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SYNERGISTIC INTEGRATION OF BIM AND PREFABRICATION FOR ENHANCED ARCHITECTURAL EXCELLENCE

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SUMMARY: *The construction industry faces escalating costs and inefficiencies driven by challenges including affordability barriers for sustainable practices, limited scalability of green technologies, and gaps in integrating sustainability metrics into architectural design. This research proposes a strategic approach harnessing Building Information Modelling (BIM) and prefabrication to overcome these challenges while enhancing architectural outcomes.Through a mixed-methods approach combining literature review, expert interviews, and simulation of a case study project in New Zealand, this study explores the collaborative potential of these technologies to elevate architectural excellence in sustainable construction. Architectural excellence is examined through four dimensions: project costs, building safety, project scheduling, and energy efficiency. Expert interviews with nine industry professionals revealed construction projects face material waste (15-30%), cost increases (10-20%), and suboptimal completion timeframes. The simulation validated integration benefits through clash detection and design coordination capabilities at LOD 350.The research demonstrates that effective integration of BIM and prefabrication can streamline project schedules and enhance architectural design processes. The triangulation of expert knowledge with simulation results provides compelling evidence that integrating prefabrication and BIM can reduce construction costs, prevent material wastage and excessive energy consumption, reduce project execution time, prevent rework, increase safety, and ultimately improve architectural excellence.*

KEYWORDS: *Building Information Modelling (BIM), Prefabrication in Construction, Sustainable Construction, Architectural Excellence, Construction Technologies.*

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1. INTRODUCTION

The construction industry remains one of the most significant economic sectors globally, constituting approximately 7% of the worldwide workforce and contributing substantially to global GDP. Despite this economic prominence, the industry has struggled to evolve beyond traditional methodologies, particularly when compared to the technological advancement of other sectors. This technological stagnation has led to persistent challenges related to productivity, sustainability, and quality management that continue to plague construction practices worldwide (Z. Zhou et al., 2015). However, in contrast to various other industries across numerous countries, this industry has remained entrenched in traditional methods, thereby grappling with numerous challenges. For example, it is alarming to note that it accounts for 30-40% of fatalities (Bidhendi et al., 2022). By 2060, it is estimated that carbon dioxide (CO_2) emissions resulting from the use of construction materials will double, constituting approximately 9% of global energy consumption (Fonseca Arenas & Shafique, 2023). Finding effective strategies to mitigate the challenges inherent in the construction industry while concurrently enhancing the overall product quality has long been a focal point for societies throughout history. Effectively addressing this issue holds immense potential to positively impact the global community's economic prosperity and environmental sustainability (Regona et al., 2024).

There exist a lot of approaches to address the multifaceted challenges encountered within the construction industry. Among these, one of the paramount and fundamental strategies revolves around the implementation of effective and optimal architectural design. It plays a vital role in determining material wastage rates and enables the integration of intelligent technologies for sustainable industry development (Schlueter & Geyer, 2018). By implementing refined architectural design and intelligent design optimisation techniques, it is possible to achieve a reduction in material wastage of up to 40% (Masood et al., 2021). This, in turn, leads to a decrease in labour wastage caused by the need for rework. This approach would enhance the efficiency of architectural design, driving the industry towards environmental sustainability and technological advancements (Wu et al., 2023).

In contemporary construction practice, technological innovations in architectural methodologies hold tremendous potential for elevatingquality benchmarks for architectural products (Eadie et al., 2013). Given that architectural production inherently carries cultural significance, the localisation and context-specific adaptation of architectural technologies is paramount for successful implementation in diverse settings (Rashid & Salman, 2024). New Zealand's construction industry, while essential to the nation's infrastructure development, confronts challenges of high pricing, suboptimal productivity, and innovation deficits. These challenges have resulted in decreased sectoral productivity, attributable to factors including procurement performance issues, management capability limitations, skill shortages, and workability concerns. Industry experts recommend the adoption of modern digital technologies and off-site manufacturing procedures to address these productivity challenges (Ghalenoei et al., 2022).

Given the potential benefits of both BIM and prefabrication individually, this research addresses the following research question: "To what extent does the integrated implementation of BIM and prefabrication enhance architectural excellence across the four quality dimensions (cost, safety, energy efficiency, and scheduling) compared to conventional construction delivery methods?" This study hypothesises that the synergistic integration of BIM and prefabrication will demonstrate measurable improvements in all four architectural quality dimensions through enhanced coordination, reduced material waste, improved safety protocols, and accelerated project timelines.

The research presented in this paper adopts a comprehensive approach to investigate how Building Information Modeling (BIM) can enhance architectural excellence in sustainable construction through prefabrication technologies. This study goes beyond previous research by employing a mixed-methods approach that combines qualitative expert interviews with simulation validation. By integrating perspectives from industry professionals with quantitative simulations, this research provides a more robust validation of the benefits derived from combining BIM and prefabrication technologies. This approach addresses a significant gap in the existing literature, which has predominantly focused on either BIM or prefabrication as separate strategies without adequately exploring their integrated potential for enhancing architectural excellence. By triangulating data from expert interviews, literature review, and simulation, this research provides a more comprehensive understanding of how these technologies can collectively transform construction practices to improve sustainability outcomes and architectural quality. The findings offer valuable insights for both industry practitioners seeking practical implementation strategies and academic researchers interested in the theoretical underpinnings of technological integration in architectural design and construction.

2. LITERATURE REVIEW

2.1 Architectural Excellence

The construction industry has garnered significant societal attention due to its extensive impact on safety, the economy, the environment, and public health. Ensuring sustainable development in this industry has become a key area of concern (Wang et al., 2022).

Quality has traditionally been interpreted as the 'ability to satisfy needs', 'conformance to requirements', and 'fitness for purpose' (W. Ma, 2024). Recent trends have seen a more holistic understanding of quality emerging in terms of providing customer satisfaction. This orientation towards the customer has focused on quality management as a process that links to the various stages of the total construction process and underpins all activities and business of an organization involved in any of those stages. Developing a formal quality management system has evolved from the need to comply with worldwide quality standards (Husin et al., 2009). Recent studies identify that achieving construction readiness for BIM-based projects faces challenges including knowledge gaps, infrastructure limitations, and coordination issues that impact project quality delivery (Radzi et al., 2025).

According to Losavio et al. (2006) quality refers to a collection of attributes and traits inherent in a product or service that bear on its ability to satisfy stated or implied needs. There are multiple perspectives to consider when examining quality. The user view focuses on the quality of the final product, while the developer view focuses on the quality of the intermediate products created by various stakeholders during the development process. The end-user manager view emphasizes meeting marketing requirements. To assess the overall quality of a product, we can combine these different perspectives. In the context of architectural excellence, we primarily consider the user and developer (architect) views. There is a distinction between two levels of quality features: factors and criteria. Factors are not directly measurable, whereas criteria can be assessed subjectively (Nahri & Motamedmanesh, 2024). The research conducted for this study reveals that the term "quality in architecture" holds various meanings in architectural research and related specialized topics. To provide clarity and structure to research in this field, this study categorizes the quantifiable qualities in architecture into four main types, as outlined in Table 1.

Table 1: Architectural qualities.

Row	Type of quality	Resource
1	Cost	(Bryde et al., 2013), (Windapo et al., 2018), (Bidhendi et al., 2023), (Q. Liu & Cao, 2021)
2	Safety	(Chatzimichailidou & Ma, 2022), (H. Guo et al., 2017), (Bidhendi et al., 2022), (Collinge et al., 2022), (Maali et al., 2024)
3	Energy	(Dubljević et al., 2023), (Bao-jie He a, 2014), (S. Liu, 2021)
4	Scheduling	(Walasek & Barszcz, 2017), (Al-Ashmori et al., 2020)

2.2 Prefabrication

Off-site construction (OSC) is an innovative and environmentally friendly building process that involves manufacturing and assembling building components in off-site factories before transporting them to the construction site for installation (Boafo et al., 2016). This approach offers several benefits, such as improved workflow continuity, increased productivity, reduced construction waste, and decreased construction time. It has gained recognition and is widely used in various countries and regions worldwide (Hwang et al., 2018).

