular attention to workflow efficiency, collaboration, communication, and project quality. Thematic coding will be applied to organize responses into meaningful categories, highlighting both the perceived benefits and the challenges of BIM implementation. Finally, the qualitative findings will be integrated with the quantitative results to provide a comprehensive understanding of BIM's impact on construction projects from both an operational and financial perspective.

## 3.5. Clash detection and rework strategy evaluation

Different construction methodologies will be compared based on cost, time, and quality to determine the most effective clash detection and rework strategies. A simulation-based approach will model and analyze rework strategies, reflecting the collected case studies' scale, complexity, and timeframe. This will provide insights into cost savings, efficiency improvements, and quality enhancements associated with each strategy.

BIM clash detection will also support identifying alternative rework strategies, such as substituting materials, adopting advanced construction technologies, or modifying construction sequences to reduce conflicts between structural and MEP systems. Each strategy will be assessed for feasibility, cost-effectiveness, and overall impact, ensuring optimal solutions are adopted.

In this context, A cost-efficiency analysis will evaluate the financial impact of various rework strategies, considering short- and long-term savings from reduced rework, increased efficiency, and improved project quality. This will assess each alternative under different conditions, visualizing potential risks and outcomes. This study will identify the most financially viable strategies for the collected case studies by systematically analyzing cost efficiency, ensuring that BIM implementation delivers maximum cost reduction and project efficiency benefits.

Return on Investment (ROI) will be calculated (see Equation 1) by comparing the total implementation costs with the quantified savings resulting from reduced rework and enhanced project performance to assess the financial feasibility of BIM implementation. The analysis will incorporate costs related to BIM software acquisition, personnel training, and maintenance while accounting for savings derived from fewer rework instances, improved scheduling, and increased construction accuracy.

$$\text{ROI} = (\text{Total Benefits} - \text{Total Costs})/\text{Total Costs} \times 100 \quad (1)$$

Afterwards, a sensitivity analysis will be conducted to evaluate the impact of key cost variables on the overall financial feasibility of BIM. This analysis will assess variations in BIM software costs, training expenses, rework reduction rates, labor costs, material costs, and project timelines. To account for uncertainties, three scenarios will be examined: 1) The best-case scenario assumes maximum cost savings with minimal training expenses and a high rate of rework reduction. 2) The worst-case scenario considers higher-than-expected BIM implementation costs, limited efficiency improvements, and unexpected delays, and 3) The most likely scenario presents a balanced estimate based on industry standards and expected project conditions. To account for the time value of money, future costs and benefits will be discounted using the Net Present Value (NPV) (Equation 2). In equation 2, Bt represents benefit during year t, Ct refers to cost during year t, r stands for discount rate, and t means year. Additionally, the Benefit-Cost Ratio (BCR) will be used to determine economic feasibility (Equation 3), where a BCR greater than 1 signifies that benefits outweigh costs.

$$NPV=\sum B_t / (1+r)^t -\sum C_t / (1+r)^t \qquad (2)$$

$$BCR=\sum B_t (1+r)^t / \sum C_t/(1+r)^t \qquad (3)$$

# 4. Framework Implementation

## 4.1. Federated BIM models and clash detection

The initial step in the framework implementation is developing the federated BIM models. This process starts with importing Revit models into the Navisworks environment to incorporate the structural, HVAC, and firefighting models. The step entails integrating structural, HVAC, and firefighting models to provide a holistic view of the whole building system. The model alignment is performed using the software's visualization capabilities to ensure that no element is missing or placed in the wrong position in the complex model. The integrated models give the various parties in the project a global picture of the overall building design and layout, as all components can be seen at once in their proper 3D position, as shown in Figure 2.

