# Enhancing Integration of Offsite Construction and Building Information Modelling; Study of Challenges, Strategies, and Stakeholders in New Zealand Construction Industry

**Nazanin Kordestani**

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*Supervised by:*

Associate Prof. Mostafa Babaeian Jelodar

Dr Daniel Paes

Prof. Monty Sutrsina

Dr Diyako Rahmani

School of Built Environment, College of Science
Massey University
New Zealand

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# Abstract

The development of prefabrication has progressively evolved into more advanced and comprehensive full-scale offsite manufacturing (OSM) processes within the construction industry, suggesting a continuum where prefabrication represents an initial stage and OSM signifies a more integrated and mature stage of industrialised construction practices. Offsite construction (OSC), which involves manufacturing components in controlled environments, has gained popularity for its efficiency and waste reduction benefits. Despite these advantages, the transition to OSC also presents various challenges. Advanced technologies such as Building Information Modelling (BIM) have been suggested as practical tools for mitigating these challenges, facilitating digital construction models, and enhancing the delivery process through a collaborative environment.

The adoption of OSC and BIM is complex, particularly when considering their individual implementation as well as their integration. While each approach presents its own set of challenges, the combined adoption and integration of OSC and BIM introduce additional layers of complexity, requiring alignment across technical, organisational, and strategic dimensions. A structured guideline could assist project stakeholders and organisations in navigating these challenges throughout the project lifecycle. Integration is influenced by the external environment at the project, organisation, and industry levels, and these challenges vary at different points during the project life cycle. Therefore, it is essential to fully map these challenges at different levels and stages to devise and deploy appropriate strategies. Currently, a multi-level integration framework is needed to focus on these challenges and reduce them through strategies involving relevant stakeholders. This study addresses this gap by developing an integration framework with a specific focus on integration challenges and understanding the relationships between challenges and strategies.

The study commenced with a scientometric analysis, a systematic literature review, and semi-structured expert interviews to investigate OSC and BIM integration challenges. Multiple themes were explored, and the triangulation of these methods supports the creation of applicable knowledge in this field. The scientometric analysis identified multiple gaps, research trends, and pioneer countries within the scope of the research. The identification of pioneer countries provided insights into global leadership, best practices, and enabling factors for successful OSC and BIM integration. These countries serve as benchmarks, offering transferable lessons and contextual understanding that informed the study's aim of addressing integration challenges and developing a strategic framework applicable to the New Zealand construction industry. The findings revealed a classified cluster of 35 challenges for OSC and BIM implementation and 21 integration strategies. The interviews provided comprehensive and complementary data sets and analyses, and the findings from the systematic literature review and interviews structured the integration framework.

Following this, a survey questionnaire was administered to measure the identified challenges and explore strategies through various methods, including Factor Analysis, resulting in eight groups of significant underlying factors affecting OSC and BIM integration. Recommendations to enhance integration were provided, identifying underlying variables such as implementation costs, integrated knowledge deficit, competency and preparedness deficit, integration facilitators, external support and policy regulation, BIM-driven OSC readiness, BIM-enabled collaboration and facilitation, and BIM-enabled OSC enhancement. This step was followed by Structural Equation Modelling (SEM), which employed three different path analysis models for integration variables, clarifying that not all variables have similar impacts on integration; some exhibit significant positive or negative effects, while others are not significant at all.

A questionnaire survey was then utilised to examine the challenges specific to various organisational levels and project lifecycle phases. Four independent case studies were used to develop and validate the survey findings, demonstrating the five levels of OSC and BIM integration maturity in the construction industry: initiate, managed, defined, quantitatively managed, and optimized. The findings demonstrated that the same set of challenges could occur during multiple project phases as well as at different organisational levels. Furthermore, each maturity level has characteristics that influence the strategies applied.

The findings highlight that challenges vary across the project lifecycle and different maturity levels. Nevertheless, continuous collaboration among stakeholders is essential to mitigate these challenges. From lower to higher levels of OSC and BIM integration maturity, the nature of challenges evolves from basic understanding and knowledge acquisition to the development of standards and guidelines. This framework aims to enhance the integration process by identifying challenges related to maturity levels and the project lifecycle, ultimately increasing the efficiency and effectiveness of OSC and BIM integration practice. By offering a comprehensive framework to address these challenges, the outcome of this research equips project stakeholders with a robust tool to navigate complexities and maximise the benefits of integration throughout the project lifecycle. Moreover, the emphasize on stakeholder collaboration highlights the importance of collective efforts in overcoming integration hurdles, ultimately contributing to the advancement and success of construction projects.

The aim of the framework is to enhance the integration process by identifying challenges related to maturity levels and the project lifecycle, ultimately increasing the efficiency and effectiveness of OSC and BIM integration practice. This integration focuses on aligning OSC methodologies with BIM’s information management capabilities, ensuring optimized workflows, improved collaboration, and streamlined project delivery processes. The study's findings are crucial for understanding and strategically addressing challenges, improving collaboration, and advancing OSC and BIM integration in the construction industry. The study narrowed the gap in understanding the challenges and strategies and empirically explored critical factors to improve integration. Findings confirmed that implementing effective management could potentially help reduce integration challenges.

*To my father, for his endless wisdom and encouragement,*

*To my mother, for her unwavering love and support.*

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## Abbreviations and Acronyms

AEC: Architecture, Engineering, and Construction

AI: Artificial Intelligence

APEDE: Automated Precast Element Design Engine

AR: Augmented Reality

AVE: Average Variance Extracted

BEP: BIM Execution Plans

BIM: Building Information Modelling

CFA: Confirmatory Factor Analysis

CFI: Comparative Fit Index

CH: Challenge

CMIN: Minimum Discrepancy

CMM – Capability Maturity Model

CR: Construct Reliability

CR – Continuous Representation

DF: Degree of Freedom

DFMA: Design for Manufacturing and Assembly

EFA: Exploratory Factor Analysis

GDP: Gross Domestic Product

GIS: Geographical Information Systems

HTMT: HeteroTrait-MonoTrait

INT: Integration

IoT: Internet of Things

ISO: International Organisation for Standardisation

KMO: Kaiser-Meyer-Olkin

LOD: Level of Development

MaxR: Maximum Reliability

MBIE: Ministry of Business, Innovation and Employment

MMs: Maturity Models

MMC: Modern Methods of Construction

OECD: Organisation for Economic Co-operation and Development

OPM3 – Organisational Project Management Maturity Model

OSC: Offsite Construction

OSM: Offsite Manufacturing

PBO – Project-Based Organisations

PClose: Probability of Close fit

PMBOK – Project Management Body of Knowledge

RMSEA: Root Mean Square Error of Approximation

RCT: Randomized Control Trial

RBV – Resource-Based View

SAP: Strategy as Practice

SBP: Smart BIM Platform

SD: Standard Deviation

SEM: Structural Equation Modelling

SLR: Systematic Literature Review

SPOs: Smart PHP Objects

SR – Staged Representation

SRMR: Standard Root Mean Square Residual

ST: Strategy

VR: Virtual Reality

VRIN – Valuable, Rare, Inimitable, Non-substitutable

# Chapter 1: Introduction

The initial section of this thesis introduces the investigation, starting with an overview of construction and the importance of adopting offsite construction (OSC) and Building Information Modelling (BIM). It then elaborates on the background and significance of the research, followed by the problem statement. The research objectives and scope are defined next.

The chapter continues with an overview of the research methodology, which includes the conceptual framework and research framework, ethical considerations, and data collection techniques. Supported by prior empirical studies, this section establishes the context of the thesis and identifies the gap in research, defining the issue and explaining the rationale behind the study for both local and international contexts based on the identified research gap.

Following this, a brief overview of the relationship between research objectives, questions, and individual chapters of the thesis is provided. The chapter also covers aspects such as research design, conceptualisation drawing from existing literature, methodology selection, research strategies, techniques for data collection and analysis, and considerations for validity and reliability. A flowchart depicting the research design is presented, illustrating the systematic progression of the study across each chapter and its alignment with the research objectives.

## 1.1 Overview Of Construction; The Importance of Adopting OSC and BIM

Construction industry is responsible for significant resource consumption, with estimates indicating that 40-50% of global material extraction is used for housing, construction, and infrastructure, leading to increasing socioeconomic and environmental challenges on both local and global scales (Brady, 2021). The construction sector contributes significantly to the GDP (Gross Domestic Product), up to 7% to 10% in highly developed economies and 3% to 6% in underdeveloped economies (Ganesan, 2019). This sector is the biggest consumer of energy (around 40% of energy consumption), water (45-70% of total raw material extractions), and material resources. Moreover, it contributes 35% of the total landfill waste stream and up to 39% of all $CO_2$ emissions to the environment (Aslam et al., 2020).

Historically, the construction industry has been one of the least efficient sectors. Construction projects often face issues like going over budget and running behind schedule. At the same time, there is a growing demand for construction materials to be delivered quicker at cheaper rates, and with better quality. These problems have put the industry in a difficult position, mainly because there is a shortage of skilled workers. This shortage not only drives up labour costs but also slows down work and lowers quality (Ganesan, 2019; Santamouris & Vasilakopoulou, 2021). A limited number of skilled workers means tasks take longer to complete, and less experienced or qualified workers may be employed, potentially compromising the quality of the work (Fu, 2019).

Additionally, several factors contribute to lower productivity in construction. These include industry fragmentation, complex standards and regulations, and insufficient investment in technology or research for efficiency improvements (Bello et al., 2023; Jahanger et al., 2023). Some organisations have set up programmes to encourage good practices or work within the current limitations of the construction industry. Others are trying to completely change and improve the way the sector operates to deal with past problems and pressures (Agapiou, 2022; Assaad et al., 2023). Fortunately, a few construction methods have started to be used more in recent decades, which help reduce common issues like delays and overspending. OSC and fast-track procedures are good examples of these construction methods as they both contribute to the shared objective of reducing construction time and improving efficiency (Razkenari et al., 2020).

Goodier and Gibb  (1999) define OSC as “...the process of manufacturing and preassembly of certain amounts of building components, modules and elements, prior to their shipment and installation on construction sites.” Quale and Smith (2017) add that this process includes “…planning, design, fabrication and assembly of building elements at a location other than their final installed location to support the rapid and efficient construction of a permanent structure.” However, the idea of OSC is not new. Back in 1624, units built in the UK were shipped to the US for construction. Later, in 1790, timber-framed shelters were brought from the UK to Australia because there were not enough local craftsmen available to build them (Ehwi et al., 2022).

The need for efficiency and productivity in construction activities has led to a great deal of effort (e.g., research initiatives, communities of practice, and government-funded forums) to promote OSM adoption in the construction sector (Cai et al., 2023). For example, a study that explored the current and potential future trends of the OSM sector in Australia was supported by the Cooperative Research Council for Construction Innovation (Blismas et al., 2010). More recent findings show significant growth in OSM adoption in New Zealand, driven by the need for faster construction and housing solutions. The Concove dashboard reports that the use of OSM in construction projects has increased from 3% to 9% between 2014 and 2021, with further growth expected (Concove, 2023). The New Zealand government has also supported OSM through the OffsiteNZ roadmap, which outlines strategies to boost adoption, enhance supply chains, and meet sustainability goals (BuiltOffsite, 2023). OSM sector's performance in Hong Kong improved through governmental initiatives and the implementation of technical approaches (Tam et al., 2015).

Nevertheless, the adoption is growing globally, even though practical challenges delay its progress. The low transformation rate of OSC adoption is caused by several challenges, including inadequate knowledge, insufficient regulation, market constraints, a lack of coordination, cultural barriers, lack of tools and skills, and high costs (Hu et al., 2019). Although extensive studies have been conducted to understand how OSC projects are managed and improved, some aspects remain unexplored (Choi et al., 2019; Peiris et al., 2022). According to the literature, adopting advanced technologies could improve OSC productivity. Among these technologies, Building Information Modelling (BIM) has been proven to enhance the productivity and quality of OSC products (An et al., 2020a).

BIM is an innovative technology that is reshaping the construction industry by facilitating the creation and management of digital representations of physical and functional characteristics of buildings and infrastructure. BIM is a digital, three-dimensional, comprehensive, cloud-based database containing all project information shared by all stakeholders. BIM enables collaboration among architects, engineers, contractors, and other stakeholders by providing a shared platform for comprehensive project visualisation and data integration (Eastman et al., 2011; Waqar et al., 2023).

This technology not only improves the accuracy and efficiency of the design and construction processes but also enhances the management and maintenance of buildings throughout their lifecycle. The integration of BIM with OSC methods holds significant promise for addressing conventional construction challenges, such as delays, cost overruns, and waste, by streamlining project workflows and improving resource utilisation (Darko et al., 2020; He et al., 2021). Therefore, combining BIM with OSC has the potential to overcome many of the challenges to OSC adoption, enabling more efficient, cost-effective, and sustainable construction practices (Abanda et al., 2017; Wang et al., 2022).

## 1.2 Background

The construction sector in New Zealand, like many other countries, has a significant impact on economic growth and support for the growing population. However, despite its importance, the sector is witnessing a decline in its margins. The increase in construction costs, including the cost of materials and labour, has caused a significant rise in property prices and poses significant challenges. In response to ongoing population growth and persistent housing shortages, there remains a significant need to enhance the efficiency and speed of construction processes. Recent findings emphasise the role of Modern Methods of Construction (MMC) and OSM in addressing these challenges (OffsiteNZ, 2024).

Low productivity, lack of innovation, insufficient quality, and inability to address construction demands frequently occur in the New Zealand construction industry (PrefabNZ, 2018b). Furthermore, factors such innovation, procurement performance, management capability, skill, and workability have contributed to making New Zealand's construction industry less productive (Mirus et al., 2018a). In this context, one of the best strategies to increase productivity in the sector is using new methods (Ji et al., 2020). One solution that sector-specific research has shown is the utilisation of prefabricated processes and pre-build parts away from the site in controlled conditions (Bell, 2019; PrefabNZ, 2018b).

The term OSC is often used interchangeably with prefabricated construction, "industrialised construction," "modular construction," and "modern methods of construction. However, the meaning of these terms can vary (Jang et al., 2021). In this thesis, the term OSC is used as a broad term encompassing various prefabrication methods, including modular construction and prefabrication-based techniques. For consistency and clarity, OSC will be the primary term employed throughout this document to represent construction practices that involve manufacturing components offsite before assembling them on-site.

For several years, OSC has been an innovative approach to building the built environment. It essentially means manufacturing and assembling whole or substantial parts of construction projects in controlled conditions before installation at their final location. OSC ranges from the prefabrication of small construction items, two-dimensional panels, and three-dimensional volumes to entire buildings (Bell, 2019).

Many studies have claimed the significant advantage of OSC in potentially saving up to 30–50% construction time compared to conventional construction since construction elements or modules could be manufactured in a factory before the on-site activity starts (Kluck & Choi, 2023; Peiris et al., 2022). Moreover, OSC can lower the overall project life cycle cost. Although transportation costs are high with this method, they do not outweigh the total cost savings (Shahzad et al., 2023). Additionally, OSC offers sustainability benefits, such as reduced construction waste and the potential for recycling and reusing building components (Harris & . 2021; Jang et al., 2021).

According to Tookey (2021), the underlying value of the OSC market has increased from 5% to 10% of the overall value of all building consents between 2011 and 2021. OSC, encompassing residential and non-residential, has the potential to be worth $13.18 billion in New Zealand. This represents that the market already exists but is restricted due to various factors, such as a small market and high capital investment (Bell, 2019; Shahzad et al., 2023; Zou et al., 2022). OSC has been widely practised in many countries, providing an effective alternative to conventional site-based construction. Although New Zealand is also one of the pioneers in this field, stakeholders need to understand the current and future demands of OSC to achieve better productivity (Zou et al., 2022).

According to a survey conducted in the Chinese OSC sub-sector, published in 2020, over 90% of construction enterprises consider the lack of advanced technology implementation a significant constraint for OSC development (Cheng & Ma, 2020). Moreover, according to a survey of contractors at a forum on OSC held in the US, 87% of 156 contractors responded that advanced technology is one of the critical enablers for OSC use with greater accuracy and efficiency (Hoover et al., 2017). Several advanced technologies can significantly enhance OSC, including IoT (Internet of Things), AR (Augmented Realty), VR (Virtual Reality), AI (Artificial Intelligence), 3D printing, drones, digital twins and Geographical Information Systems (GIS).

Among these, BIM stands out due to its comprehensive integration capabilities, widespread industry adoption, and ability to facilitate collaboration and lifecycle management across different project stages (Abanda et al., 2017; Li et al., 2018a; Ocheoha & Moselhi, 2018). While digital twins excel in real-time monitoring and predictive maintenance, their application is often more relevant to the operational phase rather than early design and planning integration (Opoku et al., 2021). Similarly, GIS offers exceptional geospatial analysis but lacks the depth required for managing multidisciplinary workflows and detailed design coordination (Anumba et al., 2005). BIM, on the other hand, provides a centralised platform for data exchange, clash detection, and synchronised communication, making it a more suitable technology for addressing the complexities of OSC (Eastman et al., 2011).

BIM serves as a foundational tool that enhances decision-making and optimizes OSC processes. Its integration into OSC is pivotal as it addresses several key challenges commonly encountered in prefabrication-based construction. These challenges include issues related to design coordination, material efficiency, and project scheduling, all of which are critical to the successful implementation of OSC (Li et al., 2019; Piroozfar et al., 2019). BIM plays a central role in managing both the physical dimensions and materials, as well as the functional interactions and performance characteristics of construction projects. In the context of OSC, where components are manufactured offsite before being assembled on-site, BIM's ability to visualise and simulate these processes allows for better coordination among stakeholders, reducing errors and miscommunication (Sabet & Chong, 2019).

The ability of BIM to provide accurate quantity take-offs and material requirements directly benefits OSC by improving material procurement, reducing waste, and ensuring that the right quantities of materials are available at the right time. By automating these tasks, BIM eliminates manual errors, leading to more cost-effective and resource-efficient projects (Zhao et al., 2019). Moreover, BIM's 3D modelling capabilities are especially valuable in prefabrication-based construction. The visualisation of the entire construction process through 3D models facilitates a better understanding of the project, helping stakeholders assess design feasibility and identify potential issues before manufacturing begins. This helps optimize the planning and production phases, ensuring that prefabricated components are manufactured to the correct specifications and are fit for assembly on-site (Sabet & Chong, 2019; Zhao et al., 2019).

In addition to design and material management, BIM supports the lifecycle management of OSC projects. The comprehensive information stored within a BIM model enables effective tracking of components throughout the construction and post-construction phases. This ensures that all project information is readily accessible for future maintenance and operational decisions, supporting long-term sustainability and performance monitoring (Zhong et al., 2017).

The integrated use of BIM and OSC has been recommended to improve the construction industry's performance, offering significant improvements in design coordination, scheduling, and material management (Yin et al., 2019). Successful OSC relies heavily on efficient information exchange between the various actors in the supply chain, and BIM provides a robust platform for managing this exchange. BIM's ability to centralise project data ensures that all stakeholders—ranging from architects and engineers to contractors and manufacturers—have access to consistent, real-time information, improving collaboration and reducing errors (Eastman et al., 2011). Moreover, integrating BIM with OSC processes can promote mass customisation in the construction sector, enabling projects to meet specific client requirements while maintaining the efficiency benefits associated with prefabrication (Li et al., 2019).

By allowing for the digital simulation of the construction process, BIM helps stakeholders visualise and optimize the design, ensuring that prefabricated components are manufactured with the right specifications before being transported to the site. In addition, the improved coordination among construction parties facilitated by BIM in OSC projects has the potential to significantly reduce rework. This reduction in errors results in cost savings, with both materials and labour being reduced (Ortega et al., 2023a). The ability of BIM to bring together the collective knowledge of various stakeholders fosters increased transparency throughout the project lifecycle, which enhances productivity and improves decision-making, further boosting the overall efficiency of OSC projects (Waqar et al., 2023).

Nonetheless, Real-time data exchange and coordinated workflows appear to be the critical components in ensuring that project objectives are not merely met but exceeded optimally (Jang et al., 2022). In response to this demand, BIM facilitates the management of OSC projects by enabling the integration of project information from its early stages. However, the process of integration involves managing relationships among numerous stakeholders, posing challenges that require a clear structure to guide them effectively through the integration process (Likita et al., 2023; McDermott et al., 2023; Phang et al., 2020; Rashidian et al., 2023).

As mentioned earlier, New Zealand's construction landscape faces escalating demands due to population growth and environmental pressures. The integration of OSC and BIM presents a promising path to restructure construction processes and accelerate project timelines, highlighting its potential to enhance industry performance and meet sustainability requirements effectively. Although extensive research has been carried out on the effectiveness of BIM in OSC, the integration of BIM and OSC in New Zealand is still in its early stages.