Prefabricated construction can generally be divided into several categories: components, panels (2D), modules (3D), hybrids, and unitised whole buildings. These classifications help to differentiate the various approaches and methods used in prefabricated building construction (Boafo et al., 2016). The time-saving benefits of prefabricated construction are primarily due to the ability to carry out on-site foundation construction simultaneously with off-site component fabrication. This concurrent approach helps minimise the impact of weather delays on the construction schedule, leading to more efficient and timely project completion. Prefabrication is said to be a sustainable building technology (Mao et al., 2016).

Prefabricated construction methods have positive advantages. Unlike traditional construction methods, in which tasks are carried out one after the other, it enables concurrent work, significantly reducing construction time. Additionally, prefabrication involves manufacturing modules in off-site factories, creating a more favourable working environment for construction workers (Hwang et al., 2018). The adoption of prefabrication in building construction offers several quantifiable benefits. These benefits include increased construction quality and safety, reduced construction time, overall cost savings, minimised material waste, and decreased environmental impact (Y. Guo et al., 2024). Contemporary cost management approaches in prefabricated construction emphasise the need for holistic cost models that integrate BIM capabilities with big data-based optimization rather than traditional estimating methods (J. Zhou et al., 2024).

Prefabrication does not hinder creativity in design; in fact, standardising components and providing customisation options can lead to cost reduction through economies of scale. For example, in Hong Kong, where waste disposal space is limited, prefabrication is being embraced to reduce waste by 84.7%. The recognition and significance of these beneficial aspects were evaluated through a survey conducted within the construction industry. Modular steel buildings are increasingly used for two- to six-story buildings where repetitive units are required (Gong et al., 2024).

2.3 Integration of Prefabrication and BIM

When compared to site-built construction, off-site construction has consistently demonstrated higher growth in productivity. It has been suggested that the greatest advancements in construction productivity will result from automated off-site activities facilitated by BIM (Li et al., 2024). Off-site construction increases the timely housing supply in New Zealand as a critical enabler. However, the utilization of this methodology remains relatively low (Ghalenoei et al., 2022). Currently, only a small percentage, approximately five to ten per cent, of newly constructed homes in New Zealand are built using off-site construction methods. However, in certain parts of Europe, this figure reaches as high as 80 per cent. To address the challenges of OSC and maximise its benefits, various studies recommend the utilisation of new technologies such as BIM (Kazeem et al., 2024). It enables detailed modelling of each building trade and helps identify and resolve trade interferences (Bao-jie He a, 2014; Boafo et al., 2016; Tulenheimo, 2015), (Han et al., 2024). BIM's ability to retain component attributes and share information is particularly valuable in off-site modelling disciplines (Mao et al., 2016). However, further investigation is needed to explore the integration between OSC and BIM, especially in the context of New Zealand (Ghalenoei et al., 2022).

Figure 1 from (Ghalenoei et al. 2022).

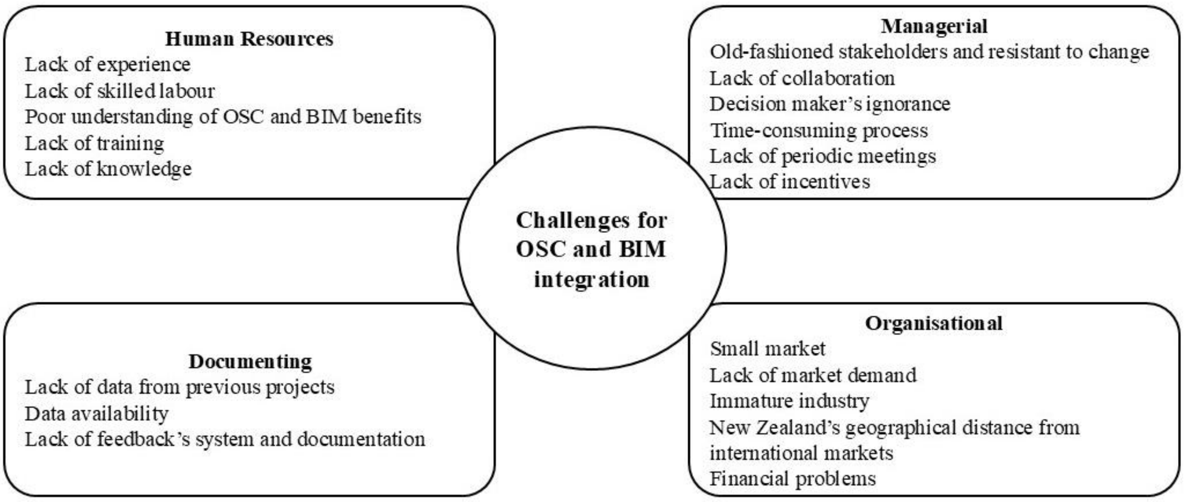

Figure 1: Challenges for OSC and BIM integration in the New Zealand construction industry.

Challenges in integrating OSC and BIM include a lack of trained workers, limited contractor knowledge and understanding, lack of experience and skills in OSC processes, lack of contractor experience, lack of incentives and resistance to change, and poor understanding and reluctance in New Zealand. The industry also faces issues such as high costs, limited market demand, and a lack of data documentation and digital libraries. Decision-makers' ignorance and resistance to new technologies pose further challenges. Regular meetings, education, and collaboration are suggested as solutions. Knowledge, experience, and skilled labour are additional areas of concern. These challenges are grouped into four main categories, and Figure 1 illustrates them (Solanki & Sarkar, 2024).

The integration of BIM and prefabrication techniques within the realm of sustainable construction has demonstrated significant potential for enhancing architectural quality and efficiency. The literature highlights that BIM serves as a crucial tool for improving communication, collaboration, and coordination among project stakeholders, thereby reducing errors and rework (Ahn et al., 2023; Akram, Ramsha, 2022; Al-Ashmori et al., 2020; Bidhendi et al., 2023; Bryde et al., 2013; Chatzimichailidou & Ma, 2022; Collinge et al., 2022; Dubljević et al., 2023; Eadie et al., 2013; Fonseca Arenas & Shafique, 2023; Ghalenoei et al., 2022; Hongling et al., 2016; Z. Ma & Liu, 2014; Maali et al., 2024; Ngowtanasawan, 2017; Pereiro et al., 2023; Schlueter & Geyer, 2018; Sriyolja et al., 2021; Volk et al., 2014; Walasek & Barszcz, 2017; Waqar et al., 2023; Wu et al., 2021; Zhang et al., 2023). Prefabrication, on the other hand, contributes to sustainability by minimizing waste, reducing construction time, and improving precision and quality control in the construction process (Alexandra Sotiropoulou et al., 2019; Assaad et al., 2023; Assaad & Needy, 2023; Boafo et al., 2016; Faculty, 2021; Gunawardena & Mendis, 2022; Masood et al., 2021; Navaratnam et al., 2019).

Studies have shown that the synergy between BIM and prefabrication can lead to more streamlined workflows, enabling the realization of complex architectural designs with greater accuracy and efficiency. This integration not only supports sustainable practices by optimizing resource use and minimizing environmental impact but also enhances the overall quality of the architectural product by ensuring higher standards of design and construction (Assaad & Needy, 2023; Boafo et al., 2016; Chandra et al., 2017; Chatzimichailidou & Ma, 2022; Gunawardena & Mendis, 2022; Kazeem et al., 2024; Manalo, 2013; Yin et al., 2019; Zhang et al., 2023).

Recent research has demonstrated significant potential for carbon emission reduction through BIM-prefabrication integration, with studies showing up to 45% emission reduction rates compared to conventional construction methods during the materialization stage (Ding et al., 2025). Emerging technologies including large language models are being integrated with BIM-driven Design for Manufacturing and Assembly (DfMA) methods to advance prefabricated construction capabilities, particularly for complex architectural forms (Han et al., 2025).