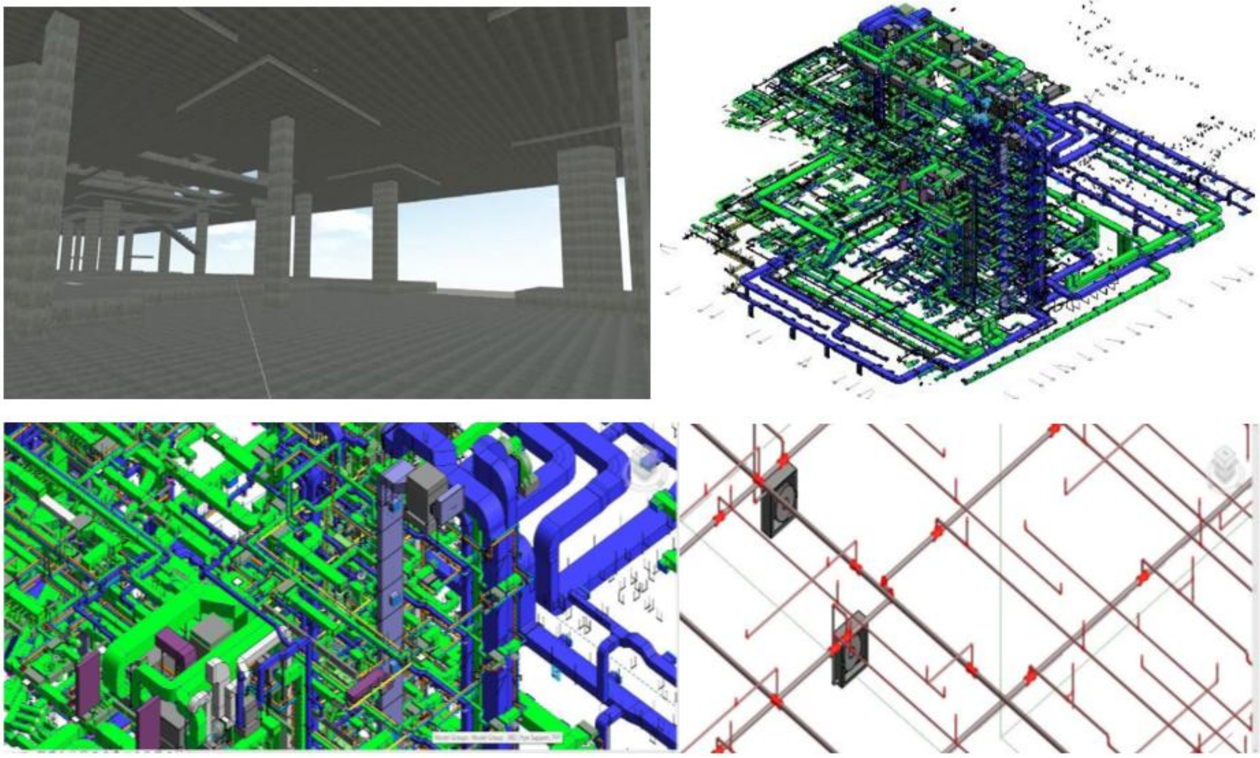


Figure 2: BIM federated model (by authors).

The implementation of clash detection using Autodesk Navisworks has been successfully executed in the selected case studies, ensuring effective coordination between structural components, HVAC ducts, piping, and fire protection systems. The process commenced with the setup of clash tests using the Clash Detective feature to identify potential conflicts. These tests were configured to detect hard clashes, where elements physically intersect, and clearance clashes, which indicate insufficient spatial separation. Once established, Navisworks analyzed the integrated Building Information Modeling (BIM) model, generating detailed clash reports highlighting conflicts with precise metadata, including element details, clash type, and location, facilitating a systematic approach to issue resolution.

Following detection, clashes were filtered based on discipline, severity, and location, prioritizing those risks to structural integrity and MEP coordination over minor interferences. The classification distinguished interdiscipline clashes between different systems from interdiscipline clashes, which arise within the same system. Minor clashes, such as a duct slightly intersecting a column, were resolved through small design adjustments, whereas major clashes, such as a pipe colliding with a slab or another MEP component, required substantial modifications, including rerouting systems or redesigning layouts.

To facilitate efficient resolution, clashes were systematically grouped and assigned to relevant engineers or designers, ensuring a coordinated approach to problem-solving. Navisworks enabled the categorization of clashes by type and discipline, allowing project teams to focus on critical issues first. Additionally, documentation and reporting tools were utilized to generate detailed records, images, descriptions, and status updates for each clash, enhancing transparency and communication among project stakeholders (see Figure 3).

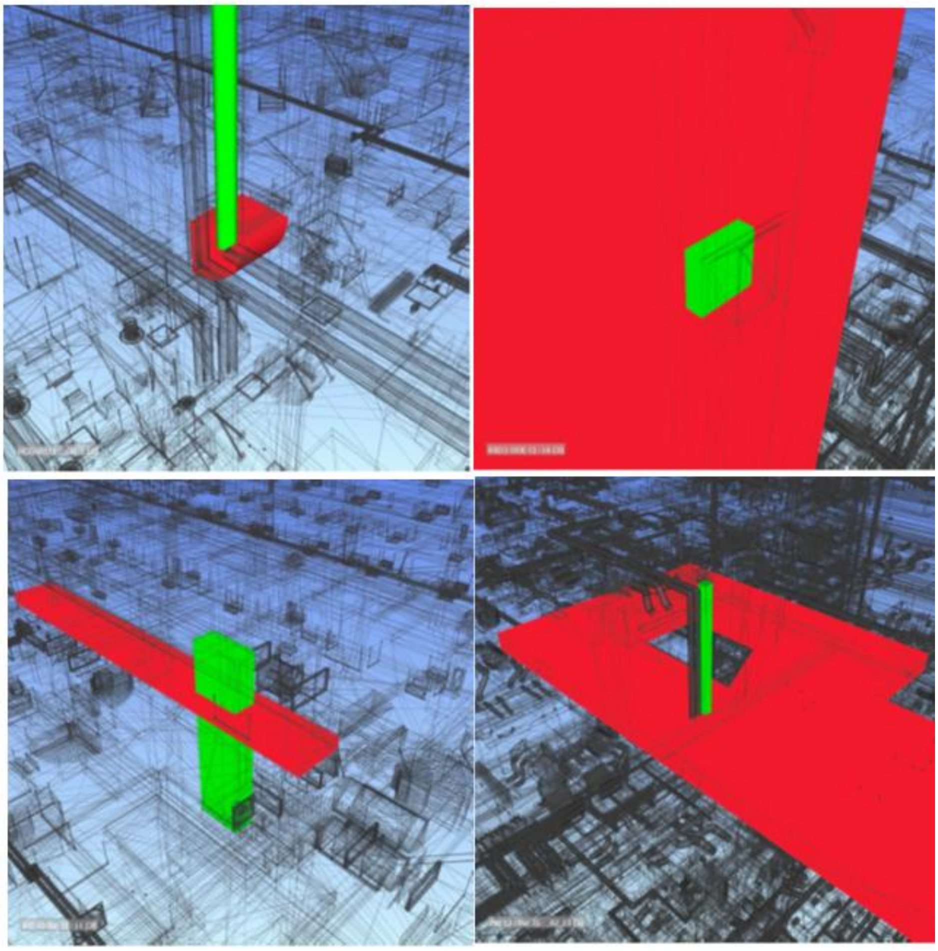


Figure 3. Clashes generated from Navisworks (by authors).