## 1.3 Problem Statement

The integration of OSC and BIM in the construction industry involves collaboration among all project stakeholders to optimize efficiency, reduce costs, and streamline delivery (He et al., 2021; Liu et al., 2019). This integration holds significant potential for enhancing economic, environmental, and social sustainability by facilitating collaboration, compliance checking, knowledge sharing, clash detection, and design optimization in OSC projects (Babaeian Jelodar & Shu, 2021; Gbadamosi et al., 2020a). Despite these benefits, the integration process remains complex and underexplored, especially in New Zealand, where the construction industry has not fully leveraged OSC and BIM's potential to improve project outcomes (Mirus et al., 2018a; PrefabNZ, 2018a, b).

Several challenges hinder effective integration. Organisational capability, a critical factor, affects the ability of projects and organisations to adopt new methods and technologies (Razkenari & Kibert, 2022). Leadership support and stakeholder collaboration are also essential but often insufficient in driving integration forward (Lopez et al., 2022). The involvement of multiple stakeholders and the unique nature of OSC projects further complicate adoption (Kordestani Ghalenoei et al., 2022a; Rahman, 2014). Additionally, the need for advanced software tools, investments in suitable technologies, workforce training, and effective change management adds layers of complexity (Gan et al., 2018b; Hwang et al., 2018a). Cultural challenges, including resistance to change and fostering collaboration among stakeholders, also hinder progress. In New Zealand, these issues are compounded by specific market conditions and regulatory environments that require tailored integration strategies (Zou et al., 2022).

Research has emphasised the importance of developing simple, structured guidelines with step-by-step approaches to overcome these challenges (Abanda et al., 2017; Gan et al., 2018b; Hwang et al., 2018a). However, no comprehensive, empirical study has systematically explored the critical factors influencing OSC and BIM integration or provided targeted strategies for overcoming challenges across the project lifecycle. Current strategies, such as continuous training, upskilling, stakeholder collaboration, standardisation, and mandating BIM in OSC projects, are often suggested but not contextually adapted to New Zealand’s construction industry (Barkokebas et al., 2021; Jiang et al., 2021).

Integration challenges can occur at different project lifecycle phases, with each phase playing a vital role in overall performance and being interconnected with others (Boafo et al., 2016). Design coordination challenges, for example, might emerge during early phases, while skill and knowledge gaps may persist across multiple phases and organisational levels. Therefore, addressing these challenges requires tailored strategies for each phase. Furthermore, effective management of resources, risks, and collaboration is necessary to achieve seamless integration and improve project outcomes (Kluck & Choi, 2023; Wuni & Shen, 2023).

A significant research gap exists in systematically understanding the relationship between project lifecycle challenges, organisational capabilities, and integration maturity. While some studies explore BIM integration with lean construction or maturity models, few provide actionable insights into achieving higher integration levels in OSC projects, particularly in New Zealand’s context (Guignone et al., 2023; Ortega et al., 2023b; Yang et al., 2022; Yi et al., 2023; Zou et al., 2023).

This research aims to fill these gaps by identifying key factors influencing OSC and BIM integration and developing a framework to guide stakeholders at various stages of the project lifecycle towards integration maturity and improved project outcomes. The framework will address lifecycle challenges, stakeholder collaboration, and organisational capabilities, offering practical strategies to enhance integration. It will also consider the unique aspects of New Zealand's construction market, including regulatory environments, market conditions, and stakeholder capacities (Mirus et al., 2018a; PrefabNZ, 2018b; Shahzad et al., 2022).

By providing structured, actionable guidelines, the framework will help manage risks, allocate resources effectively, and foster continuous improvement. Ultimately, it will promote collaboration and communication among stakeholders, enabling the New Zealand construction industry to harness the full potential of OSC and BIM integration, improve efficiency, and ensure quality control in OSC projects. The following two research questions were formulated to address the research problem: *"While BIM implementation in the OSC delivery process has grown, it is evident that their integration has not been fully realised and is facing various challenges, whereas other countries have successfully leveraged the benefits of such integration."*

1) What are the key factors influencing the integration of OSC and BIM in the New Zealand construction industry, considering organisational, project-level, and stakeholder perspectives?
2) How can construction projects achieve integration maturity through effective strategies and stakeholder collaboration across the project lifecycle?

## 1.4 Research Aim and Objectives

This study aims to advance the integration of OSC and BIM at the project level by developing a framework that guides stakeholders through different phases of the project lifecycle, enhancing integration maturity and overall project performance. The first four objectives address the first research question, while the last three address the second research question.

Research Question 1 focuses on identifying and understanding the factors influencing OSC and BIM integration at multiple levels (organisational, project, and stakeholders). This question aligns with the following objectives:

1) Assess the current state of OSC and BIM integration research and identify factors influencing integration globally and in New Zealand.
2) Develop a conceptual integration framework for OSC and BIM in the New Zealand construction industry at the organisational and project levels.
3) Explore underlying factors and investigate the relationships and effects of factors affecting integration in the New Zealand construction industry.
4) Analyses challenges from a multi-level perspective (stakeholders, project lifecycle and organisational level) in the New Zealand construction industry.

Research Question 2 focuses on achieving integration maturity through effective strategies and stakeholder collaboration across project lifecycle stages. This question aligns with the following objectives:

5) Develop an integration maturity assessment framework for OSC and BIM within New Zealand construction projects.
6) Identify effective strategies for OSC and BIM integration and clarify the roles and responsibilities of stakeholders in implementing these strategies across project lifecycle stages.
7) Develop a strategic framework to integrate OSC and BIM in the New Zealand construction industry, addressing lifecycle challenges towards integration maturity.

## 1.5 Research Scope

This study focuses on examining the integration of OSC and BIM within the construction projects in New Zealand. The construction sector in New Zealand plays a significant role as a facility provider and a driver of economic growth, typically contributing 6.7% to the GDP, employing 10.5% of the labour force, and accounting for 46.7% of all gross fixed capital formation (MBIE, 2022). With the country's population steadily increasing over the past five decades, more people require housing, which leads to a higher demand for residential buildings. Additionally, a growing population puts pressure on existing infrastructure, such as roads, schools, hospitals, and utilities, necessitating improvements and expansions to accommodate the increased usage, for example, particularly in regions like Auckland, where over 30,000 additional dwellings are urgently needed to accommodate the expanding population (Kiernan, 2019).

Conventional construction methods are currently facing challenges in meeting this demand, necessitating the exploration of alternative approaches. The OSC technique that has been successfully employed in countries such as Sweden, the UK, and Japan emerges as a promising solution due to its efficiency and effectiveness (Brown et al., 2020). Despite the potential of OSC, research by BRANZ in New Zealand indicates that the industry's current OSC output is around 2.95 billion dollars. In contrast, the capacity could support an annual output of approximately 5 billion dollars (Page & Norman, 2014a). Furthermore, different types of offsite components, ranging from panels to volumetric modules, exhibit varying utilisation rates and available capacities, suggesting significant untapped potential within the industry (PrefabNZ, 2018a).

In this study, the term "offsite construction" encompasses prefabrication of construction components, preassembly, and modularisation techniques rather than focusing solely on specific types of two-dimensional (2D) or three-dimensional (3D) components/systems. A critical aspect of the research involves selecting case studies from diverse sectors within the construction industry, including commercial, residential, infrastructure, and specialised facilities. By exploring projects across these sectors, the study aims to advance the integration of OSC and BIM at the project level by developing a framework that guides stakeholders through different phases of the project lifecycle, enhancing integration maturity and overall project performance.

The research adopts an inclusive approach, examining the implications, challenges, and prospects associated with OSC and BIM integration across diverse regions of New Zealand, including Waikato, Greymouth, Wellington, and Auckland. Stakeholder engagement is pivotal to the study, with participation from stakeholders representing both large-scale enterprises and smaller firms, including contractors, architects, engineers, developers, and governmental bodies. Through interviews and surveys, the research seeks to gather insights into stakeholder perspectives, experiences, and challenges related to OSC and BIM integration. By engaging stakeholders with diverse backgrounds and roles, the study intends to develop a comprehensive understanding of the factors influencing OSC and BIM adoption at the project level within the New Zealand construction industry.

## 1.6 Research Methodology

This research is organised based on several journal/conference articles that have been submitted or accepted for this research project. Each article includes a complete methodology section, which will be integrated as chapters in this thesis. However, research methodology and methods that were used to achieve the research aim which was develop a strategic framework to integrate OSC and BIM in the New Zealand construction industry, addressing lifecycle challenges towards integration maturity. Therefore, this section begins with a general introduction to the philosophical perspective of research that guided this research, and then describe the research approaches in this area. Finally, the selection of the approach adopted for this research study is discussed. The section presents the research design and method, the development of the sample selection, the data collection procedures, methods employed in the data analyses.

### 1.6.1 Research Philosophy

Recognising the philosophical stance of a research study is an essential first step in its development, as it plays a critical role in shaping the research process and must be clearly identified (Creswell & Creswell, 2017; Saunders, 2014). A researcher's worldview and assumptions about knowledge and reality shape how research questions are framed, and studies are designed (Kumar, 2018). These beliefs, known as a research philosophy, guide the methods for collecting, analysing, and generating data, often described through "ontology" and "epistemology" (Sutrisna, 2009). Ontology refers to the assertions and assumptions made about the nature of reality, including its existence, appearance, and interactions (Guba & Lincoln, 1994). In contrast, Epistemology is concerned with the nature of knowledge and how scholars perceive and understand reality, with positivism and interpretivism being its two major branches. and is typically divided into objectivism and constructivism (Sutrisna, 2009).

This research aims to generalise a framework for OSC and BIM integration, with the framework's development being a critical step. The researcher believes that stakeholder interactions significantly influence integration and shape the research objectives. Creswell & Creswell (2017) associates' positivism with a conventional approach, where a theory is tested and refined through data collection to build knowledge. Bryman and Bell (2011) add that positivism relies on observable facts, like natural sciences. In contrast, interpretivism emphasizes the importance of understanding human interactions to interpret social reality, rather than relying solely on scientific methods (Bryman & Bell, 2011; Sutrisna, 2009).

Furthermore, Bryman and Bell (Bryman & Bell, 2011) differentiate between objectivism, which holds that social phenomena and their meanings exist independently of human perception, and constructivism, which asserts that social realities are constructed through human interaction. Ontology and epistemology are inextricably linked, as previously discussed. Positivism is based on Objectivism, which holds that there is a single objective reality that all people perceive. Researchers are responsible for discovering and modelling this truth. Interpretivism relies on Constructivism to understand reality, which is constructed and understood differently by individuals (Sutrisna, 2009).

In this research, the goal is to generalise an integration framework at the project level that supports stakeholders throughout different stages of the project lifecycle. It is recognised that the integration of OSC and BIM is influenced by stakeholder interactions, along with various tools, systems, mechanisms, and approaches involved in the process. The study focuses on a specific context where, although the integration process may appear as an objective reality, it is essential to understand the perspectives and interpretations of the stakeholders and tools involved. The researcher did not adhere to any predetermined notion of what constitutes adequate knowledge, avoiding a strictly positivist or interpretivist stance (Saunders & Tosey, 2012; Sutrisna, 2009).

Instead of prioritising one view, the study focused on identifying the most appropriate methods and approaches to address the research problems. The literature supports the use of "pragmatism" the idea that what works best is most important for answering research questions (Murphy & Murphy, 1990; Saunders, 2014; Tashakkori, 2010). According to pragmatism, research begins with a problem and aims to provide practical solutions that can inform future practices (Saunders, 2014). Creswell & Creswell (2017) also emphasized that, regardless of the methods used, researchers should focus on the research problem and employ all necessary approaches to fully understand its challenges and solutions.

### 1.6.2 Research Approach

The approach to theory development is crucial for choosing an appropriate research design, as it depends on how clearly the theory is defined at the start of a research project (Saunders, 2014). Regardless of the study type, theory, which explains observed patterns, remains central (Bryman, 2016). In research, data collection and analysis aim to generate knowledge, which, while often practically applicable, is primarily intended to enhance theoretical understanding (Bell et al., 2018). Two key issues define the relationship between theory and research: (1) the type of theory being referred to, and (2) whether the data are used to test existing theories or develop new ones (Gray, 2021; Saunders, 2014).

Inductive and deductive reasoning are distinct approaches in research, primarily differing in how they utilise existing knowledge and approach data collection. In deductive research, hypotheses are derived from the existing body of knowledge, followed by data collection and analysis to test these hypotheses. This method aligns with objectivism and positivism, as it assumes that a single objective truth exists, with researchers relying on scientifically proven knowledge to guide their investigations (Sutrisna, 2009).

In contrast, inductive research involves gathering and analysing data to generate findings, while using existing knowledge to inform analysis when necessary. Unlike deductive reasoning, inductive reasoning allows a gap between premises and conclusions, where the conclusions are judged to be supported by the observations made (Ketokivi & Mantere, 2010). Though distinct, these approaches are not mutually exclusive and can be combined in a research project (Gray, 2021; Saunders, 2014; Saunders & Tosey, 2012). This combined method, known as the "abductive approach," allows researchers to draw on the advantages of both deductive and inductive processes (Johnson, 2010; Yin, 2018).

Since this research requires a combination of objectivist and constructivist perspectives, data collection on current practices is essential for both developing and testing theories. As a result, the study follows a mixed approach, combining inductive and deductive reasoning. This research started with the deductive reasoning approach with a problem definition and led to an inductive reasoning approach of theory building. The choice of research approach is guided by the researcher's understanding of the nature of the research questions, personal experiences, and the intended audience of the study (Creswell & Creswell, 2017).

The researcher focused on investigating the integration of OSC and BIM at the project level. By considering various factors such as challenges, strategies, integration, and stakeholders, a conceptual framework was developed using a deductive approach to understand the integration process of OSC and BIM. The researcher then explored how different stakeholders and project life cycle stages influence this framework in practice. Empirical data were gathered and analysed to test and refine the conceptual framework, applying an inductive approach. This approach aligns with the reasoning described by Saunders et al. (2014) and Gray (2021), where data are collected to explore a phenomenon, identify themes, explain patterns, and modify or create new theories, which are then tested through further data collection.

### 1.6.3 Research Methods

At the data level, collected data can generally be grouped into quantitative, qualitative, or mixed methods (Bell et al., 2022; Saunders, 2014; Sutrisna, 2009). A key distinction between quantitative and qualitative research is the type of data: quantitative focuses on numerical data, while qualitative deals with non-numerical data like words and images (Saunders, 2014). Beyond this, differences extend to philosophical assumptions, research strategies (e.g., experiments for quantitative, case studies for qualitative), and methods used for data collection and analysis (Creswell & Creswell, 2017).

Quantitative research involves defining the study's purpose, identifying the population and sample, selecting a survey instrument, and examining variables and their relationships. The measurement process emphasizes reliability and validity of the indicators (Bryman & Bell, 2011). However, it can sometimes reflect the researcher's perspective more than that of the participants. In contrast, qualitative methods explore the qualities of phenomena, with an emphasize on understanding them in their real-world context and recognising the subjective nature of reality (Sutrisna, 2009). The selection of research methods is guided by the chosen research approach. In this study, a combination of inductive and deductive approaches was employed, leading to the use of a mixed methods approach. This requires extensive data collection and a solid understanding of both qualitative and quantitative methods.

By combining qualitative and quantitative techniques, the approach balances the strengths and weaknesses of each method (Fellows, 2015; Knight & Ruddock, 2009). This approach enables the researcher to use both inductive and deductive methods, providing a more comprehensive understanding. Qualitative research, often linked to interpretivism, helps uncover subjective meanings (Denzin & Lincoln, 2011), while it can also align with pragmatism, where the research context and outcomes dictate the methods used (Creswell & Creswell, 2017; Saunders, 2014; Tashakkori et al., 2020).

Mixed methods approaches have been found to be particularly useful in several types of studies (Creswell & Creswell, 2017). They are effective for comparing different perspectives from both quantitative and qualitative data, explaining quantitative findings with follow-up qualitative analysis, and developing better measurement tools by first collecting and analysing qualitative data before testing them on larger samples. Additionally, they help in understanding experimental results by incorporating individual perspectives, gaining a complete understanding of the needs and changes required for marginalised groups, and assessing the need for and impact of intervention programs through the collection of both qualitative and quantitative data over time.

In terms of theory development, qualitative research typically begins with an inductive approach to build or refine theories (Gray, 2021; Saunders, 2014). However, it may also take a deductive approach to test existing theories (Yin, 2012). This research employs a mix of deductive and inductive approaches to address problems and develop theories (Gray, 2021; Saunders & Tosey, 2012). As illustrated in Figure 1.1, the study begins with the application of both qualitative and quantitative methods. The qualitative methods were then used to confirm and validate the findings from stage 1. The results from stages 1 and 2 were used to develop the survey in stage 3 (quantitative), followed by two qualitative methods: case studies and focus groups. This combination ensures comprehensive and reliable findings for addressing complex challenges.

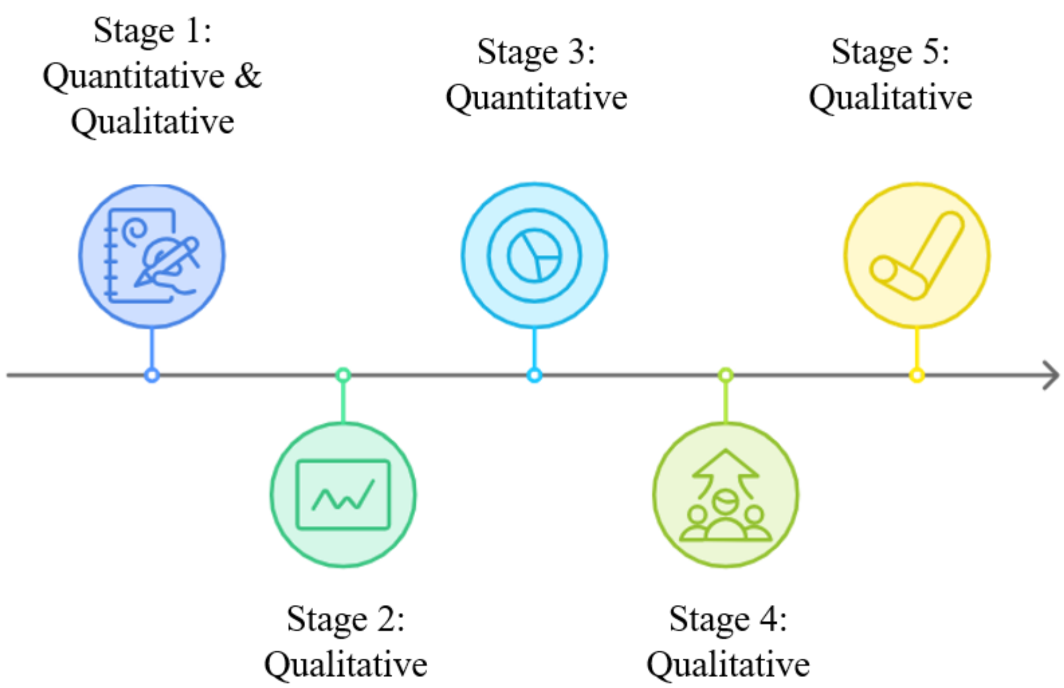


**Figure 1.1:** Research Methods

### 1.6.4 Conceptual and Research Frameworks

This doctoral thesis is organised into seven core chapters (2 to 8), each of which is influenced by one of the five primary stages of study. The theoretical connections between the concepts and factors that are examined in this study are illustrated by the conceptual framework in Figure 1.2. The framework shows further details of the various research phases but, at the same time, offers a holistic picture of the study.