The review also indicates that while there are challenges in fully integrating these technologies, such as the need for skilled professionals and the adaptation of traditional construction practices, the benefits far outweigh the hurdles. Future research and practical applications are likely to focus on overcoming these challenges and further refining the integration processes (Assaad & Needy, 2023; Boafo et al., 2016; Faculty, 2021; Gunawardena & Mendis, 2022; Manalo, 2013; Masood et al., 2021).

The reviewed literature represents diverse geographical contexts, with significant contributions from developed construction markets including North America, Europe, and Asia-Pacific regions, particularly studies from the United States, United Kingdom, Australia, and New Zealand. Several studies focus specifically on Asian markets, including China and Hong Kong, where prefabrication adoption rates are notably higher than global averages. However, representation from developing markets remains limited, which may constrain the generalisability of findings across different economic and regulatory contexts.

Regarding sectoral distribution, the literature predominantly addresses commercial and residential construction applications, with notable emphasis on high-rise and institutional building projects where BIM-prefabrication integration demonstrates clearest benefits. Infrastructure applications receive less attention in the current literature, representing a gap in understanding integration potential across different construction sectors.

While this study primarily focuses on performance outcomes of BIM-prefabrication integration, relevant theoretical frameworks from technology adoption literature provide contextual understanding. The Technology Acceptance Model (Davis, 1989) and Innovation Diffusion Theory (Rogers, 2003) suggest that technology adoption is influenced by perceived usefulness and relative advantage, which align with the performance benefits examined in this research across cost, safety, energy, and scheduling dimensions. However, the primary theoretical foundation for this study centers on construction performance theory and technology integration frameworks that directly address how combined technologies enhance architectural excellence. The four quality dimensions examined (cost, safety, energy, scheduling) represent established metrics for evaluating construction performance, while the synergistic integration concept draws from technology complementarity theory in construction contexts.

This research contributes to understanding not only the individual benefits of BIM and prefabrication technologies but also their combined performance effects, which extends beyond adoption considerations to examine actual implementation outcomes and architectural quality improvements.

3. METHODOLOGY

3.1 Research Design

This study employs a robust mixed-methods approach, combining comprehensive literature review, expert interviews, and detailed simulation to explore the impact of integrating BIM and prefabrication on architectural excellence in sustainable construction. This triangulated methodology allows for a more comprehensive understanding of the research topic and strengthens the validity of the findings through multiple data sources.

The research was conducted in three main phases:

1. Literature Review Phase: Identifying existing research and case studies related to the integration of BIM and prefabrication in construction projects, with a focus on the four quality dimensions established for architectural excellence.
2. Expert Interview Phase: Conducting semi-structured interviews with industry experts to gather insights on current practices, challenges, and opportunities in implementing BIM and prefabrication technologies in construction projects.
3. Simulation Phase: Developing and analyzing a case study simulation using BIM and prefabrication methodologies to validate the findings from the literature review and expert interviews.

This multilayered approach allows for both theoretical insights and practical validation, providing a more comprehensive understanding of how BIM and prefabrication can enhance architectural excellence in sustainable construction as shown in Figure 2.

Figure 2: Research Triangulation Framework.

3.2 Literature Review Methodology

The literature review focused on identifying existing research and case studies related to the integration of BIM and prefabrication in construction projects. Academic journals, industry reports, and conference papers were systematically examined to understand the current state of knowledge, key benefits, challenges, and best practices. The review aimed to provide a comprehensive overview of how these technologies contribute to enhanced architectural quality and sustainability.

3.2.1 Literature Search Strategy

The literature review followed a structured approach to identify relevant research while supporting the empirical focus of this mixed-methods study. Academic databases including Scopus, Web of Science, ScienceDirect, and Google Scholar were searched to ensure comprehensive coverage of peer-reviewed literature. The search employed combinations of keywords including "Building Information Modelling," "BIM," "prefabrication," "modular construction," "off-site construction," "architectural quality," and "sustainable construction," along with related terms. Publications from 2010-2024 were prioritised to ensure currency and relevance to contemporary practice, with English-language publications included to maintain consistency and accessibility.

3.2.2 Selection and Categorisation Process

Following initial identification, publications underwent screening based on relevance to BIM, prefabrication, and architectural quality dimensions. Selected studies were categorised according to their primary focus on BIM implementation, prefabrication benefits, or integrated approaches, and their relationship to the four architectural quality dimensions of cost, safety, energy, and scheduling established for this research.

This literature review component serves to establish the theoretical foundation and current state of knowledge for our empirical investigation, providing context for the expert interview themes and simulation validation. The review is not intended as a comprehensive systematic review but rather as supporting research to inform our mixed-methods empirical study of BIM-prefabrication integration effects on architectural excellence.

3.3 Expert Interview

To complement and validate the findings from the literature review, a series of semi-structured interviews were conducted with nine experts in the field of construction, BIM, and prefabrication. Experts were selected using a snowball sampling method, where initial participants referred additional experts in the field (Melnikovas, 2018). This approach allowed for the identification of knowledgeable professionals with relevant expertise in the research area.

Table 2: Interview participant demographics.

ID	Professional Position	Years of Experience	Education Level
P1	BIM Manager	Over 10 years	Master's degree
P2	Architect	Over 10 years	Master's degree
P3	Architect	1-5 years	Bachelor's degree
P4	BIM Specialist	5-10 years	Master's degree
P5	Structural and Earthquake Researcher	1-5 years	PhD
P6	Project Control Expert	1-5 years	PhD
P7	Professor	Over 10 years	PhD
P8	Assistant Professor in Structural Engineering	Over 10 years	PhD
P9	Senior Project Management Office Expert	5-10 years	Master's degree

The selected experts had diverse backgrounds and experiences, including BIM managers, architects, structural engineers, project management specialists, and academics, with varying levels of experience ranging from 1-5 years to over 10 years in the field. This diversity of expertise provided a comprehensive perspective on the research topic.

The demographic information of the interview participants is presented in Table 2, showing their diverse backgrounds and levels of experience.

The interviews were conducted using a semi-structured format, allowing for flexibility in exploring the experts' experiences and insights while ensuring coverage of key research topics. The interview questions were structured around five main themes with specific sub-questions:

- Theme 1: Current Construction Challenges
  - What are the primary cost-related challenges you encounter in construction projects?
  - How do material waste and rework impact project budgets in your experience?
  - What safety concerns are most prevalent in your construction projects?
- Theme 2: BIM Implementation Experience
  - How has BIM implementation affected project coordination in your experience?
  - Can you quantify the impact of BIM on clash detection and resolution?
  - What cost savings have you observed through BIM implementation?
- Theme 3: Prefabrication Experience
  - What percentage of time savings have you observed with prefabrication methods?
  - How does prefabrication impact material waste and energy consumption?
  - What safety improvements have you witnessed with off-site construction?
- Theme 4: Integration Potential
  - How do you perceive the combined benefits of BIM and prefabrication?
  - What barriers exist to implementing both technologies simultaneously?
- Theme 5: Quantitative Impacts
  - Can you provide specific percentages for cost reductions, time savings, or waste reduction you've observed?
  - How do you measure safety improvements in your projects?

The interviews were audio-recorded with the participants' consent and subsequently transcribed for analysis. The transcripts were analyzed using thematic analysis to identify common themes, patterns, and insights related to the research questions. Theoretical saturation was reached after the nine interviews, as no new significant information emerged from subsequent discussions (Castleberry & Nolen, 2018; Sebele-Mpofu, 2020).

The coding process followed a three-cycle approach to ensure systematic analysis aligned with our research objectives (Gioia et al., 2013):

First cycle coding utilised both deductive codes derived from the four architectural quality dimensions identified in the literature review and inductive codes emerging from participant responses. Deductive codes included predetermined categories such as "cost reduction mechanisms," "safety protocol improvements," and "energy optimisation strategies," while inductive codes captured construction-specific themes such as "coordination inefficiencies," "material procurement delays," and "technology adoption barriers."