## 4.2. Construction methods for the rework of detected clashes

The authors gathered various alternatives for opening, repairing, and reinforcing duct openings in concrete walls or slabs to determine the most cost-effective and high-quality approach. These methods were analyzed based on technical feasibility, material requirements, execution complexity, and overall impact on cost and quality to ensure efficiency and structural integrity in construction.

Core drilling was evaluated for precision and minimal structural impact for creating duct openings, while wall sawing provided deep, straight cuts for larger openings. Hammer drilling and chiselling offered a low-cost, portable solution but required additional finishing. Concrete cutting chainsaws were considered for versatile plunge cutting, though they required high maintenance. Hydraulic splitters were assessed for low-vibration concrete breaking, making them suitable for reinforced structures, while wire sawing allowed for precise, vibration-free cuts in large-scale openings.

After openings were created, different repair techniques were examined. Patching with concrete was durable and cost-effective, while epoxy injection provided strong bonding for crack repairs. Fibre-reinforced polymer (FRP) wraps improved tensile capacity, making them suitable for additional reinforcement. Grout injection was considered for void filling and structural stabilization, while self-leveling mortar ensured a smooth surface finish. Spray-applied concrete (shotcrete) allowed for fast, uniform repairs, and polyurethane foam injection offered quick expansion for sealing irregular gaps.

For cases requiring both opening and reinforcement, steel frame installation was analyzed for load-bearing enhancement and crack prevention. Prefabricated duct sleeves provided easy installation and a standardized finish, while cast-in-place concrete liners added rigidity and strength. Expanding cement mortar ensured tight void filling with strong adhesion, and precast concrete inserts minimized on-site curing time while maintaining quality. Through this systematic evaluation, the authors aimed to select the most efficient and cost-effective technique for duct openings, ensuring durability, ease of implementation, and overall project optimization in the selected case studies.

The cost analysis charts ( Figure 4) provide insights into the most cost-effective and high-quality methods for duct opening, repair, and reinforcement, and the implementation of BIM clash detection. For duct opening, Hammer Drilling & Chiseling ($36.00 per sq. m) and Electric Rotary Hammers ($36.00 per sq. m) are the most affordable, while Wire Sawing ($120.00 per sq. m) is the most expensive but highly precise. Core Drilling ($56.50 per sq. m) and Wall Sawing ($78.50 per sq. m) offer a balance between cost and efficiency.

For duct repair, Patching with Concrete ($33.50 per sq. m) and Self-Leveling Mortar ($33.50 per sq. m) are cost-effective solutions, while FRP Wraps ($92.50 per sq. m) and Shotcrete ($105.00 per sq. m) provide greater reinforcement at a higher cost. For opening and reinforcing simultaneously, Prefabricated Duct Sleeves ($38.50 per sq. m) are the cheapest, whereas Steel Frame Installation ($80.00 per sq. m) and Cast-in-Place Concrete Liners ($82.50 per sq. m) offer higher structural durability. In this regard, the BIM clash detection system requires an initial investment of $5,305.00 but reduces rework and error costs, making it a valuable long-term investment.