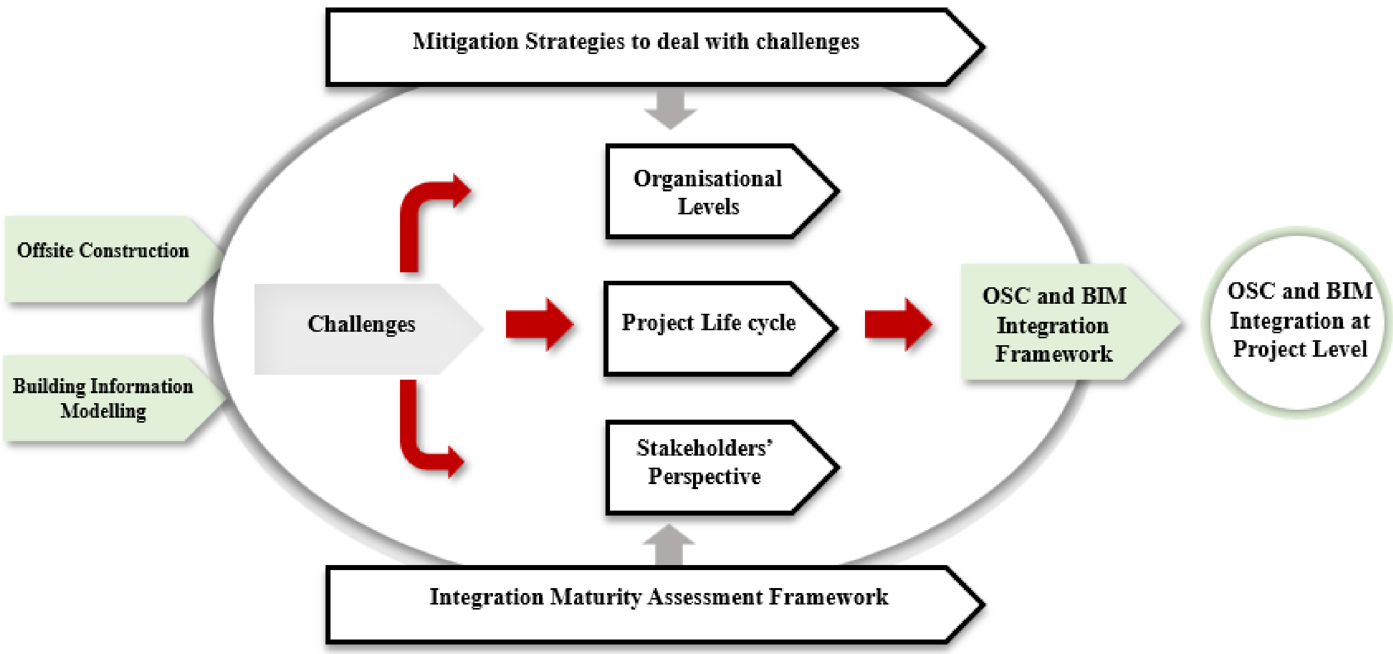


**Figure 1.2:** Conceptual Framework

The conceptual framework (Figure 1.2) illustrates the factors influencing the integration of OSC and BIM in construction projects. The framework helps to understand the path toward integration by exploring challenges and mitigation strategies from various perspectives. Since the study focuses on utilising digital tools in the delivery process of OSC projects, relevant concepts are shown as factors affecting integration to fully understand how challenges are addressed and who the most appropriate stakeholder is to take responsibility. Furthermore, it explores the levels of integration maturity levels. Consequently, the research will examine integration challenges, mitigation strategies, underlying factors influencing challenges and strategies, responsible stakeholders, integration maturity characteristics, and organisational-level challenges (at the project, organisation, and industry levels). It will investigate challenges across the project life cycle, from initiation to closeout.  Detailed research framework presented in Figure 1.3, following by the chosen methods for this research.

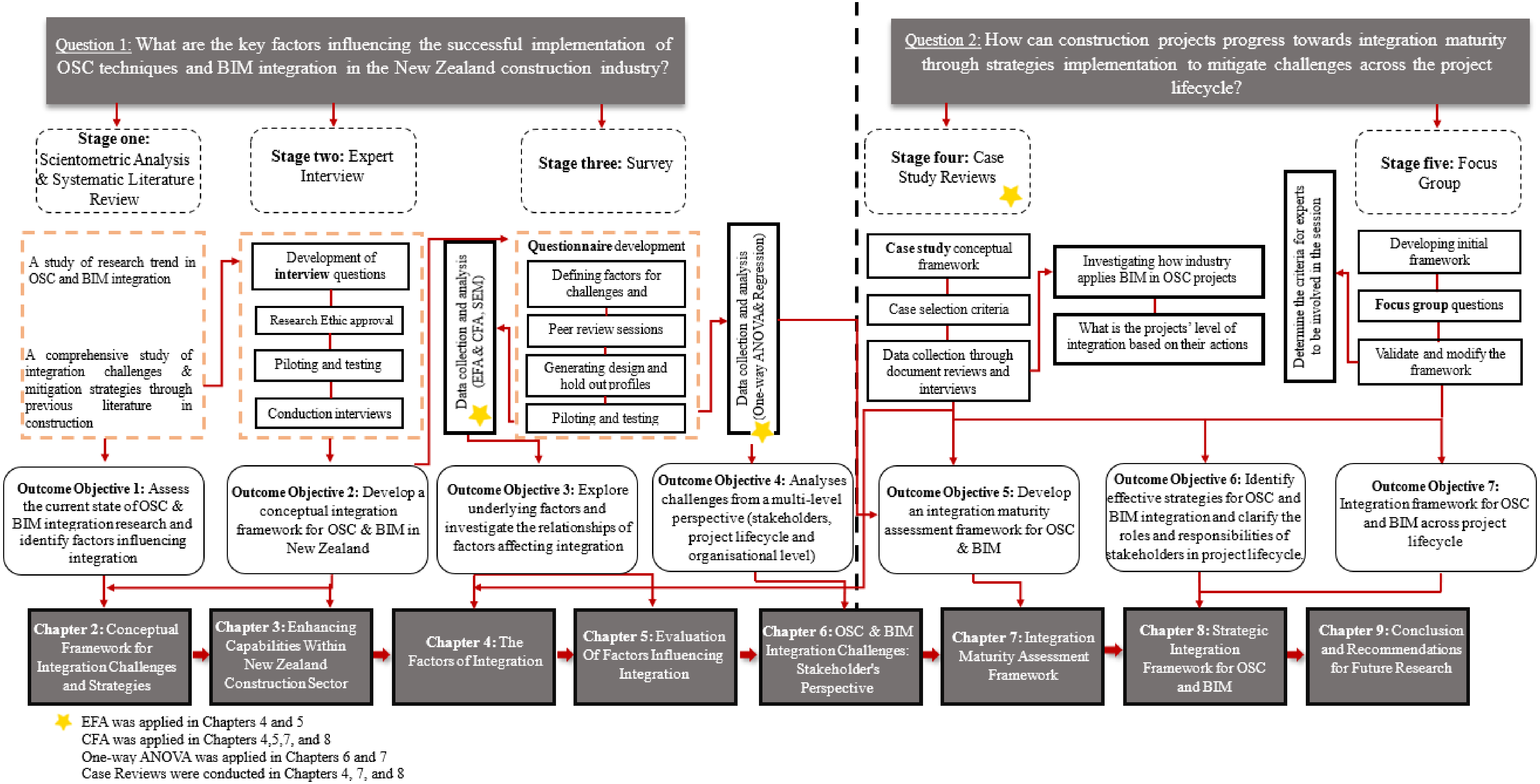


**Figure 1.3:** Research Framework

### 1.6.5 Research Process

The goals of the study were met by the way the research procedure was organised. To guarantee the effective completion of the study and the resolution of all research issues, each stage is crucial. Researchers may vary in the number of steps they take in their research process. Despite this heterogeneity, common processes usually include choosing a topic, examining the literature, designing the research, collecting data, analysing it, and publishing the results (Saunders, 2014). Figure 1.3 illustrates the five main stages of this study: scientometric and literature review, semi-structured interview, questionnaire survey, case study, and focus group.

#### *1.6.5.1 Scientometric Analysis Method*

The first stage of this research aims to identify global research trends, challenges, and integration strategies (Figure 2.1). Initially, a scientometric analysis was particularly suited to providing a broad and comprehensive overview of published literature, ensuring that no key research areas were overlooked. Scientometric analysis offers distinct advantages in identifying trends, keywords, and patterns within a large volume of academic work, making it an ideal approach for establishing a knowledge (Rashed & Mutis, 2021; Tang et al., 2019b). SCOPUS was used as the primary database because of its wide-ranging coverage of peer-reviewed journals across disciplines, ensuring inclusivity and high-quality literature for analysis (Meho & Rogers, 2008). A variety of tools for science mapping and visualisation are available, including Bibexcel, Publish or Perish, CiteSpaceII, CiteNetExplorer, and VOSviewer (Lihitkar, 2019).

Among these, VOSviewer and CiteSpaceII have seen widespread use in numerous scientific studies (Chen, 2017). VOSviewer stands out from many other tools due to its specific design for visualising scientific maps based on co-occurrence data, facilitating the easy interpretation of large-scale maps such as co-authorship, co-occurrence, and citation networks. Additionally, VOSviewer provides text-mining capabilities that allow data extraction from bibliographic database files (Van Eck, 2022).

For this research, VOSviewer was selected to visualise bibliometric networks using data from bibliographic databases. While Citespace was instrumental in identifying trends and research patterns over time (Chen, 2016). The two-phase analysis involved co-citation analysis to identify the most frequently cited studies and keyword analysis to discover emerging research topics related to OSC and BIM. The findings from this stage not only established the current research landscape but also revealed gaps that required further exploration. By maintaining inclusivity and systematically reviewing a broad range of literature, this stage achieved Objectives 1 of the study (Figure 1.3).

#### *1.6.5.2 Systematic Literature Review*

Following the scientometric analysis, a systematic literature review (SLR) was conducted to further explore the integration of OSC and BIM. A systematic review is a rigorous and structured approach that identifies, evaluates, and synthesises relevant research to address a specific research question (Mirzaei et al., 2020). It was selected for this research because it ensures a comprehensive review of the best available evidence, informing theoretical and practical recommendations for OSC and BIM integration (Rother, 2007). The systematic review followed a well-defined protocol, guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 statement (Page et al., 2021).

Chapter 3 of this thesis provides a detailed, step-by-step approach to conducting the systematic literature review. The SLR contributed to developing a conceptual framework that guided subsequent stages of the research, offering a thorough examination of available literature, definitions of key research themes, and strategies for OSC and BIM integration. The SLR process followed these key stages:

Identification: A set of keywords was developed based on the challenges and integration strategies identified in the scientometric analysis. Keywords included “Modern Methods of Construction,” “Modular Construction,” “Offsite Construction,” “Prefabrication,” “Building Information Modelling,” and related terms. These keywords were applied to the SCOPUS database, known for its extensive coverage of peer-reviewed articles, to identify relevant studies from the period 2000-2021. This ensured that the review covered the breadth of research on OSC and BIM, focusing on the time when BIM gained more prominence in research (Meho & Rogers, 2008).

Screening: The initial search yielded many articles. To ensure the quality and relevance of the studies, a screening process was applied. The search results were filtered using inclusion and exclusion criteria based on factors such as language (English), document type (peer-reviewed articles and reviews), and relevance to OSC and BIM integration. High-impact journals were prioritised. The PRISMA flow diagram was used to visually present how studies were identified, screened, and selected for the review, ensuring transparency (Liberati et al., 2009; Meho & Rogers, 2008).

Eligibility and Inclusion: The full texts of the remaining articles were assessed for eligibility, focusing on studies that directly addressed the integration challenges and strategies for OSC and BIM. In the final stage, 53 papers met the inclusion criteria and were selected for analysis. These articles were categorised according to their relevance to each research objective, providing a robust base for further investigation into OSC and BIM integration.

Analysis: The selected articles underwent descriptive and content analysis to summarise their key characteristics, including publication trends, research methodologies, and critical challenges. Content analysis helped identify recurring themes and integration strategies across the studies (Krippendorff, 2018). Additionally, thematic analysis was applied to categorise the challenges and strategies into distinct groups, allowing for a structured and in-depth analysis of the literature (Braun & Clarke, 2006). This dual approach content analysis and thematic analysis ensured a comprehensive understanding of the existing research landscape.

The analysis also involved ranking challenges based on criticality, citation frequency, and significance in the literature. NVivo 20 software was employed to facilitate the coding, sorting, and organisation of the qualitative data, ensuring consistency and rigour throughout the analysis (Gibbs, 2017). Thematic analysis was chosen because it allows for flexibility in identifying patterns and themes within qualitative data. It is particularly suited to exploring complex issues like OSC and BIM integration, where both inductive (data-driven) and deductive (theory-driven) approaches are required (Braun & Clarke, 2006). The iterative process of thematic analysis enabled the research to remain grounded in the data while uncovering key themes related to stakeholder interactions and integration strategies (Nowell et al., 2017).

By using methodological triangulation, combining multiple data sources such as scientometric analysis, content analysis, and thematic analysis, the reliability and validity of the findings were enhanced (Gray, 2021). NVivo 20 played a crucial role in managing large datasets and providing the tools necessary for a detailed and thorough analysis (Gibbs, 2017). The findings from this review contributed to the development of the conceptual framework, guiding subsequent research stages such as expert interviews and the development of survey instruments (Chapters 3 and 4). This review, in conjunction with the scientometric analysis, addressed Objectives 1 and 2 by laying the theoretical groundwork for the study.

#### *1.6.5.3 Semi-structured Interview Method*

Following the systematic literature review, semi-structured interviews were conducted to validate and expand upon the findings. These interviews aimed to gather in-depth insights into the challenges and strategies related to OSC and BIM integration in the New Zealand construction industry. This qualitative method was chosen because it allows for both consistency in asking key questions and flexibility to explore new insights based on participant responses (Fellows & Liu, 2009). The interview questions were open-ended to encourage detailed responses, allowing participants to elaborate on their experiences with OSC and BIM integration.

These questions were based on the literature review findings but also designed to explore participants' real-world experiences in more depth. These open-ended questions allowed for follow-up investigating, giving the researcher flexibility to pursue additional topics as they arose, providing a richer understanding of the integration challenges and strategies (Creswell & Creswell, 2017). For optimum tangibility and comprehension of responses, interviews were designed with key questions accompanied by follow-up questions (Chen & Partington, 2004).

Each interview lasted between 40-60 minutes, providing sufficient time for participants to discuss both the broad issues of OSC and BIM integration and their personal experiences in detail. Nine interviews were conducted with selected experts who had a minimum of ten years of experience in construction projects, and they were chosen based on their involvement in OSC and BIM projects. The sample size was determined by theoretical saturation, meaning interviews continued until no new information emerged, ensuring that the data collected was comprehensive (Glaser & Strauss, 2017).

Data collection occurred remotely due to COVID-19 restrictions, using online platforms such as Microsoft Teams. Each interview was digitally recorded with participants' consent and later transcribed for analysis. This approach ensured that all data were captured accurately and could be systematically reviewed. For data analysis, thematic analysis was applied to the interview transcripts, using NVivo 20 software to assist with coding and categorising the data. NVivo was chosen because it provides robust tools for organising qualitative data, making it easier to identify recurring themes and patterns (Gibbs, 2017).

Thematic analysis was ideal for this research because it allows the identification of common themes related to integration challenges and strategies, providing a systematic way to connect the interview findings to the literature (Braun & Clarke, 2006). This approach ensured that the semi-structured interviews contributed significantly to the research objectives by validating the challenges and strategies identified in the earlier literature review, as well as uncovering new insights specific to the New Zealand construction context, answering to Objectives 1 and 2 (Chapters 3 and 4).

#### *1.6.5.4 Survey Method*

A survey method was deemed appropriate for this study as it allows for effective analysis of numerical data and helps identify causal relationships between variable (Yin, 2009). This method also helps document norms within a population and assess associations between variables (Gaur et al., 2020). Given the objective to explore underlying factors and investigate the relationships and effects of factors affecting integration in the New Zealand construction industry, the survey method was suitable. The survey for this research was developed based on the list provided in Figure 5.1, designed to measure integration throughout the OSC delivery process, from the initial phase to project close-out (PMBOK, 2021). Drawing on previous studies in the construction management field, the questionnaire ranked various variables and factors associated with OSC and BIM integration (Asadi et al., 2023; Kordestani Ghaleenoei, 2022; Kordestani Ghalenoei et al., 2021).

The questionnaire comprised two main sections. The first section collected demographic information, while the second section measured participants' agreement on the importance of key challenges, strategies, and integration factors they experienced during the project lifecycle. Participants rated these questions on a 7-point Likert scale, with 1 representing "Not at all important" and 7 "Extremely important." The use of a 7-point scale enhanced the precision and reliability of responses, allowing for nuanced feedback (Dawes, 2008; Joshi et al., 2015).

The research methodology process is illustrated in Figure 5.2. A peer review process involving four experts from both industry and academia was conducted before distributing the survey. This process ensured that the questionnaire content aligned with the research objectives and was relevant to current industry practices (Brace, 2018). Following this, a pilot study with 30 randomly selected respondents was carried out to test the survey's practical application and usability (Dillman et al., 2014). Feedback from the peer review and pilot study informed final refinements, which were sufficient to validate the survey without requiring further iterations.

A total of 450 emails were sent to technical employees from 142 companies, selected from BIMinNZ and OffsiteNZ, New Zealand's leading organisations in BIM and OSC. Six companies operating in Australia were excluded to keep the study within the New Zealand context. After eliminating incomplete responses, 116 valid responses were analysed from the 164 received, yielding a response rate of 36.4%. This rate is higher than the threshold needed for statistical significance, and the sample size was considered acceptable within a ±8% margin of error at a 95% confidence level (Cochran, 1977).

The questionnaire was distributed to project managers, architects, draftspersons, and designers, all of whom utilise BIM in their design and project delivery processes. The 7-point Likert scale allowed respondents to express their nuanced views on OSC and BIM challenges, strategies, and integration. This approach is ideal for capturing participants' precise responses and enhances the reliability of the data (Dawes, 2008; Joshi et al., 2015).

Data collection occurred between October 2022 and February 2023 using Qualtrics, a web-based platform, allowing for efficient data collection from construction professionals. The survey link was distributed to construction companies, including clients, consultants, and contractors involved in OSC projects where BIM had been implemented. The respondents were identified based on their industry profiles and their involvement in OSC and BIM. To ensure a representative sample of experts in the New Zealand construction sector, a Randomized Control Trial (RCT) methodology was used. This approach ensures rigorous data collection and reduces biases, thereby enhancing internal validity (Chalmers et al., 1981; Spillane et al., 2010).

The use of probability sampling ensured that each participant had an equal chance of selection, promoting fairness and strengthening the survey's credibility. This combination of RCT methodology and probability sampling enabled the research to generate results that are representative of the wider population of OSC and BIM professionals (Saunders et al., 2009).

The final sample size for the survey was 116 participants, which included 48 engineers (41.4%), 36 project managers (31.0%), and professionals in other roles such as quantity surveyors, drafters, and architects. Most participants had 1-5 years of experience in OSC and BIM. Although the exclusion of participants with less than 5 years of experience was considered to focus on more seasoned professionals, their inclusion was necessary to maintain a robust sample size. Excluding them would have weakened the statistical power of the study, potentially affecting the reliability of the results.

The survey data underwent EFA to identify latent constructs, followed by CFA to validate the factor structure and assess the overall model fit. EFA method helps to detect relationships between variables and simplifies the complexity of the data (Yap et al., 2018). SPSS and AMOS software were utilised for the statistical analyses. The CFA was evaluated against recognised model fit criteria, such as CMIN/DF, CFI, SRMR, and RMSEA, to ensure the robustness of the model (Hair et al., 2010; Hu & Bentler, 1999). Inferential statistics were employed to examine the relationships between variables, ensuring the findings could be generalised beyond the immediate sample. The combination of RCT methodology, probability sampling, and rigorous data analysis enhanced both the internal and external validity of the study, ensuring the results could be generalised to the broader New Zealand OSC and BIM sector.

Structural Equation Modelling (SEM) was employed in this research as a method for understanding and testing the relationships between observed variables and latent constructs. SEM is particularly useful when dealing with complex models that include both direct and indirect relationships between variables, offering more flexibility and explanatory power than multiple regression techniques (Fornell & Larcker, 1981). In this study, SEM was used to evaluate path models that mapped the relationships between challenges, strategies, and integration variables. The application of SEM allowed for hypothesis testing in terms of how these variables interacted and influenced integration outcomes. This method was selected due to its suitability in situations with poorly measured variables, where underlying factors play significant roles (Chapter 6).

One-way ANOVA was used to compare the means between different groups of stakeholders (clients, contractors, consultants) to determine whether their experiences with OSC and BIM challenges significantly differed. This method is ideal for comparing multiple groups because it controls for Type I errors, which may arise when performing multiple t-tests, by testing the significance of the differences between group variances rather than just their means (Kim, 2017). Tukey's HSD, Bonferroni, and Games-Howell post-hoc tests were also used to identify significant differences between the groups. The use of ANOVA is appropriate when testing the impact of categorical independent variables on continuous dependent variables. ANOVA helped identify which groups experienced certain challenges more intensively and enabled the detection of underlying trends across stakeholder perspectives (Chapters 7 and 8).

Linear regression is a commonly used technique in predictive modelling that allows researchers to assess the contribution of multiple independent variables in predicting a dependent variable. In this research, linear regression was applied to evaluate the additive effects of various challenges (CH1, CH2, and CH3) on OSC and BIM integration, with the primary goal of identifying which challenges are most relevant in different project life cycle contexts.

Linear regression was chosen as it is well-suited for examining relationships between independent variables (challenges) and a dependent variable (integration outcome). The response rate and nature of the variables were aligned with the assumptions of linear regression, as the data was continuous, and the relationship between the predictors and the outcome was expected to be linear. Moreover, linear regression does not require many data points for each predictor but benefits from a sufficient sample size to ensure reliability and validity in estimating the coefficients.