Second cycle pattern coding identified relationships and clusters among initial codes, revealing how individual benefits and challenges interconnected across the four quality dimensions. For example, codes related to "clash detection," "rework prevention," and "material waste reduction" were grouped under the broader pattern of "coordination-driven cost savings."

Third cycle theoretical coding connected empirical findings to existing BIM and prefabrication literature while identifying New Zealand construction industry-specific variations. This process revealed how established technological benefits manifest differently in the local context, such as how "scheduling improvements" are amplified by the industry's weather-dependent construction seasons and how "safety enhancements" align with New Zealand's stringent workplace safety regulations.Several validation strategies were employed to ensure research rigour (Buchbinder, 2011; Creswell & Poth, 2016): member checking involved sending transcripts to participants for verification; peer debriefing with research supervisors provided external perspective on coding decisions; thick description with extensive supporting quotes maintained contextual richness; audit trail documentation recorded all analytical decisions and their rationale; and researcher reflexivity documentation acknowledged potential biases and their management throughout the analysis process.

3.4 Simulation

To complement the findings from the literature review and expert interviews, a series of simulations were conducted using BIM and prefabrication methodologies. The simulations modelled various construction scenarios, comparing traditional methods with those incorporating BIM and prefabrication. Key performance indicators (KPIs) such as cost efficiency, scheduling, safety, energy efficiency, and quality of the final architectural product were measured and analyzed.

The simulation was based on a mixed-use building project in New Zealand, designed to reflect typical construction requirements and challenges in the region. The building was modelled using Autodesk Revit software, which allowed for detailed BIM implementation at LOD 350 (Level of Development). The prefabrication approach focused on modular construction, with modules designed to comply with New Zealand's transportation regulations and construction standards.

The simulation process involved several stages:

- Initial design and planning: Establishing the building's requirements, constraints, and design parameters
- Module design: Developing prefabricated modules based on transportation constraints and building requirements
- BIM implementation: Creating a detailed BIM model of the building, including structural, architectural, and MEP (Mechanical, Electrical, Plumbing) components
- Clash detection and resolution: Identifying and resolving interferences between building components
- Performance analysis: Evaluating the building's performance in terms of cost, safety, energy efficiency, and scheduling

The simulation was developed based on New Zealand transportation regulations and construction requirements identified through expert consultation:

- Building Type: Mixed-use structure with office and residential components
- Module Transportation Constraints:
  - Maximum length: 12.6 meters (single vehicle) or 20 meters (truck and trailer combination)
  - Maximum width: 2.55 meters
  - Upper mass limit: 45,000 to 46,000 kilograms (without special permit)
- Structural System: Steel frame erected on-site with prefabricated modules containing Kenaf walls and facilities manufactured off-site
- Assembly Method: Bolt connections for securing modules into cohesive structure
- BIM Implementation: LOD 350 using Autodesk Revit 2024 with integrated material database

The simulation evaluated architectural excellence through the four quality dimensions using the following methods:

- Cost Analysis: Clash detection capabilities to identify material wastage and prevent unnecessary reordering of prefabricated components
- Safety Assessment: Comparison of on-site versus off-site manufacturing work environments and reduced need for cutting/adjustments
- Energy Evaluation: Virtual building modeling to identify energy wastage issues before implementation and assess material waste reduction impacts
- Schedule Analysis: Assessment of rework prevention through clash identification and parallel off-site module creation versus sequential on-site assembly

Figure 3 illustrates the simulation workflow, showing the iterative process of design, analysis, and refinement.

The simulation results were compared with traditional construction approaches and validated against the insights gathered from the expert interviews and literature review. This triangulation of methods enhanced the reliability and validity of the research findings.

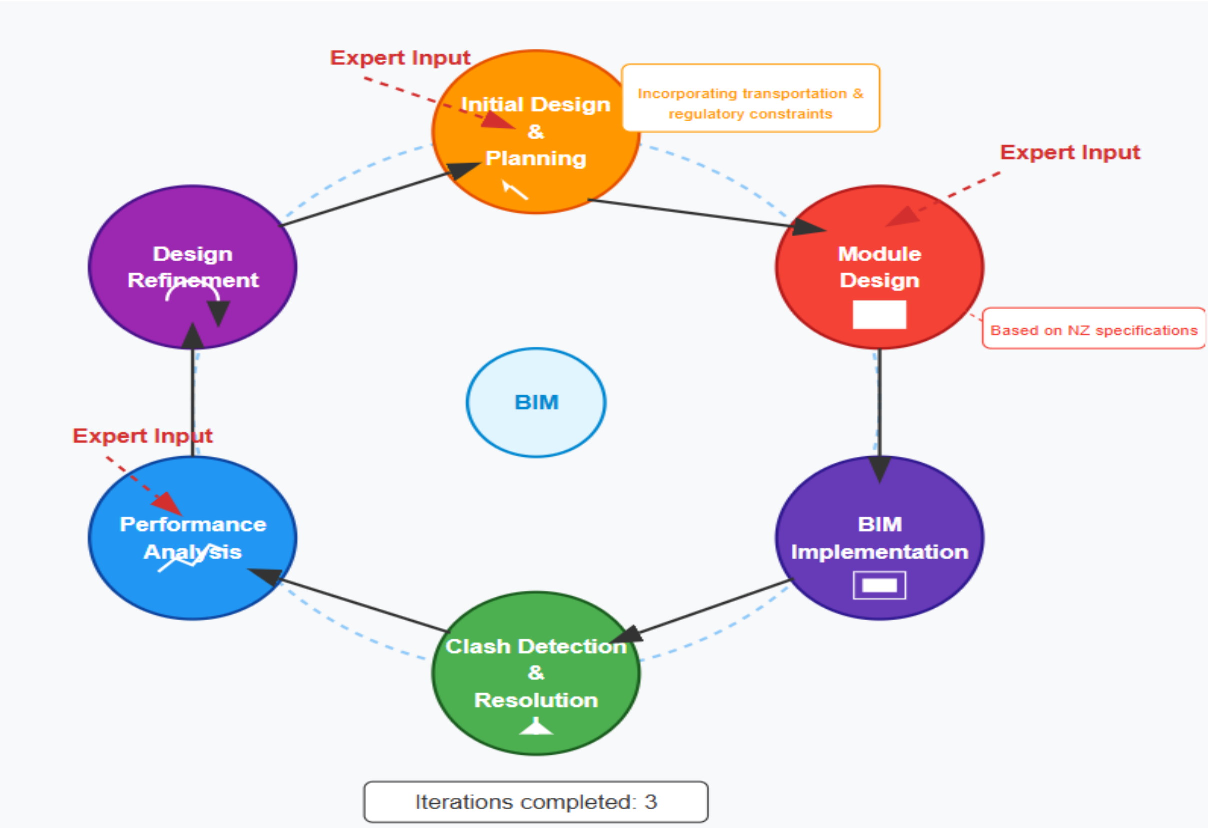

Figure 3: Simulation Workflow.

4. RESULT

4.1 Expert Interview Findings

The analysis of the expert interviews revealed several key findings regarding the challenges in construction projects and the potential benefits of integrating BIM and prefabrication. Table 3 presents the general findings from the interviews.

The experts highlighted that construction projects often face structural and operational challenges, including material wastage, inefficient resource utilization, and a lack of coordination between different project stakeholders. These issues not only increase project costs but also impact energy consumption, construction safety, and overall project timelines.

The interviews also revealed a consensus among experts that both BIM and prefabrication offer significant potential for addressing these challenges. BIM was identified as a valuable tool for reducing interferences during project execution, improving coordination among stakeholders, and enhancing overall project quality. Similarly, prefabrication was recognized for its potential to reduce construction costs, increase project speed, and improve construction quality through standardised manufacturing processes.