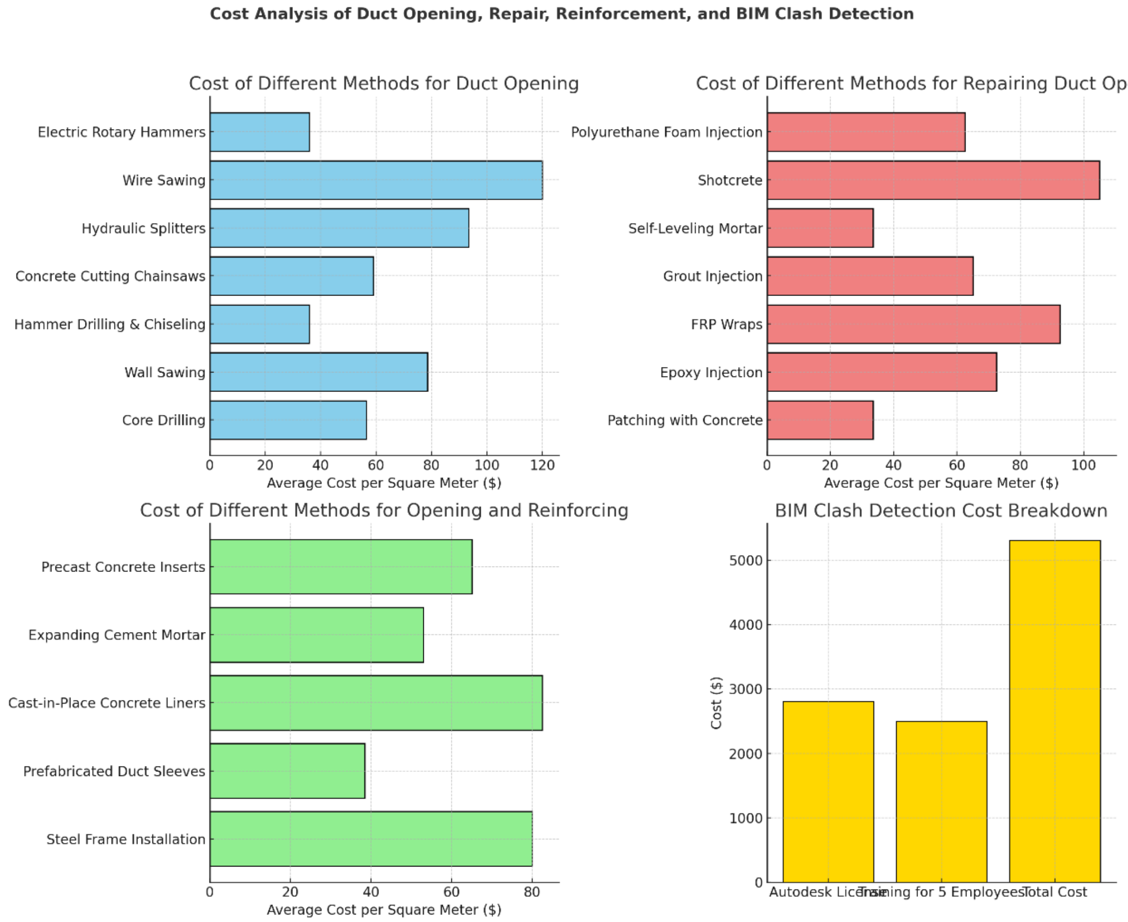
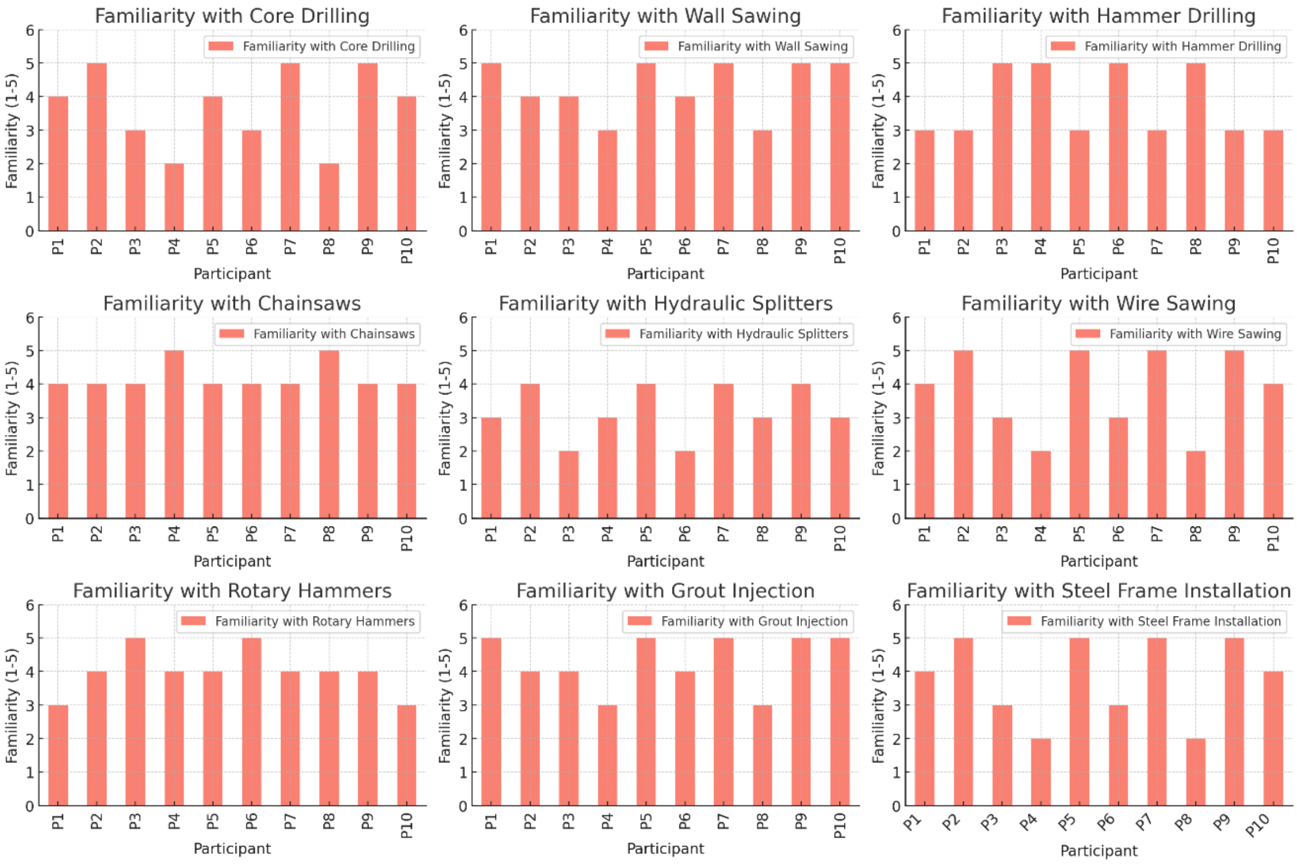


Figure 4. Cost analysis of duct opening, repair, reinforcement, and BIM clash detection (by authors).