While linear regression is often associated with prediction, in this study, its use was primarily for relationship analysis. It enabled the examination of the significance and impact of each challenge on OSC and BIM integration, providing a clearer understanding of the factors influencing integration across different project stages. The method was justified as the most appropriate choice for evaluating the interactions among multiple challenges in a complex dataset, where various factors influence the final integration process (Keller, 2022; Pallant, 2020). This model is particularly beneficial as it provides a clear equation to predict outcomes based on input variables. The method was justified as suitable for evaluating relationships in complex datasets where multiple challenges interact to affect the final integration process (Chapter 7).

In overall, the survey intended to evaluate the conceptual framework previously established in objective 2, which encompasses the challenges for OSC and BIM, along with mitigation strategies. Through factor analysis (Chapters 5,6,8,9) and SEM (Chapter 6), the underlying factors influencing integration were identified and renamed as factors affecting integration to accomplish Objective 3. To fulfil Objective 4, two analysis methods have been employed. The outcomes of One-way ANOVA determined discrepancies in stakeholders' perspectives on the challenges (Chapters 7 and 8). Furthermore, the identification of organisational levels of challenges and their occurrence at different project lifecycle phases was pursued through linear regression (Chapter 8).

#### *1.6.5.5 Case Study Method*

A qualitative exploratory case study method was employed to confirm the analysis results and develop a deeper understanding of the integration of OSC and BIM. This approach allows for the in-depth investigation of complex, real-life contexts, such as OSC and BIM integration, where the boundaries between phenomenon and context are not always apparent (Yin, 2012). The case study method was appropriate method due to its ability to explore how and why integration decisions are made, particularly when the researcher has little control over events (Yin, 2018). It is highly suited to understanding contemporary phenomena in their real-world contexts, where OSC and BIM integration processes involve multiple stakeholders and stages across the project lifecycle (Yin, 2012; Yin, 2018).

The holistic approach was selected over an embedded case study, as OSC and BIM integration are deeply interconnected, involving a wide range of stakeholders and requiring a comprehensive understanding of the entire lifecycle rather than focusing on specific sub-units. This holistic approach offered a broader view of strategies, challenges, and their interconnectedness throughout the integration process (Yin, 2018). A comparative case study framework was employed to allow for the comparison of findings across multiple projects (Snyder, 2012; Yin & Davis, 2007). This method enabled the study to replicate logic across cases and ensure the findings were consistent and reliable (Yin, 2012; Yin & Davis, 2007).

The case study framework focused on the integration challenges, collaboration processes, software tools, and information management processes of each project. This standardised structure allowed for meaningful comparison between the different projects and ensured that the findings could be generalised across diverse contexts (Woodside, 2010). The selection of four case studies from different New Zealand regions ensured diversity and captured unique characteristics in OSC and BIM implementation (Snyder, 2012). The case selection was based on three key criteria:

1. Usage of OSC components and BIM throughout the project lifecycle.
2. Accessibility to project data, including design documents, published sources, and meeting notes.
3. The willingness of participants to attend interviews, ensuring access to firsthand insights from industry experts.

***Case Study Protocol and Steps Followed:***

The case study process followed a structured protocol to ensure consistency across all four cases:

1- Identification and selection of suitable case study projects based on pre-defined criteria.
2- Initial engagement with key project stakeholders to gain access and establish participation agreements.
3- Collection of relevant project documents (design files, contracts, and meeting notes).
4- Identification and purposeful sampling of interviewees based on their involvement and experience in OSC and BIM processes.
5- Conducting semi-structured interviews with selected stakeholders, either in person or via Microsoft Teams.
6- Transcription and analysis of interviews using NVivo for thematic analysis.
7- Triangulation of findings through cross-referencing data from interviews, documents, and meeting notes.
8- Comparative analysis across cases to identify common patterns and unique insights.

***Theoretical Replication:***

1- To ensure theoretical replication, the selected cases represented diverse characteristics:

2- Variation in project size and complexity.

3- Different levels of OSC and BIM integration maturity.

4- Geographical diversity across New Zealand regions which allowed for the identification of patterns and variances in OSC and BIM integration across different contexts.

Each case study included an average of 2 interviews with stakeholders directly involved in the OSC and BIM integration process. Interviewees were selected purposefully based on their direct involvement in OSC and BIM integration and a minimum of 10 years of industry experience.

Their role is to make decisions and oversee integration processes. In overall this ensured the inclusion of participants with sufficient expertise and practical insights into integration challenges and strategies.

The case study employed document reviews and semi-structured interviews as the primary data collection methods. The reviewed documents included design files, contracts, published sources, and meeting notes to provide a detailed understanding of the selected projects. This document review helped create a comprehensive view of the integration process and highlighted key themes, which were then analysed using NVivo 20 software for thematic analysis. This software facilitated the extraction and organisation of key themes from the data, which enabled the identification of integration challenges and strategies. While NVivo assisted in coding and organising the data, the researcher performed the actual analysis, ensuring that the insights were deeply grounded in the data (Edwards-Jones, 2014; Gibbs, 2017).

Interviews were conducted with key stakeholders who were involved in the projects, including design managers, BIM managers, and a draftsperson. The interviews were conducted in person and remotely via Microsoft Teams, depending on geographical distances and participant availability. These semi-structured interviews allowed flexibility in questioning, enabling a rich exploration of the integration processes, while providing valuable insights into project-specific experiences. The interviews were digitally recorded and later transcribed for analysis. Each interview lasted approximately one hour.

The interviewees shared critical insights into the integration of OSC and BIM, further enriching the data collection process. Triangulation was employed throughout the data collection process to ensure the reliability and validity of the findings. This involved cross-validating information from multiple sources (documents, meeting notes, and interviews) and integrating them into the analysis. This method strengthened the research by ensuring that the findings were not reliant on a single source of data but were supported by multiple perspectives (Humble, 2009; Johnson, 2017).

The case study approach offered comprehensive insights into the real-world implementation of OSC and BIM in New Zealand construction projects. The case studies revealed the challenges of integrating these processes and provided empirical evidence for developing a maturity assessment framework and validation of survey results. By exploring multiple projects, this approach facilitated a thorough understanding of the strategies used at various stages of the project lifecycle and highlighted the responsible stakeholders, contributing to the achievement of the study's objectives. Based on the data collected thorough case studies review, an integration maturity assessment framework was developed (Objective 5) to guide them in enhancing their integration levels (Chapter 8). Additionally, effective strategies and responsible stakeholders for integrating BIM with OSC were identified to achieve Objective 6 (Chapter 9).

#### *1.6.5.6 Focus Group Method*

All information gathered from previous stages contributed to stage five (Objective 7), which involved providing a framework to integrate OSC and BIM in the New Zealand construction industry. This framework addresses integration challenges across project lifecycle and maturity levels (Chapter 9). Subsequently, the developed framework was validated through a focus group session to refine and optimize its effectiveness.

A focus group method was employed in the research to gather subjective data from participants and understand their perspectives on OSC and BIM integration. According to Sandelowski (2008) and Saunders et al. (2009), focus groups are effective for exploring various viewpoints on a given phenomenon. As noted by Stewart and Shamdasani (Stewart & Shamdasani, 2014), the primary purpose of a focus group is to explore in-depth topics about which little is known, making it highly suitable for validating the developed framework (Figure 5.8) from previous stages of this research. The focus group method was applied in this research for its ability to provide rich, qualitative data and generate group-based insights into the integration of OSC and BIM. Compared to one-on-one interviews, focus groups offer a more interactive environment, encouraging participants to share and debate their views. This dynamic can reveal shared attitudes and divergent perspectives, which are crucial for validating a conceptual framework (Bell, 2019).

The focus group also allowed for a more contextualised understanding of OSC and BIM integration, shifting away from individual perceptions and towards a collective sense-making process (O. Nyumba et al., 2018). The focus group method is especially valuable for validating frameworks or concepts that have been developed through other data collection methods, such as surveys or interviews. In this case, the focus group provided an opportunity to test and refine the developed framework, ensuring its applicability to industry practice and its alignment with stakeholders' experiences (Gibb, 1999; O. Nyumba et al., 2018). The feedback from the focus group contributed to the final validation of the framework, allowing for its generalisation and practical implementation in the New Zealand construction industry.

The focus group session involved seven experts selected from three key stakeholder groups: clients, consultants, and contractors/manufacturers. Specific criteria were established to ensure the participants had the requisite expertise, including:

- Senior-level practitioners within the construction industry.
- Extensive experience in project delivery methods.
- Proficiency with BIM and OSC-related software.
- Familiarity with diverse contract forms.

The selection process prioritised accessibility, given the logistical challenges of gathering individuals in one location (Breen, 2006). Initially, ten experts were contacted, but due to availability, seven participants attended the session. These experts' backgrounds ensured that their input was highly relevant to the validation of the OSC and BIM integration framework developed in the earlier stages of the research. The focus group session lasted four hours and began with an introduction to the project, including its aims and key questions. Participants were provided with handouts before the meeting that included a brief description of the project, the objectives of the session, the main questions, and the developed framework. This preparation ensured that participants could engage deeply with the material. During the session, participants were encouraged to discuss challenges they encountered with OSC and BIM integration, strategies they had applied to mitigate those challenges, and responsibility for actions based on their experiences.

Participants were then invited to discuss the various sections of the framework and validate its components, offering suggestions for modification where necessary. To enhance the validity and reliability of the collected data, triangulation was employed. This involved the use of two primary data sources including audio recordings of the focus group discussions and note-taking throughout the session. These data sources were transcribed into text to ensure accuracy (Johnson, 2017). Triangulation is critical to ensuring the reliability of qualitative data, as it cross-verifies the information from multiple angles (Coleman, 2022). The focus group discussions were analysed thematically, with key insights about the challenges and strategies for integrating OSC and BIM extracted from the discussions. This allowed the researcher to assess the collective feedback of the participants in relation to the developed framework.

Table 1.1 briefly summarises the methodology of the research according to each chapter and research objective. It also demonstrates the various methods used to achieve these objectives. In addition, the table indicates how the different manuscripts and research papers are used in the compilation of this thesis. The outcome of each article is acknowledged as a key deliverable, which will feed into the following research article, hence defining a coherent flow for the study.

**Table 1.1:** Dissertation methodology according to each chapter

| CH# | Chapter Title | Aims and Objectives | Methods of Analysis | Publication Lists (Title) | Year | Journal Name | State |
|---|---|---|---|---|---|---|---|
| 1 | Introduction | Justification and definition of the research process | - | - | - | - | - |
| 2 | Literature Review | Theorical foundation and research concepts | - | - | - | - | - |
| 3 | Conceptual Framework for Integration Challenges and Strategies | Assess the current state of OSC and BIM integration research and identify factors influencing integration globally and in New Zealand.<br><br>Develop a conceptual integration framework for OSC and BIM in the New Zealand construction industry at the organisational and project levels. | Cluster analysis<br>Thematic Analysis | Challenges of OSC and BIM implementation: providing a framework for integration in New Zealand | 2022 | Smart and Sustainable Built Environment | Published |
| 4 | Challenges for OSC and BIM Integration in New Zealand | Identify factors influencing integration in New Zealand. | Thematic Analysis | Exploring Offsite Construction and Building Information Modelling Integration Challenges; Enhancing Capabilities within New Zealand Construction Sector | 2022 | In IOP Conference Series: Earth and Environmental Science | Published |
| 5 | The Factors of Integration | Explore the underlying variables for challenges, strategies, and integration factors. | Factor Analysis<br>Case reviews | The Challenges and Strategies of BIM for Offsite Construction Delivery; the Factors of Integration | - | Smart and Sustainable Built Environment | Under Review (First Round of Review) |
| 6 | Evaluation of Factors Influencing Integration | Explore the underlying variables for challenges, strategies, and integration factors.<br><br>To investigate the relationships and effects of factors affecting integration in the New Zealand construction industry. | Factor Analysis<br>Structural Equation Modelling (SEM) | A Comprehensive Evaluation of Factors Influencing Offsite Construction and BIM Integration in the Construction Industry | 2024 | Engineering Construction and Architectural Management | Published |
| 7 | Offsite Construction and BIM Integration: Stakeholder's Perspective | Analyses challenges from a multi-level perspective (stakeholders, project lifecycle and organisational level) in the New Zealand construction industry. | One-Way ANOVA | Offsite Construction and BIM Integration Challenges in New Zealand: Stakeholder's Perspective | 2024 | The Australasian Universities Building Education Association (AUBEA) | In Press |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 | Integration Maturity Assessment Framework | Analyses challenges from a multi-level perspective (stakeholders, project lifecycle and organisational level) in the New Zealand construction industry.<br><br>Develop an integration maturity assessment framework for OSC and BIM within New Zealand construction projects. | Linear Regression<br>Case Reviews<br>Thematic Analysis | An In-depth Examination of Offsite Construction and Building Information Modelling Integration through a Maturity Assessment Framework | - | Engineering Construction and Architectural Management | Under Review (First Round of Review) |
| 9 | Strategic Integration Framework for OSC and BIM | Identify effective strategies for OSC and BIM integration and clarify the roles and responsibilities of stakeholders in implementing these strategies across project lifecycle stages.<br><br>Create a framework to integrate OSC and BIM in the New Zealand construction industry, addressing lifecycle challenges towards integration maturity. | Case reviews<br>Thematic Analysis | OSC and BIM Integration Strategic Integration Framework.<br>Navigating the Project Life Cycle | - | Journal of Construction Engineering and Management | Under Review (First Round of Review) |
| 10 | Conclusion and Recommendation | - | - | - | - | - | - |

### 1.6.6 Ethics

Since this study used human subjects, ethics approval was necessary to guarantee that both the rights and welfare of the participants were protected and to make sure the research was conducted ethically. The Massey University Human Ethics Committee reviewed the research endeavour with peers and determined that it posed little risk. The research incorporated a range of ethical considerations, such as semi-structured expert interviews, anonymous surveys, case studies, and focus group. The Massey University Human Participants Ethics Committee received an ethics application, and the research notification (4000024947) is currently in effect for three years, beginning on September 23, 2021 (Appendix 1).

### 1.6.7 Data Collection

This study utilised different sets of data for analysis at each stage. Following the initial literature review stage, a total of 9 interviews (Appendix 4) were conducted with a diverse group of industry professionals in stage two. These experts included general contractors, consultants, clients, and project managers, all of whom possess at least ten years of experience in OSC and BIM projects. Moving to stage three of the investigation, a survey was carried out (Appendix 5), resulting in 116 valid responses and achieving a response rate of 36.4%. In stage four of the study, four case studies involving OSC projects implementing BIM in their delivery process were reviewed through interviews (Appendix 6) and document analyses. Finally, in stage five of the research, a focus group session survey was conducted (Appendix 8).

## 1.7 Thesis Organisation

This doctoral thesis aligns with Massey University regulations for publishing theses. It is structured into seven main chapters (3 to 9), each titled after a paper that has been published, accepted, or submitted to conferences and journals. The introduction and conclusion of the research are covered in the remaining three chapters of the thesis (1,2 and 10). The thesis's seven chapters have been structured to cover each of the study objectives adequately. The following is a detailed list of the chapters, accompanied by their respective publications and manuscripts:

***Chapter 3: Challenges of Offsite Construction and BIM Implementation;*** explores a comprehensive analysis utilising scientometric methods to examine trends and identify research gaps. It employs document co-citation and keyword co-occurrence analysis of published journal articles to explore the integration of OSC and BIM within the construction industry. Additionally, the chapter conducts a systematic and qualitative review of challenges associated with integration and proposes mitigation strategies. Literature is followed by an interview process, which validates and confirms the results of the literature review. Findings from the literature review and interviews contributed to the development of the conceptual framework.

**Publication:** Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. and Sutrisna, M. (2022), "Challenges of offsite construction and BIM implementation: providing a framework for integration in New Zealand", Smart and Sustainable Built Environment, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/SASBE-07-2022-0139.

***Chapter 4: Challenges for OSC and BIM Integration in New Zealand;*** focuses on the challenges associated with integrating OSC and BIM within the New Zealand construction industry. This chapter conducts a comprehensive examination of these challenges through a combination of literature review and semi-structured interviews with key industry stakeholders. Experts are selected based on their expertise in Offsite Construction (OSC) and their application of BIM in the delivery process, encompassing roles such as design managers, draftspersons, and manufacturers.

**Publication:** Ghalenoei, N. K., Jelodar, M. B., Paes, D., & Sutrisna, M (2022). Exploring Offsite Construction and Building Information Modelling Integration Challenges; Enhancing Capabilities within New Zealand Construction Sector. In IOP Conference Series: Earth and Environmental Science (Vol. 1101, No. 4, p. 042008). IOP Publishing. doi:10.1088/1755-1315/1101/4/042008

***Chapter 5: Factors of OSC and BIM Integration;*** this chapter addresses the categorisation and classification of integration challenges, mitigation strategies, and integration factors. It intends to explore the underlying factors identified in Chapters 2 and 3. By systematically categorising these challenges and strategies, the chapter provides a structured approach to understanding the complexities of integrating OSC and BIM. This analysis helps to identify key factors influencing integration and offers insights into effective mitigation strategies to enhance the integration process.

**Publication:** Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D., Sutrisna, M., Rahmani, D (2024), "The Challenges and Strategies of BIM for Offsite Construction Delivery; the Factors of Integration", under review.

***Chapter 6: Evaluation of Factors Influencing Integration;*** This chapter focuses on examining the relationships among the underlying variables that contribute to integration challenges. It also explores strategies for addressing these challenges across various integration factors. By analysing these relationships, the chapter aims to provide a comprehensive understanding of how different factors influence the effectiveness of integration efforts and to offer practical solutions for improving integration processes.

**Publication:** Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D., Sutrisna, M., Rahmani, D (2024), "A Comprehensive Evaluation of Factors Influencing Offsite Construction and BIM Integration in the Construction Industry ", Engineering Construction and Architectural Management, https://doi.org/10.1108/ECAM-12-2023-1278.

***Chapter 7: Offsite Construction and BIM Integration: Stakeholder's Perspective;*** it contributes to identifying differences in perspectives among various stakeholders regarding integration challenges. It includes an analysis of viewpoints from the client, contractor, and consultant. By examining these differing perspectives, the section seeks to uncover unique challenges and considerations each stakeholder faces in the integration.

**Publication:** Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D., Sutrisna, M., Rahmani, D (2024), "Offsite Construction and BIM Integration Challenges in New Zealand: Stakeholder's Perspective", The Australasian Universities Building Education Association (AUBEA), November 2023, in press.

***Chapter 8: Integration Maturity Assessment Framework;*** it focuses on developing an integration maturity assessment framework to facilitate higher levels of integration between OSC and BIM. Additionally, it explores the challenges encountered at various stages of the project lifecycle and across different organisational levels, including project, organisation, and industry levels.

**Publication:** Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D., Sutrisna, M., Rahmani, D (2024), " An In-depth Examination of Offsite Construction and Building Information Modelling Integration through a Maturity Assessment Framework", Management in Engineering, under review.

***Chapter 9: Strategic Integration Framework for OSC and BIM;*** deals with developing a structured integration framework at the project level by addressing integration challenges across different project lifecycle stages and maturity levels. It also suggests strategies for stakeholders to mitigate these challenges at various levels and clarifies who is responsible for each aspect of the integration process.

**Manuscript:** Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D., Sutrisna, M., Rahmani, D (2024), " OSC and BIM Integration Strategic Integration Framework; Navigating the Project Life Cycle", under review.

# Chapter 2: Literature Review

This chapter presents a comprehensive review of the literature surrounding the integration of Offsite Construction (OSC) and Building Information Modelling (BIM), focusing on the theoretical foundations that inform this integration at the project, organisational, and industry levels. The primary aim of this chapter is to establish a solid theoretical base for understanding how OSC and BIM interact and how their combined application can transform the construction industry. By exploring existing research and theory, this chapter sets the stage for subsequent empirical investigations into the challenges and strategies associated with OSC-BIM integration.

The first section of the chapter introduces OSC and BIM, detailing their respective concepts, advantages, challenges, and adoption drivers. It provides a foundational understanding of both methodologies, offering insights into their individual strengths and limitations, as well as the context in which they have developed and evolved. The section will also cover terminology clarifications for OSC, addressing key terms such as modularisation, prefabrication, and industrialised construction, and drawing comparisons to other construction methods.

In the second part, the focus shifts to the integration of OSC and BIM. Here, the rationale for combining these two approaches is discussed, along with a conceptualisation of how their integration works in practice. This section identifies the various challenges involved in the integration process, including technological, cultural, and managerial hurdles, and offers strategies for overcoming these obstacles, ensuring a more effective and efficient integration process.

The final sections of the chapter delve into the theoretical foundations of OSC-BIM integration, addressing the dynamics at the project, organisational, and industry levels. By examining the key phases of the project lifecycle, the influence of organisational structures, and the broader market and industry trends, this chapter provides a holistic view of the factors that shape the successful adoption and integration of OSC and BIM. Key theoretical frameworks, including system integration theory and stakeholder management, are explored to offer a deeper understanding of how integration can be managed strategically. In addition, the role of strategic development in driving successful OSC-BIM integration is also highlighted.