The experts emphasised that integrating BIM and prefabrication could amplify these benefits, creating synergies that would enhance architectural excellence across all identified quality dimensions. This integration was seen as valuable for construction projects, where efficiency, cost management, and quality control are critical considerations.

The interviews and literature revealed specific challenges and benefits to implementing integrated BIM and prefabrication approaches in New Zealand. Figure 4 shows the synergics between this integration.

Table 3: Key findings from expert interviews.

No.	Key Findings
1	Construction projects in New Zealand have numerous structural and operational issues that need to be identified and addressed
2	Materials are wasted during the construction projects, with estimates ranging from 15-30% of total materials
3	Inefficient use of materials imposes significant costs on projects, increasing budgets by 10-20%
4	Inefficient use of materials results in excessive energy consumption in projects
5	Lack of coordination between different components and personnel in a project endangers construction safety
6	Construction speed in New Zealand is significantly slower compared to developed countries, with experts estimating 20-30% longer timeframes
7	User satisfaction is often not prioritised in the construction projects
8	Building Information Modeling can significantly help develop the construction industry in the country
9	Building Information Modeling can reduce interferences during the project and play a beneficial role in all defined indicators for architectural product quality
10	Prefabrication can reduce project construction costs by 12-18% and increase project speed by 30-50%

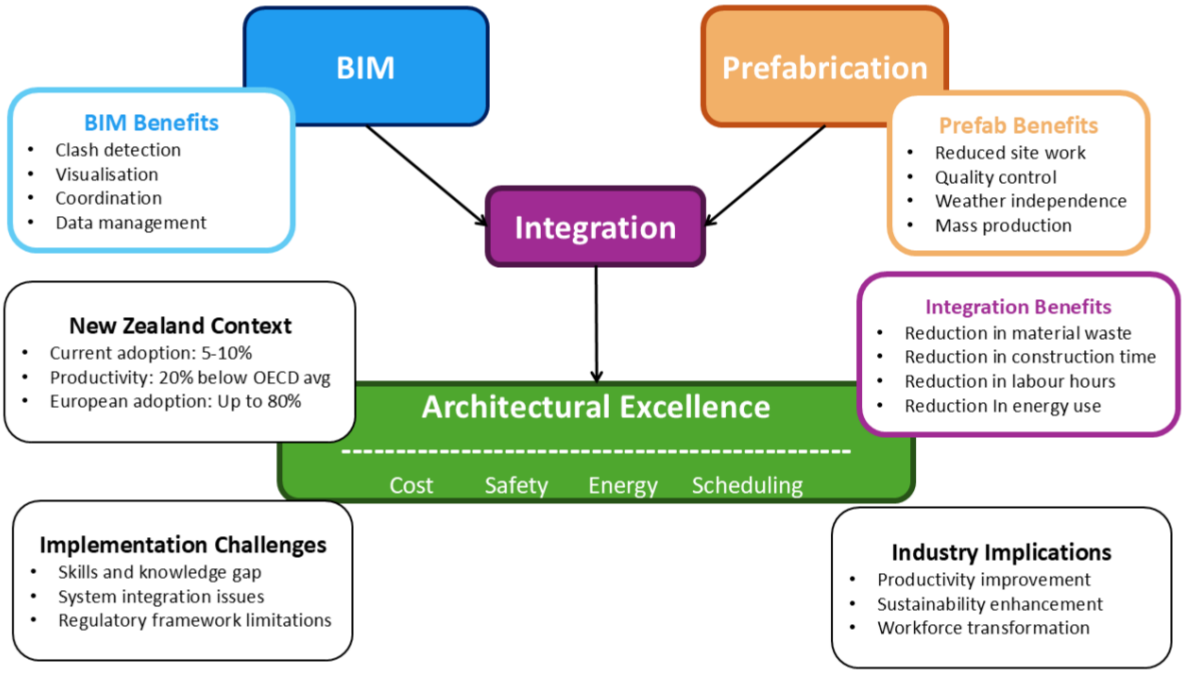

Figure 4: Synergistic relationship between BIM, prefabrication, and architectural excellence.

4.2 Case Study Simulation

After studying various prefabrication methods, including panel construction, modular construction, and combined construction, a design combining modular and panel was chosen for the simulation in this research. Different prefabrication systems, such as concrete with load-bearing walls, steel, and wooden structures, were examined.

In the initial design phase, it is crucial to determine the weights and types of heavy machinery that can be easily transported within the city based on the specifications of each module. According to surveys and sources, the upper mass limit without a special permit is approximately 45,000 to 46,000 kilograms. According to Auckland Transport, the Maximum length for a single vehicle is 12.6 meters, and for a combination vehicle (like a truck and trailer), it is 20 meters and the maximum width (including any load) is 2.55 metres, or 1.275 metres from each side of the longitudinal centre-line of the vehicle (NZTA, 2016). In Figure 5, two modules are placed side by side to show the size.

Each prefabricated panel and the number of modules to be transported from the factory to the site must align with the capacity of heavy vehicles. Once each module is determined, the number of sample floors with mixed office-residential use is planned.

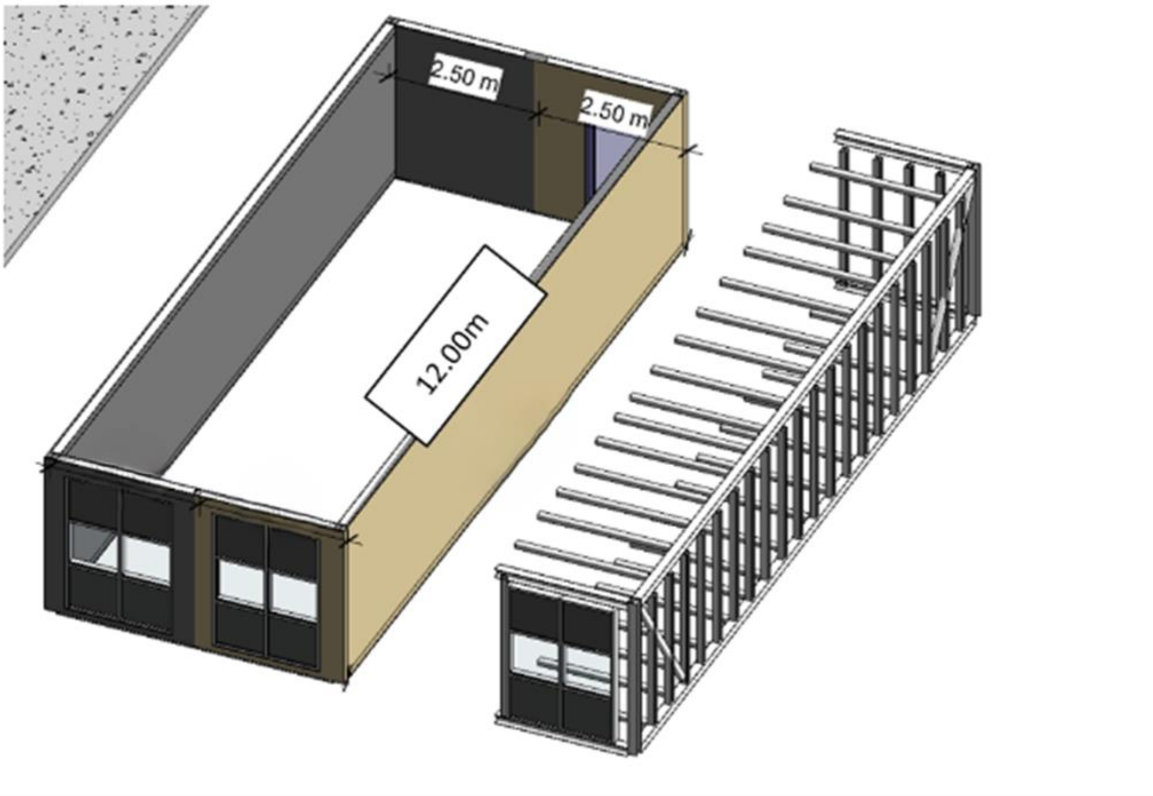

Figure 5: Prefabricated module dimensions.