Consequently, professional interviews were conducted to identify best practices for duct opening, repair, and reinforcement in the Egyptian construction industry, focusing on cost-effectiveness and structural integrity. The study involved at least ten experienced practitioners, including site managers, structural engineers, contractors, and equipment operators, all with a minimum of five years of experience. Interviews were conducted through face-to-face meetings, phone calls, and video conferencing, using a structured yet conversational guide to gather insights on various concrete cutting and repair techniques.

Participants rated their familiarity with different methods on a scale from 1 to 5, revealing high familiarity with core drilling, wall sawing, wire sawing, and concrete cutting chainsaws, while hydraulic splitters and steel frame installation showed mixed awareness. Responses were recorded, as revealed in Figure 5, analyzed, and compared to identify the most efficient and cost-effective solutions. The findings led to the selection of concrete sawing for its precision and versatility, grout filling for structural stability, and steel frame installation for long-term reinforcement. These choices were based on the practical experiences of industry professionals, ensuring their suitability for real-world applications.


Familiarity with Core Drilling

Familiarity with Wall Sawing

Familiarity with Hammer Drilling

Familiarity with Chainsaws

Familiarity with Hydraulic Splitters

Familiarity with Wire Sawing

Familiarity with Rotary Hammers

Familiarity with Grout Injection

Familiarity with Steel Frame Installation

Figure 5. Interview responses (by authors).

The cost analysis (Figure 6) highlights the major contributors to duct opening, rework, and delays, emphasizing areas where cost reductions can be achieved. High labor expenses drive the actual cost per square meter ($239/m²) in Steel Frame Installation ($60) and Grout Injection ($45), along with material and tool costs. Concrete Cutting Chainsaws, while requiring a $15 equipment rental fee, have lower material costs ($8). The total area of duct and pipe openings amounts to 471.57 m², with the majority attributed to larger duct openings of 1.0 m × 0.5 m (35.9%) and 1.2 m × 0.5 m (22.2%), which substantially increase overall project costs. In contrast, smaller pipe openings with a diameter of 0.1 m contribute only 0.3% of the total opening area, reinforcing the observation that larger penetrations are the primary drivers of rework-related expenses. The cost of project delays is estimated at $3,350 per day, with labor costs and contractual delay penalties each accounting for $1,000 per day and comprising 60% of daily costs. Additional expenditures include site overheads ($600 per day), equipment usage ($500 per day), and material wastage ($250 per day). Cumulatively, the rework cost reaches $414,205.23 over 90 days. These findings underscore the critical importance of proactive clash detection through Building Information Modeling (BIM) and the implementation of improved coordination and planning strategies to reduce design errors, mitigate rework, and minimize avoidable delays and costs.

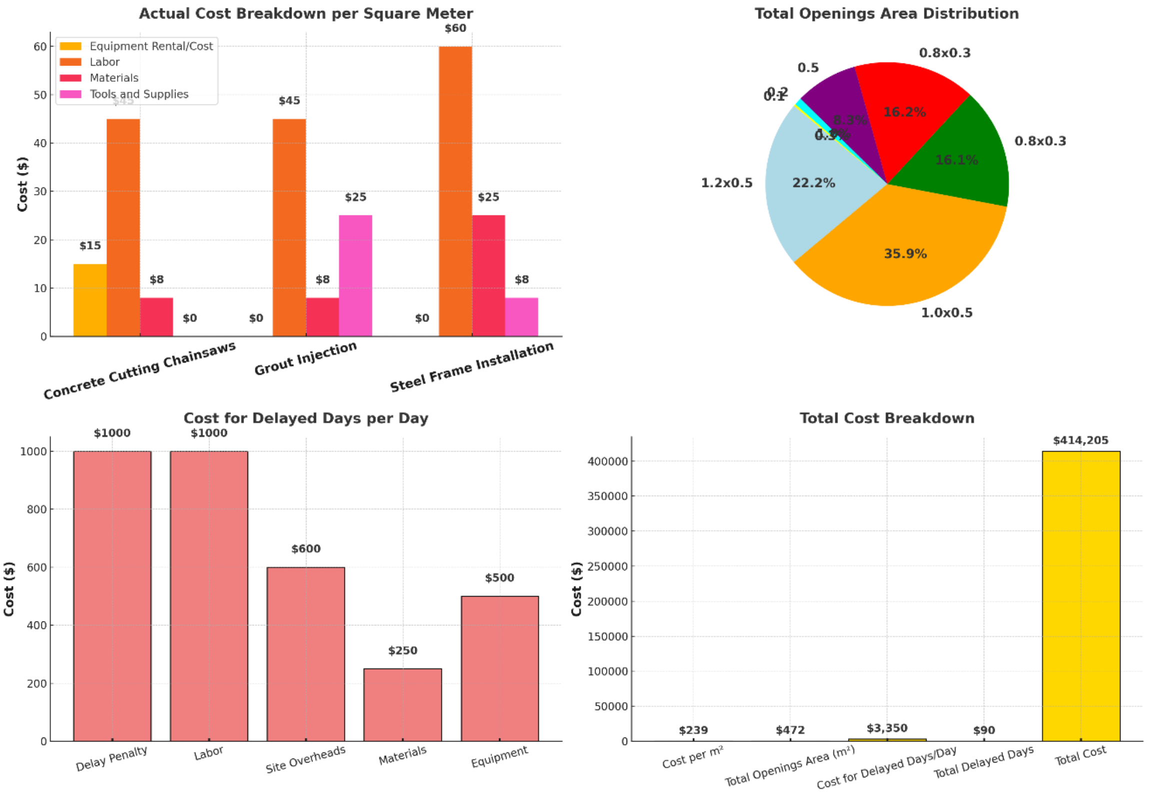


Figure 6. Cost breakdown of duct opening, rework, and delays, highlighting major cost contributors and financial impact on project efficiency (by authors).