The chapter concludes by reviewing maturity models, including the Capability Maturity Model (CMM), and their application to OSC-BIM integration, justifying the choice of a staged maturity model for this research. This discussion will set the groundwork for identifying key research gaps in the field and highlighting the theoretical contributions that this study aims to make.

Through this literature review, the chapter will not only provide a detailed analysis of the existing body of knowledge but will also lay the foundation for the research methodology in the following chapters. By addressing the theoretical underpinnings of OSC-BIM integration, this chapter contributes to the broader academic discourse while providing a practical framework for future research and implementation in the construction industry.

## 2.1 Offsite Construction (OSC)

OSC is an innovative approach that originated from the manufacturing industry, aiming to replace traditional in-situ construction processes by prefabricating components in controlled environments before transporting them to the construction site for final assembly (Kamali & Hewage, 2016). This approach leverages advanced manufacturing techniques to improve the efficiency, quality, and sustainability of construction activities. OSC encompasses a broad range of construction practices, including prefabrication, modularisation, industrialised housing, and hybrid systems. These terms are frequently used interchangeably, but their meanings and applications often vary depending on regional, industrial, and technical contexts

(Jang et al., 2021). Prefabrication typically refers to the offsite manufacturing of specific components, while modular construction involves assembling pre-manufactured volumetric modules on-site. Industrialised housing, on the other hand, emphasises standardisation and mass production techniques applied to residential construction (BCA, 2017).

OSC can be categorised into several typologies based on the extent of prefabrication and the complexity of the manufacturing process. Panelised systems involve prefabricating individual components such as walls, floors, and roof panels in factory settings, which are later assembled on-site. These systems are widely used in residential projects where standardisation is feasible (BCA, 2017; PrefabNZ, 2018a).

Volumetric modular systems, on the other hand, involve the prefabrication of complete modules, such as kitchens or bathrooms, that are equipped with fixtures and finishes before being transported and assembled on-site. This method ensures a high degree of quality control and is often employed in large-scale residential or commercial developments (Chourasia et al., 2023). Hybrid systems combine elements of both panelised and modular construction, offering flexibility to address project-specific requirements while retaining the benefits of standardised manufacturing processes (Salama et al., 2016).

### 2.1.1 OSC in New Zealand and Global Context

Globally, OSC has been successfully implemented in countries such as Sweden, Finland, the UK, and the United States. In Sweden and Finland, advanced modular systems have been extensively utilised in residential projects, supported by stringent quality control measures and technological innovation (Jiang et al., 2021). The UK has made significant progress in OSC adoption through government-backed initiatives promoting Modern Methods of Construction (MMC), which focus on improving efficiency and reducing environmental impact in public infrastructure and housing projects (Jang et al., 2021). In New Zealand, OSC is gaining traction as a response to the ongoing housing crisis and productivity challenges in the construction sector (PrefabNZ, 2018a, b). Initiatives such as KiwiBuild and pilot OSC projects have demonstrated the potential for OSC to deliver affordable and high-quality housing solutions (Tookey, 2021). However, the adoption of OSC in New Zealand continues to face challenges, including high initial investment costs, logistical complexities, and a shortage of skilled labour trained in advanced OSC methodologies (Kamali & Hewage, 2016; Zou et al., 2022).

### 2.1.2 OSC Advantages

The advantages of OSC are well-documented, with efficiency being one of its most significant benefits. By enabling concurrent offsite manufacturing and on-site assembly, OSC significantly reduces project timelines and minimises delays caused by weather conditions or on-site resource constraints (Abanda et al., 2017). Additionally, cost savings are achieved through optimised material usage, reduced on-site labour requirements, and minimal rework due to precise prefabrication techniques (Gan et al., 2018a; Hwang et al., 2018a). Sustainability is another key advantage of OSC, as manufacturing in controlled environments reduces material waste and enables better resource management. Furthermore, worker safety is enhanced by reducing on-site activities, as most processes occur in factory-controlled settings where health and safety protocols are easier to enforce (Kamali & Hewage, 2016).

### 2.1.3 Challenges in OSC Adoption

Despite its advantages, OSC adoption faces significant technical, financial, and organisational barriers. Technical barriers include the logistical challenges associated with transporting large, prefabricated components to construction sites and ensuring seamless integration during assembly (Gan et al., 2018a; Gan et al., 2018b; Hwang et al., 2018a). Financial barriers stem from the high initial investment required to establish manufacturing facilities, procure specialised equipment, and develop skilled labour (Hong et al., 2018). Organisational barriers further complicate OSC adoption, as limited workforce training, resistance to change, and a lack of standardised processes hinder seamless implementation (Jang et al., 2021). Additionally, the integration of OSC with digital tools faces challenges related to software compatibility, lack of standardised workflows, and fragmented communication between stakeholders (Yin et al., 2019).

### 2.1.4 Drivers for OSC Adoption

The adoption of OSC is driven by a combination of government support, market demands, and technological advancements (Khan et al., 2022). Regulatory incentives and policy frameworks have played a critical role in encouraging OSC adoption through pilot projects and funding schemes. Market demand for faster, more cost-effective, and sustainable construction solutions continues to push the boundaries of OSC innovation (Shahzad et al., 2022; Zolghadr et al., 2022). Technological advancements, including the integration of OSC with digital tools such as BIM, Internet of Things (IoT), and Artificial Intelligence (AI), have further enhanced manufacturing precision, collaboration, and real-time monitoring capabilities (Alsakka et al., 2023; Bakhshi et al., 2022; Shahzad et al., 2023).

## 2.2 Building Information Modelling (BIM)

BIM is a powerful digital tool that facilitates collaboration among various stakeholders in a construction project, improving productivity, accuracy, and sustainability throughout the project lifecycle (Chong et al., 2017; Eastman et al., 2011). BIM is defined as “a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle, from earliest conception to demolition” (Annex & Rules, 2015). It provides a centralised digital platform for managing project data, allowing architects, engineers, contractors, and suppliers to collaborate in real time across different project phases (Guignone et al., 2023). This collaborative environment supports informed decision-making, reduces errors, and improves efficiency by enabling stakeholders to identify and resolve design clashes early in the project lifecycle (Bryde et al., 2013; Chi et al., 2015).

In the New Zealand context, BIM adoption is steadily increasing, driven by initiatives such as the BIM Acceleration Programme, which aims to raise awareness and encourage the use of BIM in construction projects (BIM Acceleration Committee, 2019). However, challenges remain, including high implementation costs, limited expertise, and resistance to change within the construction industry (Kordestani et al., 2022).

### 2.2.1 BIM Advantages

The adoption of BIM in the construction industry offers several advantages, particularly in enhancing collaboration, visualisation, and project management. BIM facilitates improved project coordination by enabling stakeholders to work on a centralised model with real-time updates, reducing the risk of errors and miscommunication (Eastman et al., 2011). It supports advanced design simulations, including energy performance analysis and clash detection, which help optimise resource allocation and reduce material waste (Azhar, 2011).

Another significant advantage of BIM is its contribution to lifecycle management, enabling efficient maintenance and operations of assets beyond the construction phase. Through its data-rich environment, BIM allows facility managers to monitor, maintain, and optimise building performance throughout its operational life (Alazmeh et al., 2018; Jin et al., 2017; Lee & Kim, 2017). Furthermore, BIM improves productivity by streamlining design processes, facilitating early problem detection, and reducing the need for costly rework during construction (BuHamdan et al., 2021; Sun et al., 2021).

### 2.2.2 Challenges in BIM Adoption

Despite its advantages, BIM adoption faces several challenges. The high initial cost of software, hardware, and training represents a significant financial barrier, particularly for small to medium-sized enterprises (SMEs) (Alazmeh et al., 2018; Makabate et al., 2021). The fragmented nature of the construction industry also complicates BIM implementation, as interoperability issues (Ghaffarianhoseini et al., 2017) guidelines for BIM adoption, leading to inconsistent implementation across projects (Chong et al., 2017). Data ownership and intellectual property rights further add to the complexity, as stakeholders may be hesitant to share sensitive project information on shared BIM platforms (Abanda et al., 2017; Nawari, 2012). Resistance to change within organisations, particularly among senior management and decision-makers, remains a persistent barrier to BIM adoption, slowing its widespread implementation across the industry (Mao et al., 2015; Zhang et al., 2018).

### 2.2.3 Drivers for BIM Adoption

The adoption of BIM is primarily driven by regulatory mandates, market demand for increased project efficiency, and advancements in digital technologies. Countries such as the UK and Singapore have implemented mandatory BIM adoption policies for public-sector projects, significantly accelerating its integration across the construction sector (Kassem et al., 2013; Succar, 2010). In New Zealand, the BIM Acceleration Programme has played a crucial role in raising awareness and promoting BIM adoption through industry-wide initiatives (BIM Acceleration Committee, 2019).

Technological advancements, including integration with AI, IoT, and cloud-based collaboration platforms, have further enhanced BIM's capabilities, making it a central tool for managing complex construction projects (Wu et al., 2022; Xu et al., 2018). The growing need for sustainability in construction has also driven BIM adoption, as its simulation capabilities allow for energy efficiency assessments, carbon footprint analyses, and resource optimisation throughout a project's lifecycle (Azhar, 2011; Goulding & Arif, 2013).

## 2.3 Integration of OSC and BIM

The integration of OSC with BIM has become a pivotal strategy to address longstanding inefficiencies in the construction industry. Both BIM and OSC aim to enhance productivity, reduce waste, improve quality control, and optimize project planning and execution(Abanda et al., 2017; Gu & London, 2010). While BIM focuses on creating centralised digital models for precise design coordination, clash detection, and scheduling, OSC relies on accurate prefabrication and modular assembly. Integrating these two methodologies enhances both the design and execution phases of construction projects (Liu et al., 2017a; Liu et al., 2017b; Rashidian et al., 2023).

BIM plays a critical role in managing information flows within OSC projects. Its detailed design information ensures that prefabricated components align precisely during onsite assembly (Liu et al., 2021b; Porwal et al., 2023). Real-time updates in BIM help mitigate discrepancies between design and construction, which is essential for offsite manufacturing accuracy (Gu & London, 2010). Furthermore, BIM's collaborative nature facilitates communication among design, manufacturing, and assembly teams, reducing errors, delays, and cost overruns (Alazmeh et al., 2018).

The synergy between BIM and OSC creates value by integrating digital tools with physical processes, optimizing efficiency, sustainability, and overall project performance (Zheng et al., 2023). This integration not only enhances operational performance but also contributes to sustainability by reducing material waste and improving timelines (Kordestani Ghalenoei et al., 2024a).

### 2.3.1 BIM's Integration Capabilities and OSC Needs

BIM's integration capabilities are essential for addressing OSC's operational and strategic needs, particularly in enhancing precision, efficiency, and scalability. One of the key features is BIM's ability to facilitate design coordination and clash detection. In OSC, prefabricated components depend on highly accurate designs to ensure seamless on-site assembly, and BIM's clash detection helps prevent costly rework during both the manufacturing and assembly phases (Liu et al., 2017a; Ocheoha & Moselhi, 2018).

BIM also supports real-time collaboration through, where all stakeholders—designers, manufacturers, contractors—can access consistent and up-to-date information. This is crucial in OSC, where multiple participants across various locations are involved (Likita et al., 2023). Additionally, BIM's 4D modelling aligns prefabrication and on-site assembly schedules, ensuring that delays in one phase do not disrupt the entire construction process (Lee & Kim, 2017).

BIM's ability to manage material movement and streamline procurement further supports OSC's logistics and supply chain management, improving resource utilisation and reducing inefficiencies. The centralised digital repository maintained by BIM also ensures the preservation of the design intent throughout the lifecycle of the project, from design to post-completion maintenance (Kassem et al., 2013; Succar, 2010).

### 2.3.2 Rationale for OSC-BIM Integration

The integration of BIM with OSC offers significant opportunities for improving construction efficiency, reducing costs, and enhancing project outcomes. As the industry faces pressures to deliver faster, high-quality projects at lower costs, combining OSC and BIM presents a strategic approach to these challenges (Abanda et al., 2017). While OSC focuses on offsite fabrication and modular assembly, BIM provides the digital backbone that ensures seamless integration across the design, manufacturing, and construction phases (An et al., 2020b). BIM's alignment with OSC's need for precise and consistent information makes it an invaluable tool in ensuring the success of prefabricated components. Through real-time collaboration and a shared data environment, BIM ensures that all project stakeholders are on the same page, reducing errors and improving communication (Jang et al., 2022).

Additionally, BIM supports the standardisation of components, a fundamental aspect of OSC. Its parametric design tools ensure that prefabricated elements meet the required specifications, improving quality control and facilitating better logistics (Bakhshi et al., 2022). The integration of BIM with OSC also enhances sustainability by reducing material waste, optimizing resource efficiency, and managing the lifecycle of the project more effectively (Khan et al., 2022). In conclusion, integrating BIM with OSC creates a more streamlined, collaborative, and sustainable approach to construction. This synergy addresses the industry's current and future challenges by enhancing project efficiency, quality, and sustainability.

### 2.3.3 Challenges in OSC-BIM Integration

While the potential benefits of integrating BIM and OSC are clear, there are several challenges that organisations must address to successfully implement this integration. These challenges are primarily technological, cultural, and managerial in nature, each of which can create barriers to successful adoption and implementation (Kordestani Ghalenoei et al., 2022a, b).

Technologically, the integration of BIM with OSC requires compatibility between the digital tools used for design and those employed in offsite manufacturing. Many offsite construction processes rely on specialised software to produce modular components, which may not always be directly compatible with the BIM software used for design coordination.

This lack of interoperability can hinder the smooth exchange of information between the different stakeholders involved in a project (Sacks et al., 2010a).

Culturally, the integration of BIM and OSC often requires a shift in mindset and working practices. The construction industry is traditionally fragmented, with distinct silos between design, manufacturing, and construction teams. Adopting BIM and OSC requires breaking down these silos and fostering a collaborative, integrated approach to project delivery (Ocheoha & Moselhi, 2018; Sabet & Chong, 2019). This cultural shift can be difficult, particularly in organisations that have long-standing practices or where there is resistance to change from stakeholders (Luo et al., 2019).

One of the key challenges is ensuring that the integration process is well managed throughout the project lifecycle (Kamali & Hewage, 2016). Effective integration requires coordination across multiple phases, from design and manufacturing to on-site assembly and maintenance. This requires strong project management skills and the ability to maintain a cohesive workflow across all stages of the project (Ji et al., 2020; Kamali & Hewage, 2016). Furthermore, organisations must address issues related to training and skill development to ensure that all team members are capable of using BIM and OSC tools effectively (Jiang et al., 2020; Jiang et al., 2021).

### 2.3.4 Strategies for Effective Integration

To overcome the challenges associated with OSC-BIM integration, several strategies can be employed to ensure its effectiveness. These strategies focus on fostering collaboration, improving interoperability, and enhancing project management practices (Kordestani et al., 2022). One of the most important strategies is to establish a clear and structured framework for collaboration among all stakeholders. This involves creating a shared understanding of the project's goals, requirements, and workflows. By establishing a proper workflow, stakeholders can ensure that all project participants have access to accurate, up-to-date information, which is essential for preventing errors and delays (Kordestani Ghalenoei et al., 2024b; Porwal et al., 2023). This collaborative framework can also be supported by using cloud-based platforms and digital communication tools that allow for real-time updates and coordination across different project phases (Xu et al., 2018).

Another key strategy is to focus on improving the interoperability of BIM with the software and tools used in OSM. This may involve selecting BIM tools that are compatible with existing manufacturing processes or adopting software that enables easy data exchange between design and manufacturing platforms (Tan et al., 2024). In addition, organisations should invest in training and capacity-building efforts to ensure that all team members have the necessary skills to work with BIM and OSC technologies. This includes providing training on both the technical aspects of BIM and the collaborative practices required for successful integration (Ji et al., 2020; Yin et al., 2019).

From a managerial perspective, it is important to implement robust project management practices that ensure effective coordination between the design, manufacturing, and construction phases. This may involve using BIM to create detailed schedules and project timelines, which can help synchronise manufacturing and onsite activities, reducing the risk of delays (Liu et al., 2017b). Additionally, employing a phased approach to BIM-OSC integration can help organisations manage the transition more smoothly, starting with smaller-scale applications and gradually scaling up as the team gains experience (Razkenari & Kibert, 2022).

## 2.4 Theoretical Foundations

### 2.4.1 System Integration

Integration as a theoretical concept is rooted in systems theory, organisational theory, and management science. It involves bringing together subsystems, processes, and entities to function as a cohesive whole, ensuring alignment between disparate parts. The challenge lies in managing interdependencies and achieving unified objectives across organisations, technologies, or projects. General Systems Theory, introduced by von Bertalanffy (1969), offers a foundational framework for understanding integration. It views systems as interconnected, where interactions between parts are as important as the parts themselves.

In this context, integration refers to the coordination of these parts to ensure effective system operation. Fragmented systems lead to inefficiencies and miscommunication, preventing collective goals from being achieved. Cybernetics, closely tied to systems theory, highlights feedback loops and control mechanisms that maintain system stability in response to changes (Ashby, 1956a).

In organisational theory, integration refers to how departments and teams collaborate to achieve overarching goals. Lawrence and Lorsch (1967) introduced the differentiation and integration theory, which posits that as subsystems become specialised, the need for integration grows to ensure the organisation functions as a whole. Both formal mechanisms (e.g., hierarchical control and standardised procedures) and informal ones (e.g., collaboration and negotiation) are essential.

Similarly, Galbraith's (1974) information processing theory underscores the importance of information flows in managing complexity, with lateral relationships and cross-functional teams becoming critical in modern organisations. The Project Management Body of Knowledge (PMBOK) (2021) highlights integration as a central project management area, ensuring all aspects of a project are aligned towards common objectives. While this structured approach provides clear guidance, scholars like Hobday (2000) and Weick (1988) argue that in highly dynamic and complex environments, flexibility through informal communication channels and shared leadership often becomes more effective. Such "loose coupling" can better handle uncertainty and rapidly evolving requirements, where formal processes may constrain innovation.

The rise of digital technologies has added complexity to integration efforts. Traditional integration theories, while foundational, are limited in addressing challenges posed by modern technological infrastructures. Today, integration requires aligning diverse digital systems, ensuring seamless data flows, and maintaining interoperability across platforms (Rajabalinejad et al., 2020) Digital transformation demands a more flexible, multi-layered approach, especially in industries like construction and software development, where rapid technological advancements necessitate dynamic, cross-functional collaboration (Shaikh et al., 2020).

### 2.4.2 Strategy Development

Strategy development focuses on the creation, implementation, and evaluation of decisions aimed at achieving long-term organisational goals. Classical theories, such as Porter's (Porter, 1991) Five Forces Model and his Generic Strategies, provide foundational insights into competitive positioning, emphasising responses to industry forces. These models advocate for cost leadership, differentiation, or focus as routes to competitive advantage, but their focus on static market conditions and competition overlooks the increasing importance of collaboration in globalised markets.

The Resource-Based View (RBV), as discussed by Barney (2001), shifts focus from external competitive forces to internal capabilities. RBV argues that competitive advantage arises from valuable, rare, inimitable, and non-substitutable (VRIN) resources. While RBV effectively highlights the importance of leveraging internal strengths, it can downplay the role of rapidly changing external market conditions. As a response to the limitations of RBV and classical theories, Teece et al.'s (1997) Dynamic Capabilities framework focuses on how organisations adapt and reconfigure resources to stay competitive in tense markets. This approach stresses the importance of flexibility, organisational learning, and continuous resource renewal, especially in innovation-driven industries.

Whittington's (2006) Strategy as Practice (SAP) further shifts attention to the micro-level actions and decisions involved in strategy-making. SAP views strategy as an ongoing practice involving individuals at all levels of an organisation, focusing on decision-making processes, power dynamics, and organisational culture. Mintzberg's (1987) Emergent Strategy offers a complementary view, suggesting that strategies often evolve through learning and adaptation, particularly in uncertain and changing environments. These perspectives challenge top-down approaches, highlighting flexibility and human agency, though they can be critiqued for their lack of prescriptive clarity on how to shape deliberate strategies.

While traditional models like Porter's provide structured competitive analysis, they are criticised for their static nature and lack of attention to dynamic market changes. RBV and dynamic capabilities add a flexible and internal focus but may overlook broader external factors. Modern approaches like SAP and Emergent Strategy recognise adaptability and human involvement but often lack specific guidance on strategic success.