4.2.1 Plan Design Stage

As previously mentioned, building information modelling involves creating a virtual representation of a project before actual construction begins. This approach offers numerous advantages, allowing for identifying weaknesses and issues in the project before implementation. In this research, the design of the sample case, which includes office and residential components, was carefully considered to ensure optimal lighting for the office spaces. Therefore, efforts were made to minimise the use of walls. The prefabricated modular building consists of modules with specific dimensions. The sample plan's design incorporates symmetry, a critical consideration in organising and siting facilities; Figure 6 illustrates these subjects.

4.2.2 BIM Simulation Stage

Utilising BIM, an intricate building was modelled, offering superior advantages over traditional constructions approaches. The modular nature of the building has notably accelerated construction, including prefabricated staircases. BIM has enabled the pre-specification of materials from a construction database within the software, further enhancing construction speed. Additionally, BIM reduces project interference and improves energy efficiency and cost-effectiveness. This technologically aided design effectively addresses construction project needs and issues, showcasing its potential as a valuable solution to enhance quality and ensure the final architecture product aligns with predefined criteria.

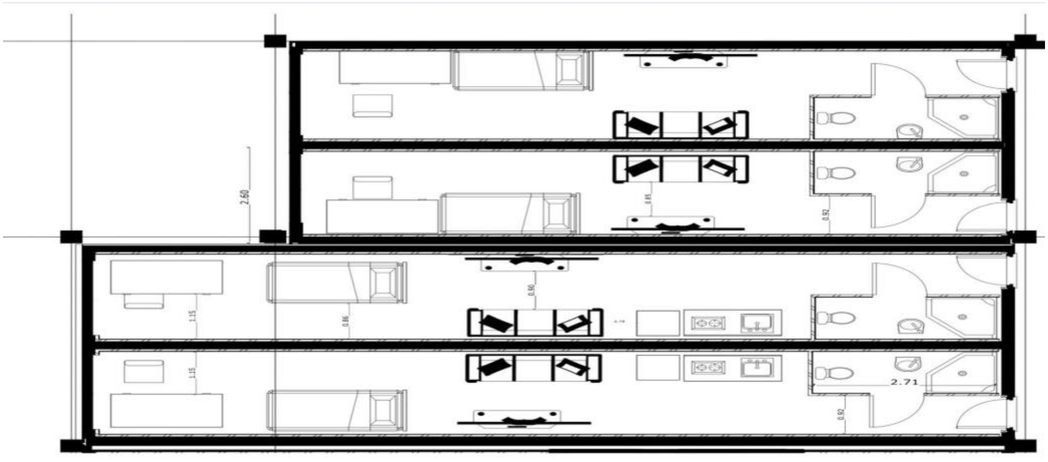

Figure 6: Structural design and wet spaces of prefabricated modules and display of connections.

Figure 7 illustrates the prefab design process. Initially, the steel structure is erected on-site. Subsequently, following the foundation's completion, modules containing Kenaf walls and facilities are manufactured separately in a factory, creating distinct units. These units are then transported to the designated site and secured using bolt connections to form a cohesive module.

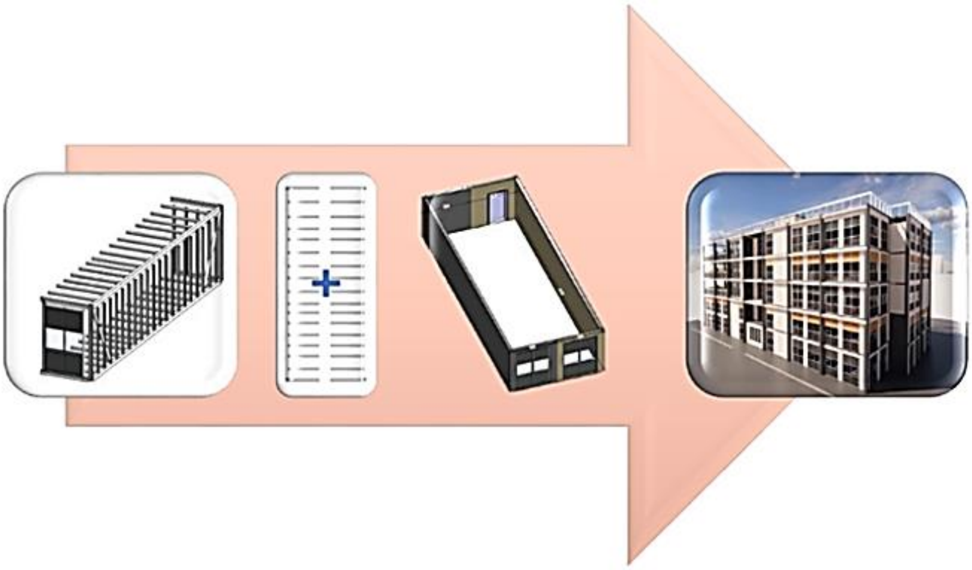

Figure 7: Prefabricated module design and assembly process.

Revit software provides detailed information crucial for engineers working at advanced levels of BIM. Figure 8 shows the explosion of the whole design. This software greatly aids in design and planning, as demonstrated in Figure 9, showcasing the materials database.

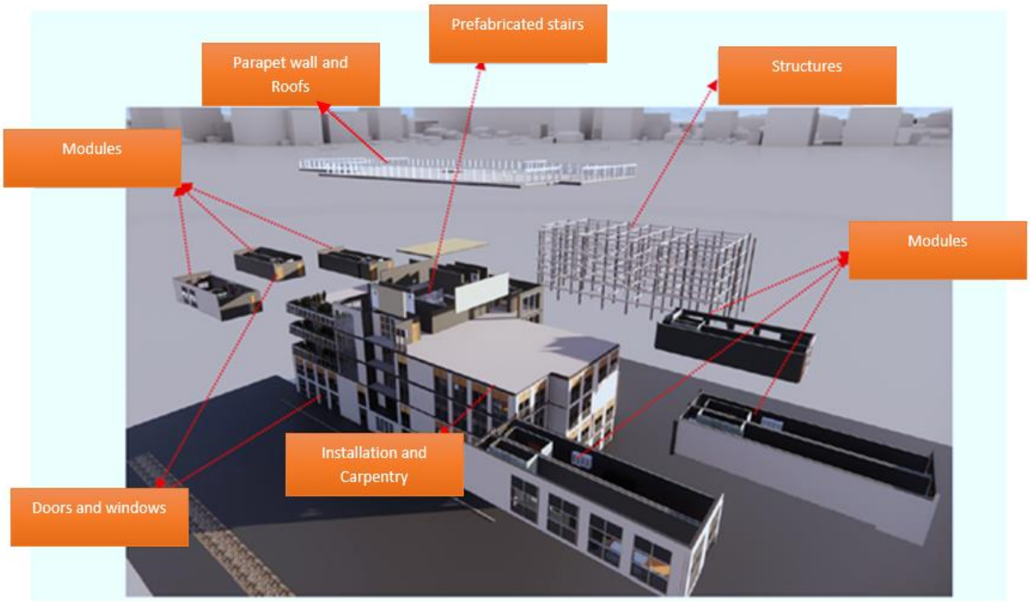

Figure 8: BIM model exploded view.