## 4.3. Cost-benefit analysis

The cost-benefit analysis evaluates the financial feasibility of implementing BIM by comparing the investment cost against projected savings from reduced rework. BIM implementation costs $5,305, while the estimated savings from reduced rework over five years amount to $414,205.23. An inflation rate of 35.7% and a discount rate of 18.75% are applied to account for economic conditions.

The annual savings, assuming a constant reduction in rework costs, amount to $82,841.05 annually. However, after adjusting for inflation, the real value of yearly benefits decreases over time, starting at $61,056.71 in the first year and reducing to $17,997.47 in the fifth year. After discounting future benefits, these savings' Net Present Value (NPV) totals $123,020.59. Subtracting the initial BIM investment, the final NPV is $117,715.59, indicating a highly favourable return.

The BCR calculated by comparing total discounted benefits to costs results in 23.18, demonstrating that every $1 invested in BIM generates $23.18 in savings. Additionally, the Return on Investment (ROI) is exceptionally high at 7,704.23%, confirming that BIM implementation significantly reduces costs associated with construction rework and delivers substantial financial benefits.

The analysis demonstrates that the initial investment in BIM technology is recovered and generates substantial financial gains, making it a highly viable investment. The positive NPV of $117,715.59 from the first year indicates that BIM adds considerable value to the project, exceeding its costs and proving its financial soundness. Despite a high discount rate of 18.75%, the strong returns on investment confirm BIM's ability to provide long-term financial benefits while considering opportunity costs. Additionally, by accounting for a high inflation rate (35.7%), the analysis ensures a realistic and conservative projection of future cash flows, preventing overestimating benefits.

With a BCR of 23.18, the benefits of BIM are 23 times higher than its costs, reinforcing its financial feasibility. This high ratio also indicates significant cost savings due to reduced rework and improved project coordination, making BIM an efficient tool for large-scale construction projects. A higher BCR implies lower financial risk, as the extensive benefits buffer against potential cost overruns or delays. Similarly, the exceptionally high ROI of 7,704.23%

highlights the disproportionate financial returns compared to the setup costs, proving that BIM implementation is cost-effective and highly profitable.

From a strategic perspective, BIM adoption provides a competitive advantage, as construction projects typically operate on slim profit margins. The financial superiority of BIM-supported projects establishes an industry benchmark, encouraging widespread adoption. This financial viability is crucial for decision-makers, justifying the required resources for BIM implementation. Furthermore, BIM enhances operational efficiency by reducing design clashes, rework, and resource wastage, leading to better labor and material management. Including high inflation and discount rates strengthens the robustness of the financial analysis, demonstrating that BIM remains beneficial even in adverse economic conditions.

For stakeholders, this data-driven financial assessment fosters confidence in BIM adoption. A well-documented ROI and cost-benefit analysis solidify BIM's role as a strategic investment, enhancing the project's attractiveness to investors and business partners. The demonstrated financial and operational gains position BIM as a transformative tool in construction, ensuring long-term profitability and efficiency in large-scale projects.

## 4.4. Sensitivity analysis

The sensitivity analysis confirms the financial viability of BIM implementation by evaluating the effects of discount rate, inflation rate, and rework reduction percentage on key financial metrics. As the discount rate increases from 10% to 30%, NPV declines but remains positive, indicating strong financial returns even at higher opportunity costs. At 10%, NPV is significantly high, while at 30%, it remains positive, proving project feasibility. BCR decreases with increasing discount rates but stays above 1, ensuring benefits outweigh costs, as rendered in Figure 7. Inflation impacts NPV by reducing the real value of future savings, with 20% inflation yielding a high NPV and BCR, while 50% inflation results in lower but viable financial outcomes. ROI remains constant across all inflation scenarios, based on nominal values (see Figure 8). As the extent of rework reduction increases from 50% to 100%, all financial indicators improve. Even at a 50% reduction, NPV remains positive, proving BIM's efficiency at moderate performance levels. With an 80%-100% reduction, NPV and BCR rise sharply, indicating substantial cost savings and stronger financial returns, as seen in Figure 9. The findings reinforce that, despite economic fluctuations, BIM remains a highly beneficial investment, providing cost efficiency, reduced rework, and financial predictability, with an NPV of $117,715.59, BCR of 23.18, and ROI of 7,704.2.