### 2.4.3 Stakeholder Management

Stakeholder management is central to project management and organisational theory, especially in complex, multi-stakeholder environments like construction projects. Freeman's (Freeman, 1984) stakeholder theory expands the focus from a shareholder-centric model to one that includes a variety of groups, such as employees, customers, and suppliers, all of whom have a stake in the organisation's outcomes. In construction, this theory is crucial as stakeholders range from clients and contractors to regulators and future users of the built asset. The ability to balance and satisfy these diverse interests is seen as fundamental to project success. Mitchell, Agle, and Wood's (1997) Stakeholder Salience model advances this theory by categorising stakeholders based on power, legitimacy, and urgency, providing project managers with a practical framework for prioritising stakeholder engagement.

In organisational theory, Hillman et al. (2009) resource dependence theory suggests that organisations depend on external resources controlled by stakeholders, making stakeholder management crucial for long-term success. In construction, these resources are not just financial but include materials, labour, and regulatory approvals, necessitating ongoing engagement. Network governance theory (Jones et al., 1997) further supports this by emphasising the role of trust and relational ties in facilitating coordination, particularly in construction where various subcontractors and suppliers must collaborate. Dynamic stakeholder management is particularly relevant in large-scale projects, where stakeholder roles and interests can evolve over time.

Shenhar and Holzmann (2017) highlight the need for flexibility and adaptability in managing stakeholders across the project lifecycle, while Bordat et al. (2004) stresses the importance of communication in preventing delays and budget overruns. Effective communication frameworks, including regular meetings and digital platforms, are essential for aligning stakeholder interests and mitigating conflicts.

Oluleye et al. (2023) further explores how enhanced communication fosters innovation and operational success, particularly in the early planning and post-completion phases. However, traditional models often treat stakeholders as static entities and place too much emphasis on formal communication, overlooking the importance of informal networks, trust, and collaboration in complex projects. Additionally, while digital tools and real-time communication platforms are increasingly essential for stakeholder management, they are often not fully integrated into these frameworks, leaving gaps in how technology can enhance stakeholder engagement (Nguyen et al., 2022; Ninan et al., 2019).

### 2.4.4 Organisational Structure

In this research, the decision to focus on the project level while differentiating between the project, organisation, and industry levels is supported by a combination of theories that, together, offer a coherent and comprehensive theoretical foundation. These theories—Contingency Theory, Project-Based Organisations (PBO) Theory, Systems Theory, and Pragmatism—provide an integrated perspective that justifies both the scope and structure of this research.

***Integrated Theoretical Justification***

The first pillar of this framework is Contingency Theory, which argues that there is no one-size-fits-all approach to organisational structure and management; instead, the best approach depends on the specific circumstances in which the organisation operates (Donaldson, 2001). In this research, the focus on the project level reflects the contextual contingencies encountered during the study, particularly the accessibility of project-level data and the greater flexibility for implementing changes at the project level compared to the organisational or industry levels. Thus, contingency theory supports the choice of narrowing the research scope to projects, as this approach best suited the constraints and opportunities presented by the research environment in the construction industry.

Building on this, Project-Based Organisations (PBO) Theory further strengthens the argument for focusing on projects by highlighting that, in many industries—especially construction—projects serve as the central operational unit (Turner & Keegan, 2001). PBO theory explains that organisations structured around projects rely on project management practices to drive their operations, making the project level a natural focal point for research. By structuring the research around projects, this study aligns with how construction organisations typically function, ensuring that the findings are directly applicable to real-world organisational dynamics in the industry.

While Contingency Theory and PBO Theory justify the focus on the project level, Systems Theory provides a broader framework for understanding how the project, organisation, and industry levels are interrelated. Systems theory, as articulated by Von Bertalanffy (1968), views organisations as systems composed of interdependent subsystems. In this research, the project, organisation, and industry levels are conceptualised as distinct yet interconnected subsystems, where changes at one level influence and are influenced by the other levels. For example, industry-wide regulations may affect organisational strategies, which in turn impact project-level execution. By acknowledging these interactions, systems theory justifies the differentiation between these levels while also validating the need to study the project level in relation to the broader organisational and industry contexts.

Finally, Pragmatism serves as the practical underpinning for this research approach. Pragmatism emphasises the importance of selecting methods and approaches based on their practical utility and the specific goals of the research (Creswell, 2013). In this case, the project level was chosen not only for theoretical reasons but also for practical ones: it offered the most accessible data and allowed for a more actionable investigation into OSC and BIM integration. Pragmatism justifies this decision by prioritising what works best in achieving meaningful and real-world outcomes, reinforcing the practical relevance of the research findings.

### 2.4.5 Industry/ Market Dynamics

Industry and market dynamics focus on the forces shaping industries and markets, including technological advancements, regulatory changes, shifts in consumer demand, and competitive pressures. Theories such as Michael Porter’s Five Forces (Porter, 1991) provide a framework to assess competition, examining five forces: rivalry among existing competitors, the threat of new entrants, the threat of substitutes, and the bargaining power of buyers and suppliers. Porter's model helps firms position themselves strategically to gain a competitive advantage, but it has been critiqued for being static, as it doesn't account for the rapid technological changes and market disruptions prevalent today. Hypercompetition theory responds to this, suggesting industries are characterised by fast-moving competition where success relies on continuous adaptation and innovation, challenging the idea of stable industry structures (D'Aveni et al., 2010).

The Resource-Based View (RBV) of the firm complements Porter's model by focusing on a firm's internal resources and capabilities as drivers of competitive advantage. RBV argues that valuable, rare, and difficult-to-imitate resources can help firms achieve sustained success (Barney et al., 2001). However, it has been criticised for underestimating the role of external market conditions and rapid change, which can outdate the value of these resources. Dynamic capabilities theory (Teece et al., 1997) extends RBV by emphasising the need for firms to continuously reconfigure and adapt their resources in response to evolving market conditions. It highlights the importance of strategic flexibility, especially in industries characterised by rapid technological advancements and changing customer preferences.

Disruptive innovation theory (Markides, 2006) further explains market dynamics by showing how new entrants with niche or lower-market offerings can eventually disrupt established industry leaders, fundamentally reshaping entire industries. While foundational theories like Porter's Five Forces and RBV offer valuable insights, they tend to overlook the complexities of today's fast-changing industries. Hypercompetition, dynamic capabilities, and disruptive innovation provide more dynamic perspectives but pose challenges in maintaining both short-term agility and long-term strategy. Firms must integrate these models to leverage internal resources while adapting to technological and market changes.

### 2.4.6 Maturity Models

It is essential for organisations to assess their processes and overall maturity levels to create a roadmap for progressive improvement. Maturity models, originally designed in the software engineering field, provide a conceptual framework that outlines current maturity levels of services or specific tasks. These models allow organisations to develop action plans for improving their maturity levels (Backlund et al., 2014; PMBOK, 2021). However, not all organisations need to achieve the highest maturity level, as doing so may require significant resources and substantial changes. Instead, the focus should be on the appropriateness of the maturity improvement process, rather than solely on reaching the highest level (Król & Zdonek, 2020; Poeppelbuss et al., 2011).

Numerous maturity models have been developed to help organisations compare their current state against best practices and industry standards (Fabbro & Tonchia, 2021). These models can be adapted for different organisational purposes and contexts. For example, the Capability Maturity Model (CMM) assesses process maturity, while the Organisational Project Management Maturity Model (OPM3) evaluates organisational capabilities (Mustafa, 2015). CMM is designed to assess and improve the maturity of processes or activities within an organisation, focusing on defining inputs and expected outputs for optimisation. It is widely used to enhance efficiency in areas such as asset management, including property and maintenance management (Jayanetti et al., 2022; Macchi et al., 2011).

***Capability Maturity Model (CMM)***

There are two representations in CMM: the Staged Representation (SR) and Continuous Representation (CR) (Uskarcı & Demirörs, 2017). The SR is characterised by five predefined maturity levels (Initial, Managed, Defined, Quantitatively Managed, Optimizing), each with specific process areas and goals (Macchi et al., 2011). SR presents a rigid improvement path where organisations must follow a sequential roadmap, progressing through the maturity levels. In contrast, CR offers more flexibility, allowing organisations to measure and improve specific process areas individually. CR defines six capability levels, ranging from Incomplete to Optimising, with a focus on prioritising improvements aligned with business objectives. CR is particularly useful in sectors with limited budgets, as it enables organisations to target areas most in need of improvement (Team, 2002; Team, 2006).

While these two representations are well-defined, individual organisations often develop their own in-house maturity models, which vary due to differences in structure, culture, and business context. The criteria for reaching a "competent" or "excellent" level may differ between sectors, making the application of these models complex across different organisational contexts (Jayanetti et al., 2022).

# Chapter 3: Conceptual Framework for Integration Challenges and Strategies

***The current chapter is based on the following article:***

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. and Sutrisna, M. (2022), "Challenges of offsite construction and BIM implementation: providing a framework for integration in New Zealand", Smart and Sustainable Built Environment, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/SASBE-07-2022-0139.

## 3.1 Introduction

The construction industry is typically the most significant sector for infrastructure development in any country, including New Zealand. The industry faces significant challenges, including high costs, low productivity, and a lack of innovation (Ghalenoei et al., 2022; Mirus et al., 2018a). One of the main strategies to increase productivity is digital technologies and offsite manufacturing (PrefabNZ, 2018a, b). Offsite Construction (OSC) is a method that involves moving the construction process away from the site into a controlled factory environment (Jiang et al., 2018; Martinez et al., 2020). It allows simultaneous site planning and production of building elements (Kamali & Hewage, 2016) and can save between 30–50% of project delivery time compared to conventional construction (Kamali & Hewage, 2016). OSC is deemed a viable solution to the difficulties of meeting the demands for high-quality and low-cost construction. However, the lack of widespread adoption of advanced technology is a significant constraint for OSC implementation worldwide (Abanda et al., 2017).

OSC is considered part of industry 4.0 advancements, which can be facilitated through Building Information Modelling (BIM) in many ways (Abanda et al., 2017). BIM is "a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" (Annex & Rules, 2015). BIM tools and processes play an essential role in supporting OSC and facilitate the efficient management of functional digital construction models (Herrera et al., 2021; Zhong et al., 2017).

While BIM is known to enhance current advantages like reducing time, clash detection by helping to address existing problems associated with OSC, many studies highlight the need to investigate further the integration between these technologies (Hosseini et al., 2018; Li et al., 2019; Wang et al., 2020). The joining of different parts into a whole is called integration. In the context of construction, this entails bringing together all parties involved in project delivery so that they can cooperate to achieve a single objective (Liu et al., 2021b; Sanvido & Medeiros, 1990). In this research, integration means combining OSC and BIM advantages to improve productivity in New Zealand's construction industry.

Overall, while previous studies have provided valuable insights for recent OSC and BIM applications and advances, there have been no investigations on the practical integration strategies for reducing OSC and BIM implementation challenges. It should be noted that, despite the rapid global growth of OSC and BIM, their integration in many countries, including New Zealand, seems to be overlooked (Mirus et al., 2018a; PrefabNZ, 2018a, b). Developing robust integration strategies at the organisational and project levels will assist stakeholders in identifying what needs to be done and at what level in order to reduce challenges.

Therefore, there is a need to identify, structure, and document strategies to improve the integration of OSC and BIM in New Zealand (Abanda et al., 2017; Tan et al., 2019). Consequently, this study develops a robust OSC and BIM integration framework for the New Zealand construction industry. This is done through investigating integration challenges and proposing appropriate strategies to overcome these challenges. New Zealand construction will primarily benefit from such an integration framework, given that OSC can deliver solutions to its current housing shortage problems (PrefabNZ, 2018a). Outcomes will also provide a solid platform for further studies investigating the same topic in similar construction markets worldwide. Specific objectives include a) Assess the current state of OSC and BIM integration research and identify factors influencing integration globally and in New Zealand, b) Develop a conceptual integration framework for OSC and BIM in the New Zealand construction industry at the organisational and project levels.

## 3.2 Literature Review

This section provides a comprehensive review of the existing literature related to OSC and BIM. It covers the key concepts, benefits, and challenges associated with OSC, as well as the role of BIM in addressing these challenges. The review also explores the current state of OSC and BIM integration, summarising relevant studies, conceptual frameworks, and practical implementations. Finally, it identifies critical gaps in the research, emphasizing the need for a holistic integration framework to enhance the implementation of OSC and BIM in the construction industry.

### 3.2.1 Overview of Offsite Construction, Benefits and Challenges

OSC is an innovative construction approach that originated from the manufacturing industry o eventually replace the conventional in-situ construction process (Kamali & Hewage, 2016). significant number of studies highlights the benefits of OSC over conventional on-site construction and have explained why OSC has gained popularity in recent years (Hwang et al., 2018a; Wong et al., 2017; Zhong et al., 2017). These advantages include improved efficiency, reduced construction time, and enhanced sustainability. Despite these benefits, the adoption of OSC faces several challenges. Common challenges include the lack of advanced technology, insufficient transportation logistics, and inadequate onsite assembly processes (Gan et al., 2018a; Hong et al., 2018).

Further challenges include a shortage of trained and skilled operatives, limited educational programmes, and insufficient project management knowledge, all of which impact the effective implementation of OSC (Ayalp & Ay, 2020; Lou & Kamar, 2012). Additionally, while OSC offers cost savings over the project's lifecycle (Darko et al., 2020; Wong et al., 2017), the initial capital investment required can be a deterrent (Ayalp & Ay, 2020; Lou & Kamar, 2012; Sutrisna et al., 2019). Efficient OSC implementation demands the sharing of practical knowledge among stakeholders, which in turn necessitates robust information management systems and the use of advanced technologies, such as (Li et al., 2019).

### 3.2.2 Introduction to Building Information Modelling

BIM is a powerful tool that facilitates collaboration among various parties involved in a construction project, promoting increased productivity and sustainability throughout the project lifecycle (Eastman et al., 2011). Many issues in different stages of OSC can be effectively handled by BIM technology (Chong et al., 2017). For instance, BIM is particularly effective in addressing many of the challenges encountered in different stages of OSC. It enables virtual testing of inefficient or non-value-adding onsite operations, improving processes such as clash detection and rework management (Bryde et al., 2013). This capability can reduce material waste, minimise labour requirements, and prevent costly rework during construction (Chi et al., 2015). However, the integration of new technologies like BIM is not without its challenges. Key obstacles include a lack of training, high implementation costs, and unclear guidance on best practices for its adoption (Alazmeh et al., 2018; Jin et al., 2017; Lee et al., 2015).

### 3.2.3 Integration of OSC and BIM

Although BIM applications have progressed within more conventional construction methods, their integration with OSC has yet to be realised practically (Goulding et al., 2015; PrefabNZ, 2018b; Wang et al., 2020). Integration remains rudimentary and highly undocumented (Abanda et al., 2017) and thus requires further development (Yin et al., 2019). Tang et al. (2019b) showed a strong link between BIM deployment and the performance of OSC through integrative management and cooperative behaviour. Yin et al. (2019) pointed out directions for future research on OSC and BIM integration, including BIM-based generative design for prefabrication, Cloud BIM-based data exchange for OSC, robotics and 3D printing for OSC, BIM-enabled big data analytics toward best OSC practice, and benefits assessment models of BIM for OSC.

The integration of BIM with OSC has evolved through various studies, each contributing to a deeper understanding of their interplay. A study done by Goulding et al. (2015) indicated that BIM adoption in OSC is a significant issue but did not propose any integration strategies. Following this, Nath et al. (2016) introduced a technologically enhanced BIM-based workflow, demonstrating improvements in productivity through enhanced digital processes. In another study, Li et al. (2017) designed an RFID-enabled real-time BIM platform for prefabrication. This platform was aimed at mitigating schedule risks by integrating stakeholders, streamlining information flow, and improving communication among different parties.

Liu et al. (2017a) explored the role of critical drivers, including business environment factors and entrepreneurial cognition, in promoting a technological shift towards modular prefabrication. Subsequently, Li et al. (2019) proposed a conceptual framework for integrating BIM and prefabricated housing production. Their framework introduced the Smart BIM Platform (SBP), Smart Work Packages (SWPs), and Smart PHP Objects (SPOs), providing a structured approach to integration. More recently, Liu et al. (2021b) examined the integration of BIM and steel fabrication machine codes (BVBS) using open BIM standards. They presented a BIM approach aimed at improving data interoperability and information flow, addressing a critical technical challenge in OSC-BIM integration.

The evidence presented in this section suggests that integration with BIM is crucial to mitigating the OSC challenges. The literature suggests that integrating BIM with OSC is crucial for overcoming the challenges associated with OSC adoption. Although various studies have examined both OSC and BIM applications, there remains a lack of a comprehensive integration framework that consolidates the recommended strategies into a holistic approach. This gap represents a critical area for future research and development in the construction industry.

## 3.3 Research Methods

The mixed-methods approach has been applied in this study, where quantitative and qualitative methods are used in a complementary manner (Harden & Thomas, 2010; Sutrisna, 2009). This approach provides a powerful way to reach assertive conclusions in the event of any paradox or contradiction in either analysis by using the triangulation rationale (Gough, 2015). The research framework consists of three stages. An explanatory sequential design was utilised to integrate scientometric analysis, systematic literature review (SLR), and semi-structured interviews (Gutiérrez Braojos et al., 2020). This approach was selected because it allowed the study to begin with a quantitative phase, which helped identify the broader trends, research gaps, and key topics related to OSC and BIM integration (Jin et al., 2019; Makabate et al., 2021; Saad et al., 2021) and thus illustrates OSC and BIM integration trends up to this point in time.

This sequence allows for a comprehensive exploration of the existing literature on OSC and BIM from a quantitative perspective. The scientometric analysis provides valuable insights into research trends, publication patterns, and gaps in the literature, which informs the subsequent qualitative SLR. Following the scientometric phase, a qualitative SLR was conducted, building on the keywords and trends identified. This allowed for a more in-depth understanding of the issues at hand, conceptualising key themes in OSC and BIM integration. The aim is to assess the current state of OSC and BIM integration research globally and in New Zealand (Ahmadzade Razkenari et al., 2018; Cavalieri et al., 2019; Davis et al., 2014).

The qualitative phase was completed by semi-structured interviews with experts, validating the findings and providing richer, context-specific data to refine the challenges and strategies identified. The aim was to identify the factors influencing integration globally and in New Zealand and then develop a conceptual integration framework for OSC and BIM in the New Zealand construction industry at the organisational and project levels. Overall, the choice of exploratory sequential design was made because it allowed for a systematic progression from broad trend identification (quantitative) to deep thematic exploration (qualitative).

This approach ensured that the findings were robust and grounded in both statistical trends and real-world expert insights, facilitating the development of a comprehensive integration framework for OSC and BIM (Creswell et al., 2003; Ivankova et al., 2006; Tashakkori, 1998). Figure 3.1 shows the research framework based on the methodology stages. The framework and each stage methodology are mapped against each objective mentioned in the introduction section. The result of each stage is provided in the coloured ovals, and the results describe how the findings from a previous stage helped the next stage. The details of the three stages of the methodology are discussed in this section.

## 3.1 Stage 1: Scientometric Analysis

The first stage in this study is a 'scientometric analysis' or 'science mapping' to objectively visualise the current state of research, including identifying which countries generated prominent papers, tracking research keywords, and investigating the knowledge base of ontology research (Rashed & Mutis, 2021; Tang et al., 2019b). It offers distinct benefits for visualising and evaluating scientific material, which together aid comprehension of prior research by methodically constructing various accessible graphs. These graphs can aid in discovering implications concealed in a large quantity of data (Tang et al., 2019b). Out of several scientific mapping tools available, this study used VOSViewer (its special text-mining functions make it suitable for viewing more extensive networks) and Citespace (usually used for identifying trends and patterns) software for creating, visualising, and studying bibliometric relationships.

The keywords selected for the analysis were: "Modern Methods of Construction" OR "Modular Construction" OR "Modularisation" OR "Prefabrication" OR "Offsite Construction" OR "Off-site Production" OR "Off-site Prefabrication" OR "Off-site Manufacturing" OR "Precast" OR "Industrialized Housing" AND "Building Information Modelling" OR "BIM." The document type was restricted to academic articles in English published over the last two decades, when BIM research and application gained more attention (Hong et al., 2018).

The extent to which the issues covered by a study are addressed is proportional to its number of citations. As part of this study's first objective, a two-phase scientometric analysis was performed by investigating pioneer nations, historical patterns, and future trends. The first phase included a co-citation analysis of research articles by filtering the most-cited research and recognising Citespace's knowledge trends. In the second phase, a keyword analysis with VOSViewer was performed to discover and demonstrate emerging topics and any related keywords used in the previous articles (Valderrama-Zurián et al., 2015).