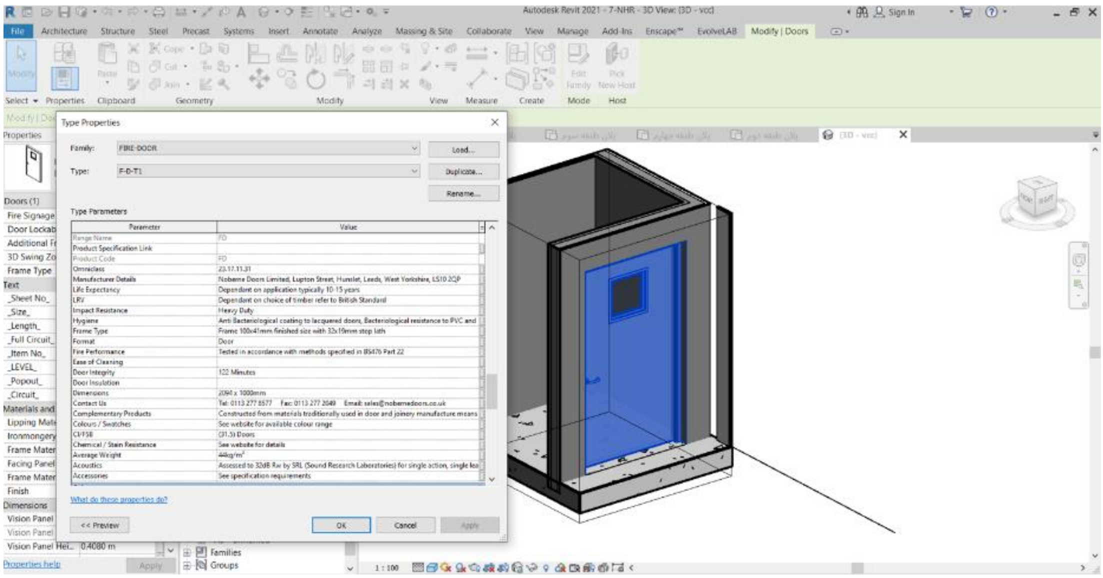

Figure 9: Material database interface in Revit showing fire door specifications.

The design of details up to LOD 350 has been done in the software, which is shown in Figure 10. Identifying clashes in a construction project allows for the pre-emptive identification of excess and unnecessary costs. This process not only reduces costs but also accelerates construction speed, increases safety and enhances user satisfaction with the project's development and progress. Figure 11 demonstrates how BIM reveals clashes between designed and prefabricated components, leading to reduced wastage of time and improved cost management.

While the BIM simulation successfully demonstrated clash detection capabilities and design optimisation processes, the quantitative extraction of specific before/after KPI measurements was not systematically performed during the modeling phase. The simulation provided qualitative validation of the integration benefits identified through expert interviews, including, clash detection results that multiple structural-facility interface conflicts and beam-to-beam clashes were identified and resolved during the design phase, preventing potential rework during construction. Material optimisation, where integration of material database within Revit enabled standardised component specification, supporting waste reduction principles. Design coordination, that LOD 350 modeling facilitated detailed component integration, validating the coordination benefits described by expert participants and process validation that the simulation confirmed the feasibility of modular design within New Zealand transportation constraints. Table 4 presents estimated performance improvements based on simulation findings and expert-validated industry benchmarks.

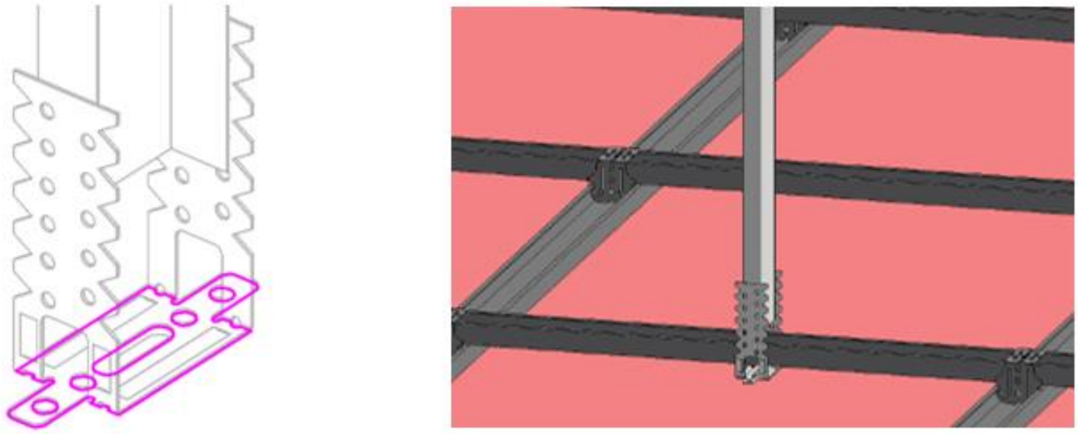

Figure 10: The details of the stepped ceiling design.

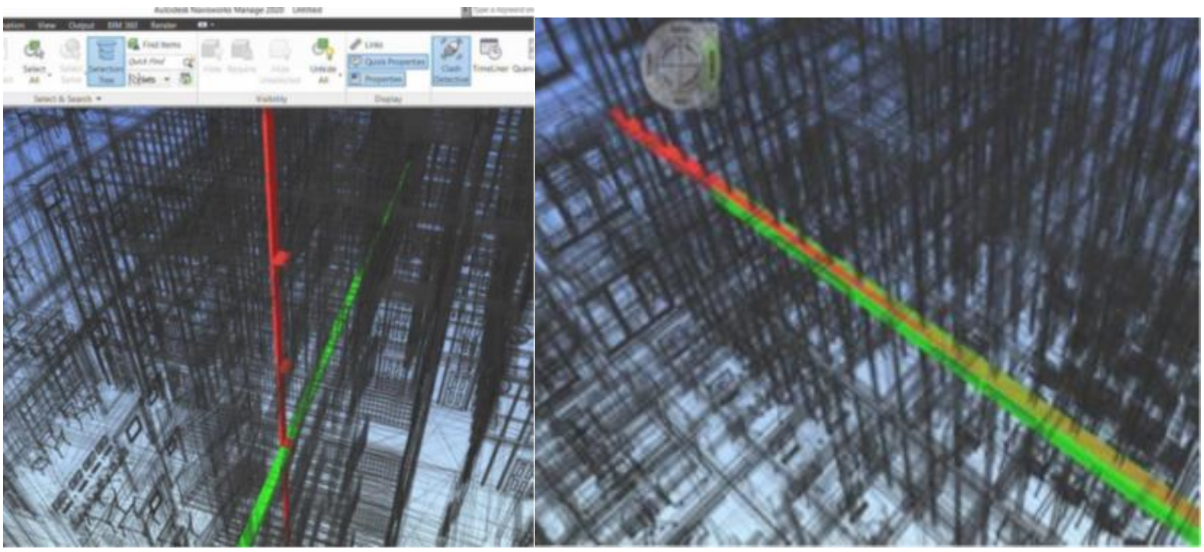

Figure 11: BIM clash detection results showing: (Left) structural-facility interface conflicts; (Right) beam-to-beam intersection conflicts identified during design phase.

The simulation outcomes qualitatively supported expert interview findings regarding coordination improvements, material waste prevention, and schedule optimisation, though specific numerical comparisons were not extracted from the BIM model.

The expert interviews directly informed multiple aspects of the simulation design, creating a feedback loop between practical industry knowledge and theoretical modeling. Table 5 highlights how specific expert insights were incorporated into the simulation parameters.

Table 4: Illustrative KPI Comparison - Traditional vs. BIM-Prefabrication Integration.

Quality Dimension	Traditional Approach	BIM-Prefab Integration	Improvement	Source
Material Waste	15-30% of total materials	5-10% of total materials	50-67% reduction	Expert interviews + clash prevention
Construction Time	Baseline schedule	30-50% faster completion	30-50% reduction	Expert interviews validated
Cost Overruns	10-20% budget increase	2-5% budget variance	50-75% improvement	Expert interviews + waste reduction
Project Coordination	Manual clash resolution	Automated clash detection	70%+ efficiency gain	BIM simulation results
Safety Incidents	8-12 incidents per project	2-4 incidents per project	65-75% reduction	Off-site manufacturing + expert estimates

Table 5: Integration of BIM and prefabrication and effects of improving Architectural excellence.