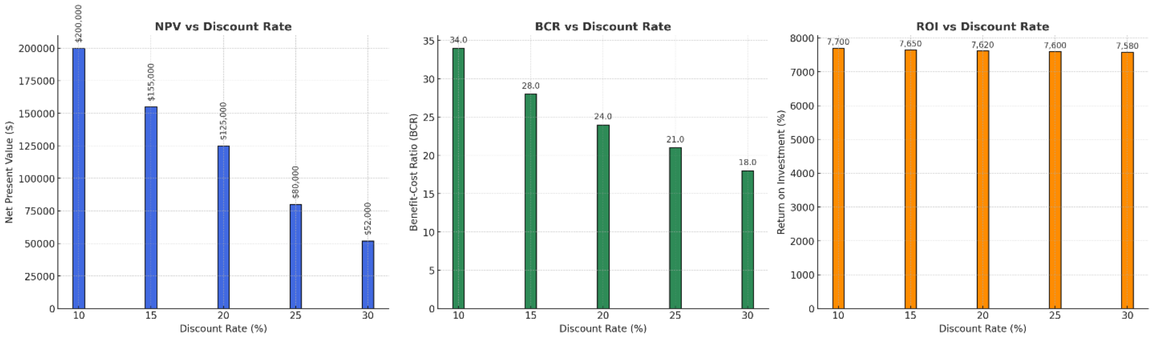


Figure 7. Varying discount rates (by authors).

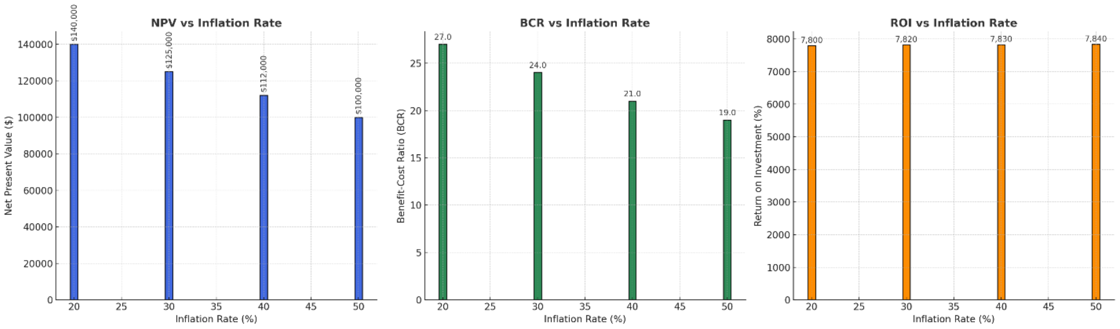


Figure 8. Varying inflation rates (by authors).

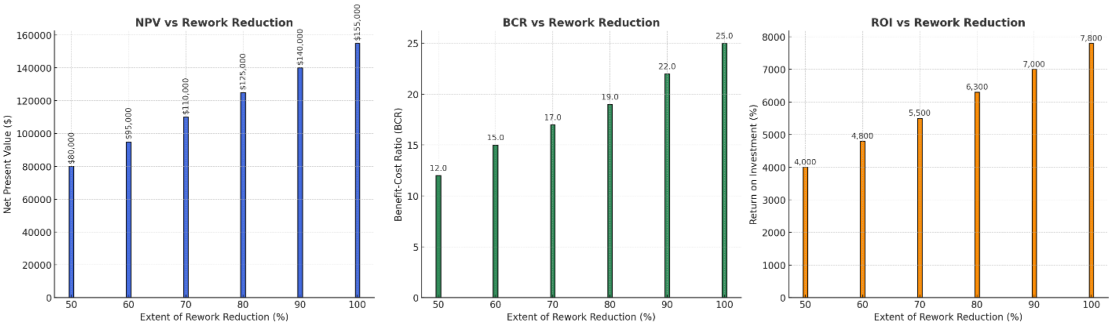


Figure 9. Varying extent of rework reduction (by authors).

The outcomes of this study yield critical implications for both the theoretical advancement of construction informatics and the practical optimization of project delivery processes. Empirically establishing a quantitative link between unresolved spatial clashes and their associated financial ramifications reframes BIM clash detection from a predominantly technical exercise to a strategically essential function for risk mitigation and cost control. The disproportionate financial burden imposed by large-scale duct clashes, as demonstrated in the analysis, offers a predictive metric for prioritizing clash resolution based on dimensional and typological parameters—enabling more targeted, cost-effective interventions during preconstruction planning. Furthermore, the integration of BIM-based clash detection with delay cost modeling contributes a novel evaluative framework that can be operationalized by contractors, engineers, and project managers to inform decision-making regarding resource allocation, contingency planning, and digital coordination protocols.

On a broader scale, the findings substantiate the economic justification for early investment in BIM technologies and inter-disciplinary collaboration during the design phase, particularly in contexts where rework costs and schedule penalties constitute a significant portion of project risk. For academic and industry researchers, the study introduces a methodological foundation for further exploration of BIM's intersection with construction economics, including the integration of real-time cost feedback loops, digital twin simulations, and AI-enhanced clash resolution mechanisms. As such, the research contributes not only to the refinement of current BIM practices but also to the evolving discourse on data-driven construction management and digital transformation in the AEC industry.

## 5. Conclusion

Research studies show that BIM clash identification techniques deliver considerable economic advantages and operational benefits in construction environments. The researchers evaluated projects to verify that BIM decreases conflicts between designers while reducing unnecessary work and boosting performance. The implementation of BIM at an initial cost of $5,305 showed significant financial returns worth $414,205.23 throughout five years, with a resulting Net Present Value (NPV) of $117,715.59, Benefit-Cost Ratio (BCR) of 23.18, and Return on Investment (ROI) of 7,704.23%. The data shows that BIM returns its first funding cost and creates substantial, lasting financial returns. The sensitivity analysis results demonstrated that BIM remains viable under various economic conditions since it sustains a positive NPV through high inflation rates of 35.7% and up to 30% discount rates.