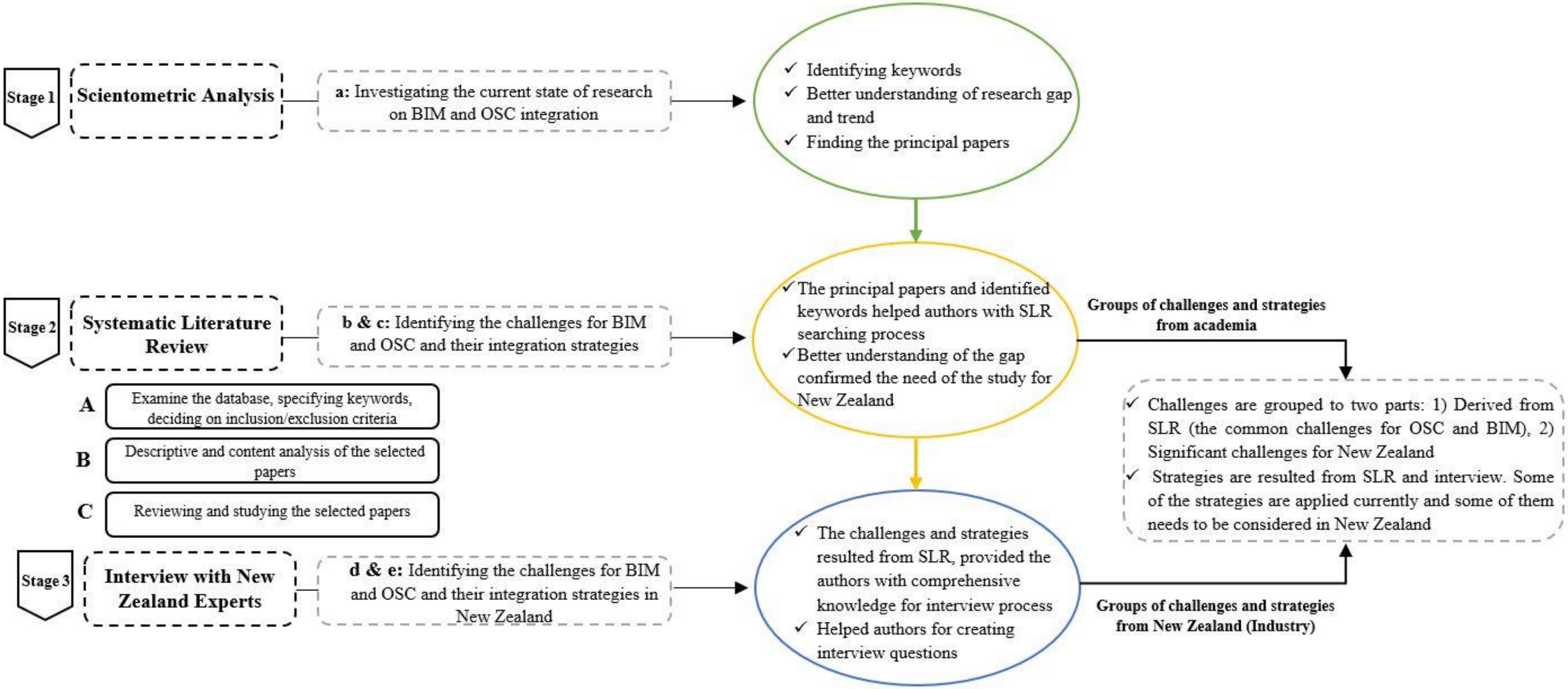


**Figure 3.1:** Research Framework

## 3.2 Stage 2: Systematic Literature Review

A three-step systematic literature review was conducted as part of the first objective (Davis et al., 2014). The SCOPUS database was used to search a significant portion of the papers that reflect the many strands of literature on the current topic, and it covers a wide range of peer-reviewed journals (Cavalieri et al., 2019; Meho & Rogers, 2008). The identification of keywords and the selection of inclusion/exclusion criteria were made at this stage. The next step involved descriptive and content analysis of the selected articles by coding and identifying themes or patterns (Li et al., 2018b). Content analysis was deployed to draw accurate conclusions from large sets of literature (Krippendorff, 2018). The final step involved studying the selected articles one by one to identify the challenges of implementing OSC and BIM and their integration strategies. After refining, the final search criteria were:

a) the study's period (2000-2021).

b) the study's goal and scope, which had to be related to OSC and BIM.

c) selecting keywords and search phrases (OSC, BIM, prefabrication).

d) the criteria for inclusion/exclusion (high-impact journals and studies on OSC and BIM implementation challenges and their integration).

A method was developed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) group to prevent bias and misinterpretation in the SLR. A four-phase flow diagram and a 27-item checklist comprise the PRISMA recommendations. The PRISMA flow diagram depicts the criteria for identification, screening, eligibility of reports included in the scope of a review. PRISMA elements serve as a guide for writers, reviewers, and editors using this flow diagram and checklist (Liberati et al., 2009; Moher et al., 2009). The PRISMA flow diagram shown in Figure 3.2 illustrates the screening of articles examined over the systematic literature review. In this stage, the exact keywords used were the same as those in the scientometric stage, along with some others acquired from the previous stage. The initial search yielded 244582 articles. The search then was limited to year, language, source impact (Q1 and Q2 journals, document type [article and review papers]), and 2195 articles were identified for further examination. After carefully examining their titles, abstracts, and keywords, 1945 publications were eliminated. The full texts of the remaining 338 articles were thoroughly reviewed. Following this step, 53 publications were included in the final content analysis.

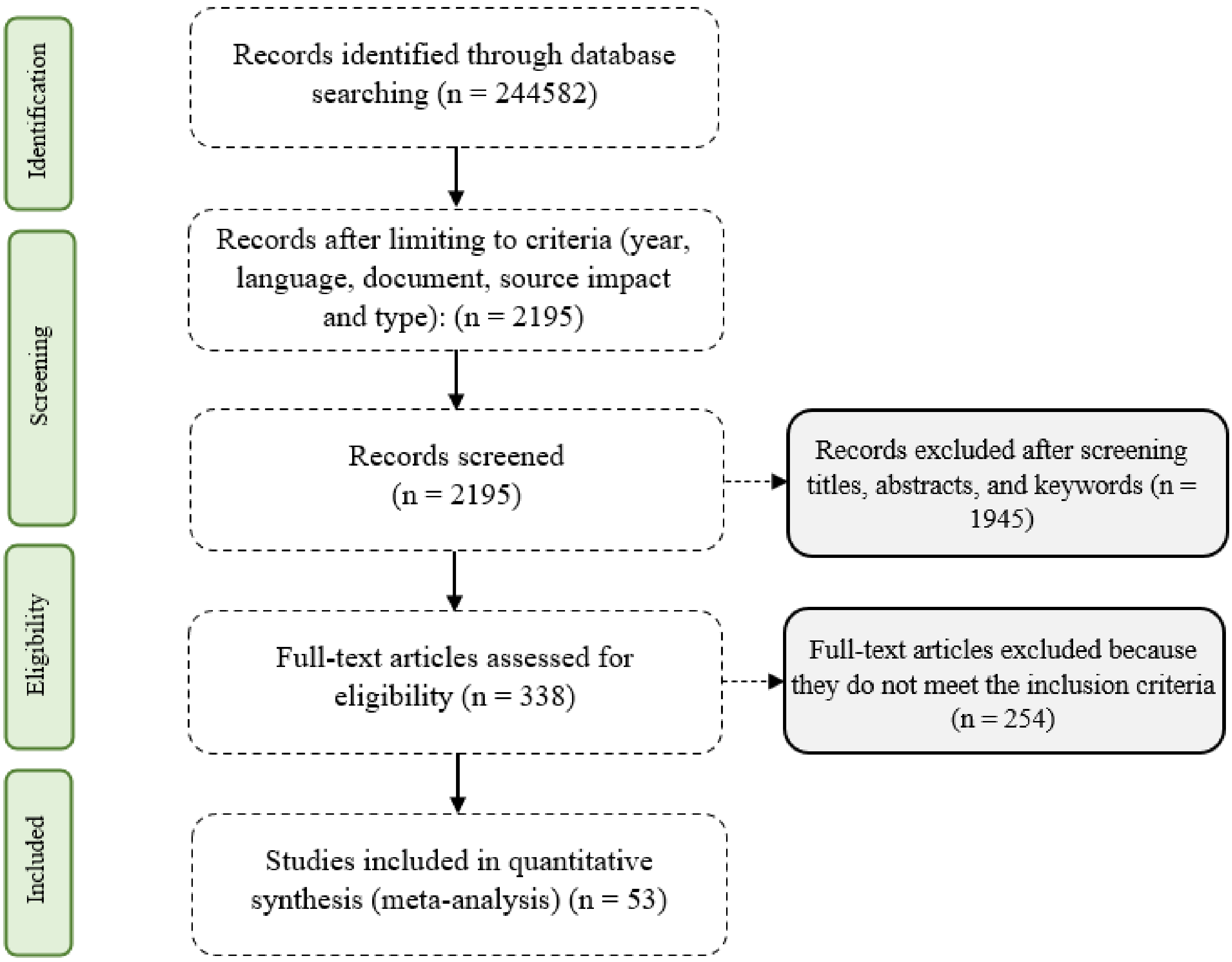


**Figure 3.2:** PRISMA flow diagram of the Systematic Literature Review

The final 53 articles were divided into three groups according to their relevance to each research objective. For articles reporting challenges, a specific approach was employed for analysis, including incorporating measurements of criticality, citation, and significance in the literature (Meng, 2010; Yeung et al., 2012) in order to establish the most significant challenges from the literature. Criticality is measured through an index for assessing the significance of the attributes cited in each paper based on specific terminology and language developed by Jelodar et al. (2016). The criticality ranges from 1 (uncritical) to 5 (very critical) according to the distinction between the lowest and highest critical words used for the challenges identified in the literature (Appendix 3).

NVivo 20 was used to calculate the criticality score by analysing the broken-down statements for each strategy. The other measure used in this analysis is citation, which simply refers to the number of times these attributes have been cited in the selected literature. Finally, the significance of each concept is calculated using Eq (3.1). However, the authors used decontextualization through content analysis for integration strategies because a limited number of studies were available. In this process, strategies are defined through the key worlds and context of the papers.

$$\text{Significance in literature} = \frac{Citation}{Total\ number\ of\ articles} \quad \text{(Equation 3.1)}$$

## 3.3 Stage 3: Semi- structured Interviews

Following the two previous stages, interviews with New Zealand industry experts were conducted (Appendix 4) to provide data on objective a (introduction). Interviews can provide critical expert insights relevant to practice and uncover various problem-solving methods (Flick, 2009). The interviews and SLR informed the subsequent development of a framework for facilitating the integration of OSC and BIM into construction projects, which is the final objective of this study. Interviews helps to gain broader and deeper perspectives of interview participants on a topic (Brinkmann & Kvale, 2018; Flick, 2009). The number of interviewees was determined by achieving theoretical saturation, and in the end, nine interviews were conducted.

Theoretical saturation is defined as the point where further interviews cease to provide additional insights for the specific purpose of a study (Glaser & Strauss, 2017). For optimum tangibility and comprehension of responses, interviews were designed with key questions accompanied by follow-up questions (Chen & Partington, 2004). The interviews lasted between 40-60 minutes, providing sufficient time for participants to discuss both the broad issues of OSC and BIM integration and their personal experiences in detail.

NVivo 20 was used to analyse the interview transcripts. The qualitative coding process was repeated iteratively to identify the patterns throughout the interviews. Descriptive coding aided the research team to shape the original data and extract the related codes from the interview's transcriptions. Moreover, the research team used pattern coding to assess the first cycle codes and examine their similarity and patterns to answer objectives b. The first step was understanding the most significant challenges for implementing OSC and BIM in New Zealand. This was followed by identifying and evaluating OSC and BIM integration practices or strategies applicable to the New Zealand construction industry.

## 3.4 Findings

### 3.4.1 OSC Current State of Research (Scientometric Analysis)

As described in the preceding discussion, scientometric was utilised to satisfy objective "a". CiteSpace provided a broad understanding of research topics in different countries by including an analysis of 421 research articles. The findings showed that New Zealand lags behind all Organisation for Economic Co-operation and Development (OECD countries in integrating OSC and BIM ) (Arntz et al., 2016). There are no previous studies on OSC and BIM integration in New Zealand (Sooriyamudalige et al., 2020; Zou et al., 2022). Based on the selected keywords-related themes tracked since 2005, the peak number of articles on OSC and BIM occurred during 2017-2018, with the United States, Canada, China, United Kingdom, and Hong Kong leading the way (Figure 3.3). In terms of the most cited related papers, the United States was first, with China second, followed by the United Kingdom.

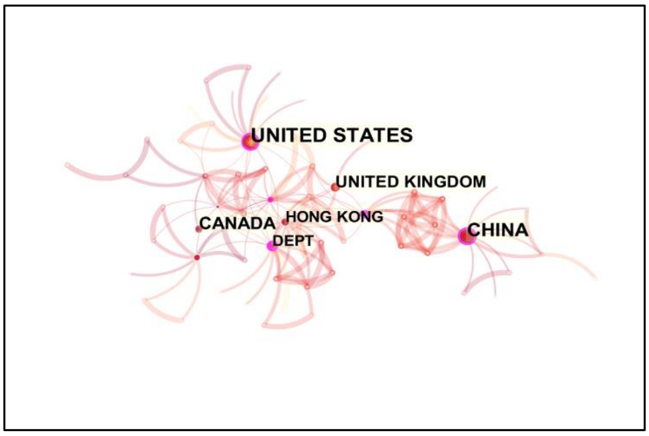


**Figure 3.3:** A visualisation of the collaborating countries

The progression of the themes in publications from 2000 to 2021 is shown in Figure 3.4 based on selected keywords, and a clear upward trend is observed. It emphasizes the role of academic research in OSC, prefabrication, and new technologies. Six dominant clusters were identified based on citation counts and linked themes in different periods. From 2000 to 2017, there were no dominant clusters based on citations. However, in 2017 a dominant cluster emerged; the keywords associated with this cluster are OSM, modular manufacturing, sustainable building, productivity, and buildings. One of the main themes in this cluster is the focus on BIM's potential for OSM and conventional construction (Abanda et al., 2017). Furthermore, issues such as modular construction, innovative use of technology to promote sustainability, reduction of quality defects and reworks, reduction of construction delays, and reduced cost overruns through 4D BIM were captured in this cluster (Lee & Kim, 2017).

The next identified cluster from 2018 to 2019 includes linked studies on information modelling methods, flexible volumetric elements, product platforms, configurations, and industrialized house building. Topics within this cluster include Design for Manufacturing and Assembly (DFMA), Lean principles, and BIM applications (Xue et al., 2018; Yin et al., 2019; Yuan et al., 2018). This cluster's highest number of publications is associated with the year 2020.

The themes within this cluster are future directions, OSC, digital technology adoption, sustainable modular integrated construction, supply chain management, high-rise modular buildings, digital deconstruction, and decision-making. The 2021 period in Figure 3.4 shows the recent increase in scientific effort and detection of two separate clusters about Lean principles and configuration. The major themes identified are offsite construction, Lean principles, robotic system, building penalisation design, modular construction, and premanufacturing phases. This indicates that while many aspects of OSC and BIM have been investigated recently, there is an evident lack of OSC and BIM integration-related studies (Abanda et al., 2017; Barkokebas et al., 2021; Darko et al., 2020).

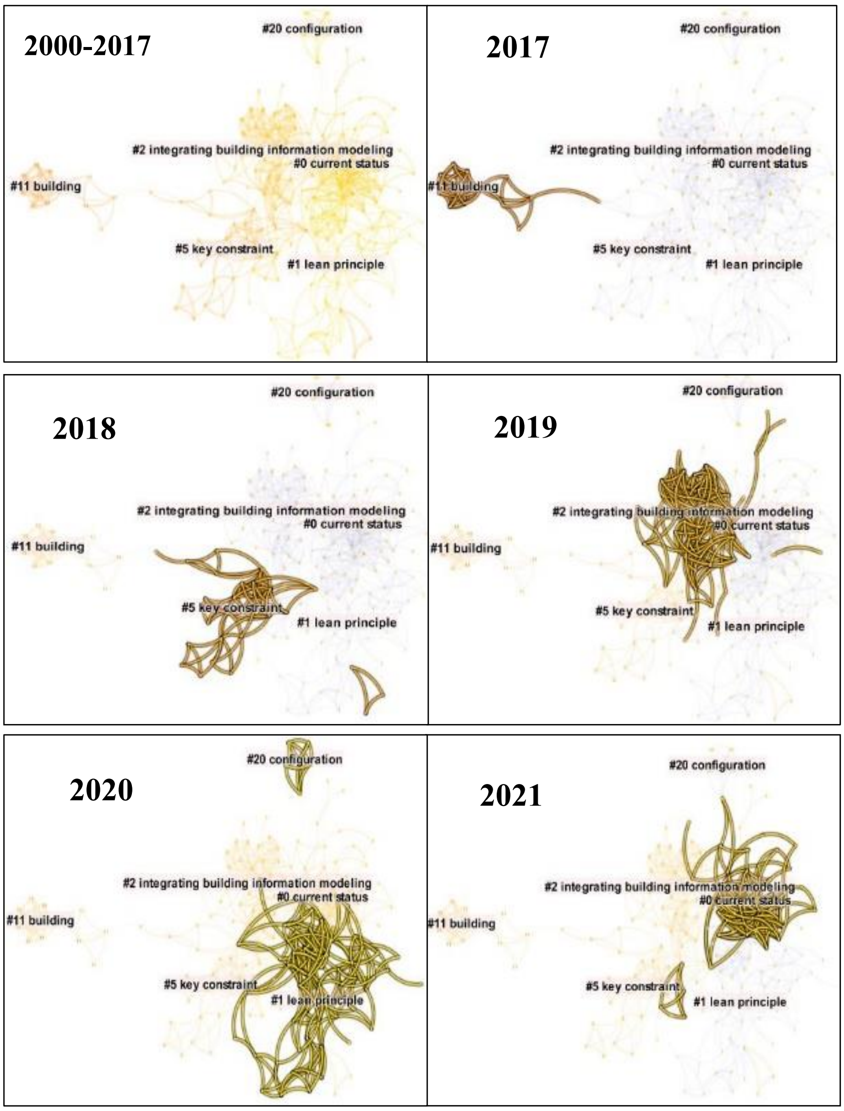


**Figure 3.4:** Cluster citation significance from 2000 to 2021

Figure 3.5 shows the relationship between the keywords investigated. The dominance of studies associated with architectural design, construction industry, and building information modelling can be seen. Studies on prefabrication, modular construction, OSC, and precast concrete are significant too. However, the relatively smaller number of links between integration, BIM, and prefabrication/OSC indicates that most studies focused on each keyword separately (Abanda et al., 2017; Hosseini et al., 2018; Li et al., 2019; Yin et al., 2019).

A close inspection of the timeframes revealed that since 2010, most of the keywords are the ones that the construction industry benefits from, like BIM, Lean construction and production, sustainability, automation, prefabrication, and modular construction. In 2016 and 2017, prefabrication was linked with information delivery, buildings, structural design, and automation. Between 2017 and 2018, productivity, construction industry, and project management were linked. The literature also referred to productivity as one of the main benefits of OSC that can be enhanced via BIM application (Abanda et al., 2017; Steinhardt & Manley, 2016). From 2018 to the present, the focus shifted to modular building, BIM, decision-making, IoT, integration, Lean production, DFMA, and OSC (An et al., 2020a; Barkokebas et al., 2021; Darko et al., 2020; Liu et al., 2019; Piroozfar et al., 2019; Yin et al., 2019; Zhai et al., 2019).