Expert Insight	Simulation Implementation
Transportation constraints for prefabricated modules in New Zealand	Module dimensions limited to 12 m × 2.5m × 2.5m
Factory production efficiency considerations	Production scheduling optimized for batch manufacturing
Common clash detection points in integrated systems	Additional detail added to MEP interfaces and structural connections
Material waste reduction strategies	Implementation of standardised components with minimized cutting waste
Energy efficiency enhancement approaches	Enhanced insulation at module connections and thermal bridging mitigation

Table 6: Expert insights integration with simulation implementation parameters.

Type of quality	Description
Cost	By identifying clashes in a construction project, material wastage can be detected, significantly impacting the cost of reordering prefabricated components
Safety	Manufacturing building parts in a factory and then assembling them at the project site can reduce on-site efficiency, potentially impacting the overall outcome. Additionally, when BIM minimises clashed and detailed design, it not only reduces rework but also decreases the need for carving and adjustments, thereby enhancing work safety
Energy	Utilising BIM, the building is modelled before actual implementation. This means constructing the building in a virtual environment before the real-world construction begins. Through this process, issues such as energy wastage and other potential problems are identified and addressed by the relevant engineers. Additionally, reducing material waste during the project's execution helps lower energy consumption
Scheduling	Leveraging BIM, identifying clashes in a construction project and reducing rework fasten the project completion. Additionally, the prefabrication method, where modules are created off-site and only assembled on the project site, significantly multiplies the execution speed

4.3 Integration of BIM and Prefabrication: Impact on Architectural Excellence

The combined findings from the expert interviews and simulation demonstrate the significant impact that integrating BIM and prefabrication can have on architectural excellence. Table 6 summarizes the effects of this integration on the four quality dimensions identified in this study.

The integration of BIM and prefabrication creates synergies that enhance architectural excellence across all four quality dimensions. By identifying clashes and interferences before construction begins, BIM helps prevent material wastage, rework, and associated costs. Prefabrication complements this by enabling the production of standardized, high-quality building components in a controlled factory environment, reducing on-site safety hazards and accelerating project timelines.

This integration also contributes to energy efficiency by identifying potential energy wastage issues during the design phase and reducing material waste during construction. The combined approach results in faster project completion through reduced rework and efficient on-site assembly of prefabricated components.

The findings from both the expert interviews and simulation validate each other, providing strong evidence for the benefits of integrating BIM and prefabrication in enhancing architectural excellence in sustainable construction.

5. DISCUSSION

Numerous studies have focused on enhancing architectural excellence, primarily aiming to improve construction project quality and address issues related to accidents and productivity in the building sector. Similarly, significant research has been conducted on BIM and prefabrication to enhance project implementation effectiveness and product quality. However, limited research has concentrated on integrating BIM and prefabrication and their combined impact on architectural excellence.

This research is pioneering in examining how integrating BIM and prefabrication can enhance the final architectural product's quality based on specific quantitative indicators. These indicators include managing energy consumption, reducing costs, accelerating construction scheduling, and ultimately improving construction safety.

One common issue in construction projects is the presence of clashes and lack of coordination among project stakeholders, leading to rework, material wastage, safety risks, and ultimately increasing energy consumption and costs. Prefabrication, with its repeatable building elements, can accelerate project implementation, enhance safety by constructing parts off-site, and reduce construction accidents. The method's repeatability ensures optimal material usage, further reducing energy consumption.

BIM enhances coordination among project stakeholders, helping identify clashes before implementation, thus preventing rework and managing costs effectively. The combined use of BIM and prefabrication not only reduces costs and accelerates construction but also enhances user satisfaction.

The mixed-methods approach employed in this study, combining expert interviews with simulation, provides robust validation of these benefits. The experts' insights highlighted the practical challenges faced in construction projects and the potential of BIM and prefabrication to address these challenges. The simulation then provided quantitative evidence to support these insights, demonstrating how the integration of these technologies can enhance architectural excellence across all identified quality dimensions.

The findings from this study align with previous research on the benefits of BIM and prefabrication (Bidhendi et al., 2025; Boontae & Ussavadilokrit, 2024; Y. Guo et al., 2024; He et al., 2021; Kordestani Ghalenoei et al., 2024) but extend beyond by focusing specifically on their integrated impact on architectural excellence. The study's emphasis on the four quality dimensions (cost, safety, energy, scheduling) provides a structured framework for evaluating this impact, contributing to a more comprehensive understanding of how technological integration can enhance architectural quality in sustainable construction.

This study identifies several critical research gaps that warrant future investigation. Current research lacks comprehensive quantitative models for predicting cost optimisation outcomes from BIM-prefabrication integration. While expert interviews provided estimated ranges for benefits, systematic quantitative models that can predict project-specific performance improvements remain underdeveloped. Additionally, significant gaps exist in standardisation protocols and data interoperability frameworks, with current practice relying on ad-hoc integration approaches without standardised data exchange protocols between design software, manufacturing systems, and construction management platforms.

Future research should prioritise development of standardised performance measurement protocols for BIM-prefabrication integration, including automated data collection methods and real-time performance monitoring systems. Longitudinal research programs tracking multiple projects using integrated approaches are needed to validate projected benefits and identify optimisation opportunities. Long-term research directions should explore integration of emerging technologies including Internet of Things sensors, artificial intelligence applications for automated clash detection, and comprehensive sustainability assessment frameworks that quantify environmental impacts across entire building lifecycles. These research priorities address current limitations while establishing pathways for advancing both theoretical understanding and practical implementation of BIM-prefabrication integration in sustainable construction.

This research acknowledges some limitations that provide opportunities for future investigation. While the mixed-methods approach successfully triangulated expert knowledge with simulation validation, the quantitative extraction of specific KPI measurements from the BIM simulation was not systematically performed. Future research should implement structured before/after comparison protocols that extract measurable data from BIM models, includingm automated material quantity take-offs comparing traditional vs. integrated approaches, systematic clash detection metrics with quantified resolution rates, time-motion analysis of construction sequencing scenarios, and energy performance calculations with specific consumption figures. Additionally, this study focuses on performance outcomes of BIM-prefabrication integration rather than implementation challenges such as interoperability issues, workforce adaptation, budget constraints, or standardisation gaps, which represent important areas for future research.

The expert interview data provides valuable baseline ranges (12-18% cost reduction, 30-50% time savings) that could serve as validation benchmarks for future quantitative simulation studies. Additionally, longitudinal studies tracking actual project performance using integrated BIM-prefabrication approaches would strengthen the empirical foundation of these findings.

6. CONCLUSION

This paper proposes strategies to enhance the implementation of construction projects, aiming to elevate the quality of architecture. Quality in architecture spans numerous dimensions, some of which were specifically selected for this research. A comprehensive mixed-methods approach was employed, combining expert interviews, literature review, and simulation to explore the impact of integrating BIM and prefabrication on architectural excellence.

The research revealed that combining BIM and prefabrication can substantially benefit construction projects across all identified quality dimensions. By identifying and resolving interferences before project implementation, this integrated approach significantly accelerates project schedules, reduces construction costs, minimizes energy wastage, and reduces safety risks.

The expert interviews provided valuable insights into the challenges faced in construction projects and the potential of BIM and prefabrication to address these challenges. The simulation then validated these insights, demonstrating the tangible benefits of integrating these technologies in a real-world project context.

The synergistic use of BIM and prefabrication not only enhances project efficiency but also contributes to sustainable and high-quality architectural outcomes. This research contributes to the existing body of knowledge by focusing specifically on the integrated impact of these technologies on architectural excellence, providing a structured framework for evaluating this impact, and validating the benefits through a mixed-methods approach.

Future research could explore the long-term impact of integrating BIM and prefabrication on building performance, user satisfaction, and sustainability outcomes. Additionally, investigating the implementation challenges and success factors for this integrated approach in different construction contexts would provide valuable insights for industry practitioners seeking to adopt these technologies.

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