This research's economic and operational feasibility evidence needs readers to recognize specific study constraints. The research was based its results on particular case study examples that could reduce the ability to apply findings across various construction projects or regulatory frameworks. New investigations should take on multiple construction projects at different scale levels using diverse contractual frameworks and market situations. External elements, like technological adoption learning times, system integration problems, and software maintenance expenses, did not receive a comprehensive assessment within the cost analysis framework. Research into BIM needs to determine how future projects will handle long-term technological adoption issues and lifecycle assessment expenses. The research needs to expand the investigation into stakeholder perspectives by studying how contractors, engineers, and decision-makers implement BIM technology with digital constructs such as AI project management, Internet of Things, and automation for optimum performance.

To further enhance the relevance of BIM implementation in modern construction environments, future research should expand to incorporate diverse stakeholder perspectives, particularly those of contractors, engineers, and decision-makers, on the integration of BIM with emerging digital technologies. The convergence of BIM with artificial intelligence (AI) based project management tools, Internet of Things (IoT) sensors, and construction automation has the potential to significantly elevate project performance, accuracy, and responsiveness. These technologies can augment BIM's capabilities by enabling real-time data-driven decision-making, predictive maintenance, automated clash detection, and advanced scheduling optimization. Understanding how various stakeholder groups operationalize and benefit from such integrations is essential for optimizing digital workflows, improving communication across disciplines, and achieving strategic project outcomes. Therefore, future studies should systematically evaluate how these actors adopt and adapt BIM in tandem with digital constructs to address specific project needs, mitigate implementation challenges, and maximize long-term performance and cost efficiency.

While the findings of this study offer valuable insights into the financial benefits of BIM-based clash detection, several limitations should be acknowledged. First, the analysis is grounded in case studies from a specific regional and regulatory context, which may limit the direct applicability of the results to projects in different countries or construction markets with varying cost structures, contract frameworks, or BIM maturity levels. The material pricing, labor rates, and delay penalties used in the rework cost model are reflective of local economic conditions and may not be representative of global averages.

Second, the study's reliance on a single software ecosystem (Autodesk Revit and Navisworks) constrains the generalizability of technical workflows, particularly in projects utilizing alternative BIM platforms or bespoke coordination systems. Third, while the empirical approach offers a robust quantification of rework costs, it does not account for intangible factors such as productivity losses, stakeholder conflict, or long-term reputational damage resulting from coordination failures. Finally, the study focuses primarily on mechanical, electrical, and plumbing (MEP) clashes and their financial implications; other forms of clashes (e.g., temporal or operational) and their cascading effects on project delivery remain outside the current scope.

Building on the findings and limitations of this study, several avenues for future research can be proposed. One promising direction involves the integration of predictive artificial intelligence (AI) models for real-time clash detection and resolution. Machine learning algorithms, trained on historical clash data, could be used to anticipate high-risk zones in design models and recommend corrective actions before issues materialize, thereby further reducing rework and associated costs. In parallel, future work could explore the development of intelligent rule-based systems that classify clashes not only by geometry but also by cost impact and constructability constraints, enhancing the decision-making capabilities of project teams.

Another important area for future investigation is the formulation of effective BIM adoption strategies tailored for small- to medium-scale construction projects, particularly in developing regions. These projects often face resource constraints, skill shortages, and limited access to high-end BIM platforms, which present barriers to implementation. Research could examine scalable, low-cost BIM workflows and policy frameworks that promote digital uptake in such settings. Additionally, interdisciplinary studies could explore how BIM integrates with Internet of Things (IoT) technologies for dynamic construction monitoring, or how digital twins can simulate the cost and schedule implications of clash scenarios in real-time. These forward-looking initiatives would not only extend the operational utility of BIM but also position it as a central component in the digital transformation of the construction industry.

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## Ethics approval.

All research activities were conducted in full compliance with international and national ethical standards governing scientific research. The study followed the principles outlined in the Declaration of Helsinki (World Medical Association, 2013), the CIOMS International Ethical Guidelines for Health-Related Research Involving Humans (2016), and the Ethics of Scientific Research in Egypt: Current Status and Future Outlook (Academy of Scientific Research and Technology, 2022). These frameworks emphasize the core principles of respect for human dignity, beneficence, justice, transparency, and informed consent, which were strictly upheld throughout the research process. Ethical approval for this study was obtained from the Research Ethics Committee of The British University in Egypt (BUE) under approval code BUE-REC-2025-014. The Committee operates in accordance with the national ethical governance structure established by Egypt's Academy of Scientific Research and Technology (ASRT) and its National Committee for Bioethics.

Before data collection, all participants were provided with clear and comprehensive information about the study's purpose, procedures, potential risks, and benefits. Participants were assured of the confidentiality and anonymity of their responses, and all data were securely stored and used solely for academic and scientific purposes. The ethical framework of this study fully aligns with Egypt's national code of ethics for research, which integrates international standards with Egyptian cultural and legal contexts, as detailed in Ethics of Scientific Research in Egypt: Current Status and Future Outlook (ASRT, 2022, pp. 68–71, 109–124, 562–597)

## Conflict of interest.

The author(s) declare that there is no competing interest.

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