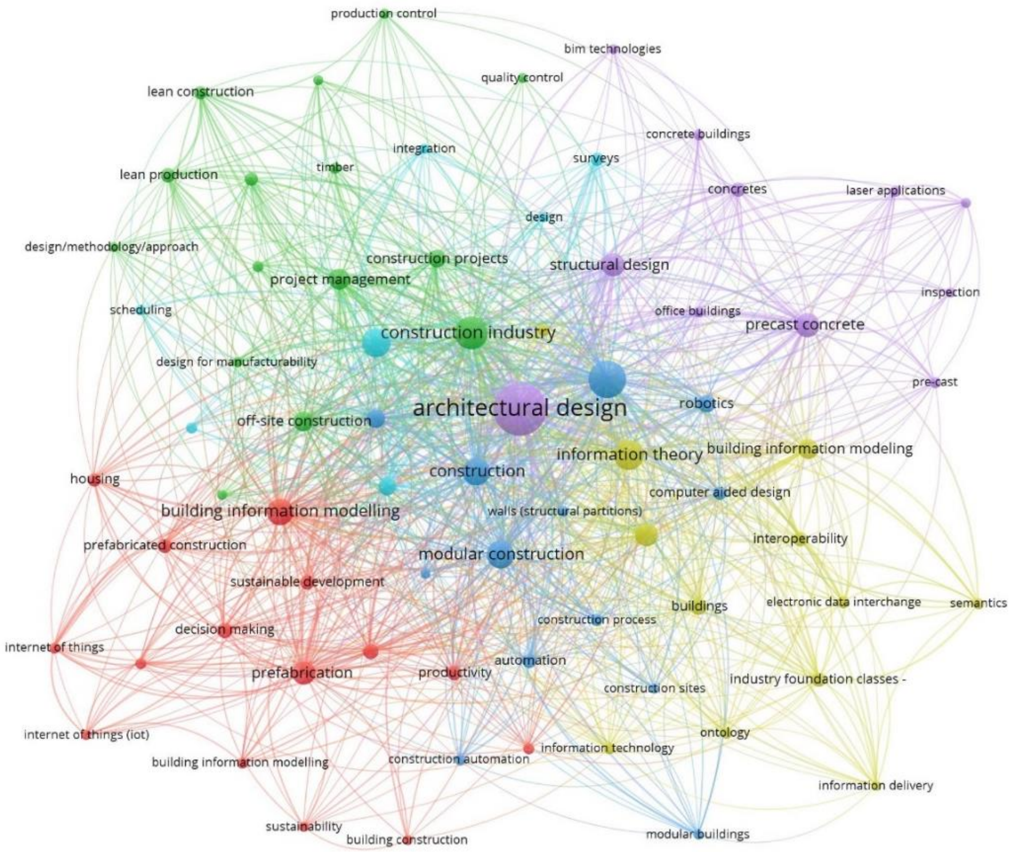


**Figure 3.5:** Keyword co-occurrence network

### 3.4.2 Systematic Literature Review Findings

This section provides the findings of the reviewed literature and is structured into three groups: OSC challenges, BIM implementation challenges, and OSC & BIM integration strategies. Rest of the Objective a is addressed in this section. The findings of the previous step helped the authors figure out the research gap, the principal articles, and unidentified keywords for the SLR search. The 53 identified articles were categorised into three groups. A total of 31 articles belonged to OSC challenges, 17 were BIM related and 20 cited some integration strategies. Some of the articles investigated integration related issues, and some indirectly pointed to strategies which were then recognised and grouped by the authors. In addition, some of the identified articles were categorised into more than one group.

***Offsite Construction (OSC) Challenges***

Related articles were included in an in-depth analysis based on relevance and the selection criteria. Table 3.1 shows the challenges of implementing OSC as the outcome of objective a. The table includes all the documented challenges within the identified literature. The findings are clustered into six clusters based on the criticality, citation, and significance measures described in the methodology section (Appendix 2).

**Table 3.1:** OSC Challenges

| OSC Challenges | Criticality | Citation | Citation significance in literature | Average criticality | Total citation | Significance in literature | Cluster |
|---|---|---|---|---|---|---|---|
| Transportation of modules, issues of logistics and transport, long-distance transport, improper transportation methods, limitation to design due to transportation restrictions. | 4 | 28 | 90.33 | 4 | 28 | 90.33 | Transportation |
| Unavailability of training, lack of trained and skilled operatives, lack of educational programmes. | 3 | 16 | 51.62 | 2.9 | 24 | 77.42 | Training and experiences |
| Lack of project management knowledge, lack of a knowledge portal, lack of contractor experience, poor understanding. | 2.8 | 27 | 87.10 | | | | |
| Lack of experience, absence of technically skilled trained labour, limited skilled on-site labour available, lack of manufacturer or suppliers' skills. | 3.1 | 18 | 58.07 | | | | |
| Lack of standard designs, low standardisation, lack of repetition possibility and risk increase, lack of codes and standards available, lack of appropriate scale and repetition possibilities. | 3.3 | 20 | 64.52 | 2.8 | 15 | 48.39 | Planning and designing |
| Poor aesthetic performance, impaired aesthetics, and monotonous architecture. | 0.2 | 10 | 32.26 | | | | |
| Need for additional project planning and design efforts, failure to adhere to the schedule. | 5 | 15 | 48.37 | | | | |
| Insufficient industry investment, higher initial cost, cost and time aspects, and sizeable initial investment. | 3.5 | 18 | 58.06 | 3.5 | 13 | 41.94 | Financial |
| Lack of stakeholder's collaboration, extensive and detailed coordination, lack of periodical meetings, and the inadequate flow of information. | 4.2 | 15 | 48.39 | 3.8 | 22 | 70.97 | Collaboration and commit |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Early commitment, upfront commitment. | 3.5 | 3 | 9.67 | | | | |
| Loss of control at the site, difficulties in inventory control, and constraints caused by site conditions. | 0.5 | 6 | 19.36 | 1.9 | 12 | 38.71 | **Industry, innovation, and process** |
| The limited capacity of suppliers, and lack of manufacturers and suppliers. | 1.5 | 8 | 25.81 | | | | |
| Lack of project procurement methods. | 2 | 7 | 22.59 | | | | |
| Low-quality imports, quality issues, inadequate quality, and aggregate dimensions. | 2.6 | 13 | 41.93 | | | | |
| Practices of government, lack of legislation. | 2 | 5 | 16.13 | | | | |
| Lack of contractor's incentives, manufacturers' reluctance, lack of social climate & acceptance, negative perception, conservative industry culture. | 2.7 | 14 | 45.17 | | | | |
| Dominance of conventional project process, historically robust tendering framework. | 4 | 12 | 38.71 | | | | |
| Limited market demand. | 1 | 8 | 25.81 | | | | |
| Management problems, inappropriate business model. | 1 | 7 | 22.59 | | | | |

*Building Information Modelling (BIM) Implementation Challenges*

Many studies emphasized the importance of BIM for a different range of projects, alongside it's challenges and benefits. A total of 17 articles fit the criteria for this study, and the same method implemented for OSC challenges was used. Indexes such as criticality, citation, and significance in literature were determined. Accordingly, six categories of knowledge, human resources, financial, legal constraints, interoperability and collaboration, and standardisation related challenges were identified and categorised for BIM implementation. Table 3.2 provides the breakdown of BIM implementation challenges in the selected literature (Appendix 2).

**Table 3.2:** BIM Implementation Challenges

| BIM Implementation Challenges | Criticality | Citation | Citation significance in literature | Average criticality | Total citation | Significance in literature | Cluster |
|---|---|---|---|---|---|---|---|
| Inadequate project experience, practitioners' Knowledge, lack of training. | 3 | 16 | 94.11 | 3 | 15 | 88.24 | **Lack of Knowledge** |
| Cultural resistance, lack of motivation, and issues related to the willingness to share data. | 3 | 13 | 76.48 | 3 | 6 | 35.30 | **Human resources** |
| Higher initial cost, BIM adoption cost, cost barriers. | 2 | 11 | 64.70 | 2 | 5 | 29.42 | **Financial** |
| Legal issues, legal barriers, intellectual property rights concerns, and lack of a mature BIM contract. | 1.7 | 8 | 47.06 | 1.7 | 7 | 41.18 | **Legal Constraints** |
| Low interoperability, insufficient interoperability and collaboration among different disciplines, interoperability problem among various BIM software tools, difficulties in applying BIM, different ' 'stakeholder's needs, and difficulties in implementing BIM. | 2.4 | 16 | 94.11 | 2.4 | 16 | 94.11 | **Interoperability and collaboration** |
| Lack of clear guidance, no clear orientation or adequate practical studies, lack of industry standards, unclear business value, system complexity, and poor integration with existing systems. | 3.2 | 14 | 82.36 | 3.2 | 12 | 70.58 | **Lack of Standardisation** |

***OSC and BIM Integration Strategies***

This section addressed objective c of the study. A total of 20 articles with mentioned actions and strategies were identified and examined, which resulted in six different integration strategy categories: accurate definition and detailing, communication, documenting, training and professional development, government development and incentivization, and contract development. These strategies and their associated actions vary at the project and organisational level (Table 3.3). This provides an understanding of what is currently being done for OSC and BIM integration worldwide.

**Table 3.3:** Strategy and Actions for BIM & OSC Integration

| Strategy Levels | Strategy | Action | Reference(s) |
|---|---|---|---|
| Project | Accurate definition and detailing | Accurate project tender definition<br>Building trade detailing<br>Trades interferences detection<br>Accurate cost estimation<br>Visualising and tracing<br>3D modelling | (Arif et al., 2012; Boyd et al., 2013; He et al., 2021; Jang & Lee, 2018; Jin et al., 2017; Li et al., 2016) |
| | Communication | Exchange data<br>Collaboration<br>Management processes<br>Partners integration<br>Streamlining logistics | (Alazmeh et al., 2018; Blismas & Wakefield, 2008; Hwang et al., 2018a; Jiang et al., 2021; Jin et al., 2017; Jin et al., 2019; Ma et al., 2020; Piroozfar et al., 2019; Zhang et al., 2018) |
| | Documentation | Store data and information in BIM<br>Accurate and extensive information | (Abanda et al., 2017; Ho et al., 2018; Jiang et al., 2021; Jin et al., 2017; Nawari, 2012; Sacks, 2004; Vernikos et al., 2014; Zhang et al., 2018) |
| | Training and professional development | Educating BIM experts<br>Working with college graduates<br>Courses and learning programmes like symposiums, industry events, internship programmes, mentoring programmes | (Aburas, 2011; Arif et al., 2012; Ayalp & Ay, 2020; Hwang et al., 2018a; Jin et al., 2017; Razkenari et al., 2020; Vernikos et al., 2014) |
| Organisational | Government development and incentivization | Government intervention, legislation, and promotions<br>Driving factors | (Aburas, 2011; Jiang et al., 2021; Pan et al., 2007; Xu et al., 2020; Xue et al., 2021; Zhang et al., 2018) |
| | Contract development | New contract (use of contract language to support BIM collaboration) | (Ho et al., 2018; Jiang et al., 2021; Jin et al., 2017; Nawari, 2012; Sacks, 2004; Zhang et al., 2018) |

### 3.4.3 Semi-structured Interview Findings

At stage 3, semi-structured interviews with New Zealand experts were conducted between September and October 2021. As a result of the previous stages, a group of OSC and BIM challenges and strategies for integration of were identified. The SLR findings provided a thematic categorisation of knowledge for better understanding the current global challenges and strategies of OSC and BIM integration. Although the authors did not present the findings of the SLR during interviews, the findings were used to assist and facilitate a comprehensive discussion with experts and gain a broader overview of the current status of OSC and BIM in New Zealand. Experts with over ten years of experience in construction projects and a bachelor's degree or higher education level made up the original pool of interviewees.

Further selection criteria included relevant expertise in prefabrication, OSC, and BIM in New Zealand. The experts are experienced construction professionals working with OSC and BIM applications in various projects at different construction stages. Table 3.4 provides the details of the interviewees. Each interview took around 40-60 minutes and was digitally recorded and transcribed.

**Table 3.4:** Interviewees Details

| Expert | Current position | Experience (years) |
|---|---|---|
| R1 | Digital Assets & Engineering Lead | 11+ |
| R2 | Digital Engineering Leader | 21+ |
| R3 | Head of Product Design | 19+ |
| R4 | Project Analyst and Planner | 19+ |
| R5 | Head of Modular Design for Manufacture | 20+ |
| R6 | Architectural Technician | 10+ |
| R7 | Chief Executive Officer | 30+ |
| R8 | Consultant | 20+ |
| R9 | Head of Product Design | 15+ |

***Offsite Construction Challenges in New Zealand***

Table 3.5 presents the most significant challenges in New Zealand from experts' point of view. The challenges were clustered, and the relationship was established. Details of the findings are provided in the discussion section.

**Table 3.5:** Significant OSC Challenges in New Zealand

| OSC Challenges in the New Zealand Construction Industry | |
|---|---|
| Transportation | Transportability of OSC components |
| Training and experiences | Experience and knowledge of staff<br>Costly and time-consuming training<br>Lack of understanding of OSC applications |
| Planning and designing | Lack of the programming |
| Financial | The high initial cost of applying OSC |
| Collaboration and commitment | Collaboration among designers and other stages |
| Industry, innovation, and process | Absence of national standards for OSC<br>Inefficient manufacturer's procurement processes<br>Lack of digital documentation for OSC<br>Small market<br>Conservative industry people<br>Resistance to change<br>Fragmented tendering models hindering integration<br>Project-by-project approach in construction<br>Lack of government mandated OSC requirement |

***Building Information Modelling Implementation Challenges in New Zealand***

Table 3.6 presents the most significant challenges to BIM implementation. Some of the challenges stated by the interviewees are the same as findings from SLR. This means that the nature of humans and projects cause the same challenges in many parts of the world.

**Table 3.6:** Significant BIM Challenges in New Zealand

| BIM Challenges in New Zealand Construction Industry | |
|---|---|
| Lack of Knowledge | Lack of knowledge<br>Lack of appropriate education<br>Lack of training<br>Lack of understanding of BIM applications |
| Planning and designing | Lack of the programming |
| Financial | The initial cost of applying BIM<br>Cost of BIM as an additional tool |
| Lack of Interoperability and collaboration | Lack of collaboration |
| Human resources | Immature industry to deliver BIM |
| Lack of Standardisation | Lack of standards<br>Lack of digital documentation for BIM<br>Lack of government-mandated BIM requirement |

***OSC and BIM Integration strategies in New Zealand***

Results from the expert interviews also led to identifying particular strategies implemented for OSC and BIM integration. These strategies were not highly structured; however, they were associated with OSC advancements via the enhanced application of BIM tools. Table 3.7 presents the strategies suggested by New Zealand experts as the existing and recommended strategies that the industry should apply for integrating OSC and BIM. Findings indicate that strategies are required at both organisational and project levels.

**Table 3.7:** OSC and BIM Integration Strategies in New Zealand (Expert interview results)

| Strategy Levels | Strategies | Current strategies | Recommended strategies |
|---|---|---|---|
| Project | Accurate definitions and detailing | Project delivery.<br>Describing the details of the work and its expected outcome.<br>Explain the benefits of BIM to the stakeholders. | - |
| | Technology management | - | Using digital twin |
| | Communication | Changes in communication style<br>Value chain analysis by explaining that projects will gain, such as the amount of saving by reducing material wastage and the risk reduction level. | Collaborating from the early stages (early engagement of stakeholders). |
| | Documentation | Developing quality standards. | Providing resources.<br>Documenting information.<br>Set up a library of workflows. |
| | Training and professional development | Providing client's business requirements document. | Educating and informing through meetings and webinars.<br>Collaborate with trained and educated people. |
| Organisational | Policy document | Providing action plans at the project's early stages. | Creating road maps |
| | Governmental development and incentivization | Government support | Government mandatory regulations.<br>Providing the industry with increased credits and incentives. |

Some strategies have already been applied from the table above, and the experts recommended other strategies that could be applied in the future. Each group of strategies can be investigated further separately. The interview findings were then used in the analysis in each group as practical input, which complemented the systematic literature review findings.

## 3.5 Discussion

### 3.5.1 OSC Specific Challenges

Several clusters of OSC challenges were identified in the literature. A group of research works have identified transportation as one of the most critical challenges for OSC. A strong relationship between heavy and oversized OSC components and their transportation over long distances has been reported in prior studies (Hwang et al., 2018a; Razkenari et al., 2020; Wuni & Shen, 2020). The cluster had twenty-eight citations, a criticality score of four out five and 90.33% significance in the literature. What is surprising is that even though oversized OSC components still are not standard in New Zealand, transportability is considered one of the significant challenges for OSC (Table 3.5).

The next challenge with 77.42% significance in the literature is training and experiences. Results from the experts' interviews identified lack of experience and knowledge by construction project staff as one of the major OSC challenges. This is supported by other studies in this area, which link training with knowledge (Ayalp & Ay, 2020; Jang et al., 2021; Wuni & Shen, 2020). In this study, costly and time-consuming training (Table 3.5) shows that in New Zealand this factor is the leading cause of resistance to apply new technologies in small-sized companies.

The other identified OSC challenge with the significance of over 50% is collaboration and commitment. This is due to the fragmented nature of construction projects and the tendering models which prohibit full collaboration (Table 3.5). There are similarities between the attitudes expressed by interviewees in this study and those stated by Gan et al. (2018a) and Zhang et al. (2018). Some unanticipated findings were that the relatively small scale and the adopted project-by-project approach of the OSC sector makes OSC implementation much more expensive. Experts believe that because of the small size and remoteness of New Zealand, there is a degree of uniqueness in its construction environment. For instance, demand is relatively lower for mass production facilities, and without mass production, OSC becomes less economically viable. Therefore, specific provisions are required to address these challenges. The findings support that shift in level of understanding, knowledge, and working culture are required to increase mass production and OSC implementation.

Planning, which entails different planning activities such as designing to standards and intended performances, has been identified as another challenge. Experts believe that using new methods in construction such as BIM and OSC, require more effort and time. This is in line with the results of a case study done by Hwang et al. (2018a), who pointed out the huge challenges and efforts needed for schedules and planning of OSC supplies. Planning-related issue are also some of the most significant challenges in New Zealand; especially where there is a lack of standards too. Based on the literature, there are some enterprise-level standards, but national standards are required for the entire industry (Mao et al., 2015).

Financial issues also were identified as challenges; however, these challenges had the lowest significance in the literature among the other clusters identified. Although one of the significant benefits of OSC is reducing the overall cost of the project (Darko et al., 2020), high initial capital is needed (Ayalp & Ay, 2020). The experts stated that the initial cost of applying OSC may cause resistance in the industry as they perceived a need for financial support first.

The last cluster identified relates to industry, innovation, and process challenges (Table 3.1). This cluster consists of nine different categories of challenges. Among these factors, the lack of incentives, stakeholders' reluctance and their resistance toward any change are the main challenges. Rahman (2014) stated that stakeholders believe that because of the quick adoption of OSC, architectural creativity is being destroyed. Moreover, because of OSC's disruptive character, conservative attitudes are bolstered. Interestingly, the widespread use of this method will alter many long-standing practices and will necessitate the acquisition of new skills and approaches if construction firms are to remain relevant and competitive. As a result, there are still many struggles ahead to get people to change their attitudes. Experts also named this challenge one which is common in New Zealand. Many people involved in construction projects are conservative and are not interested in using new methods.

### 3.5.2 BIM Specific Challenges

There are similarities between BIM implementation challenges in the New Zealand industry and the OSC challenges. Table 2.6 presents the most significant BIM challenges mentioned by the interviewees, which are similar to the SLR findings. However, some challenges were stated to be more critical than others, like lack of government-mandated requirements, immature industry or finding BIM as an additional tool that leads to charging clients more. Prior studies noted the importance of interoperability and collaboration as one of the major challenges in BIM implementation, with 94.11% significance in the literature (Table 3.2). This is somewhat surprising due to the role of BIM tools in facilitating various methods of construction, like OSC. This is partly a resistance to change and technology transition issue and is one of the main challenges in New Zealand projects.

Lack of Knowledge is the next significant challenge for applying BIM, with 88.24% significance in the literature score. In reviewing the prior studies, the necessity of training and experience for any new technologies is apparent, and according to the experts, BIM in New Zealand is not an exception. The outcome indicates that most people working in New Zealand construction is not familiar with BIM (Table 3.6). Therefore, these results further support that many challenges are relevant in New Zealand, like lack of training and proper education, lack of understanding, and immature industry.

Lack of Standardisation is the other identified challenge with above 50% significance in the literature (Table 3.2). Many standards are provided, but they are not used effectively to improve communication, collaboration, and productivity (Jin et al., 2019; Piroozfar et al., 2019).

Contrary to expectation, this study found that the mandated requirement by the government (Table 3.6) for applying BIM is much more significant than any standards or training. Industry experts believed that if the New Zealand government strictly applies mandatory regulations, the industry would be forced to adopt (Table 3.6).

Another challenge here are legal constraints. Teams utilising BIM should be cognisant of legal constraints such as data ownership, proprietary issues, and risk-sharing. Such difficulties must be addressed in contract documents (Azhar, 2011). On the other hand, potential collaboration with third parties is frequently hampered by legal and contractual commitments (Liu et al., 2017b). According to one expert, resistance to change is the number one challenge regarding the human resource. Furthermore, there is lack of knowledge and education, which means that much work needs to be done by the industry and the government to educate people more about the advantages of BIM for New Zealand. The conclusion is that the value of BIM is not clear yet to all parties. Besides the industry, studies mentioned people's reluctance toward any new changes (Jiang et al., 2021; Li et al., 2019).

BIM implementation also has financial implications, which can be challenging. The interview findings showed that consultancies in New Zealand see BIM as a different device. They usually charge clients more than the usual time when working with it, which makes it the biggest problem for adopting BIM. Unless stakeholders use BIM and its principles together with digital engineering principles to save and reduce the time. Initially, it may take more time to build a BIM, but it should save more time in the overall design and construction process because there is no need to make manual changes in the projects and finally reduce the cost. The literature also mentioned the cost challenges as one of the factors which impede the BIM (Azhar, 2011; Darko et al., 2020; Eastman et al., 2011; Jiang et al., 2021; Ma et al., 2020).

### 3.5.3 OSC and BIM Integration Strategies

Some BIM and OSC integration strategies were identified and classified as current and recommended (Table 3.7), with current being what is practiced and recommended being potential advancements that could be made. Comparison between all the identified strategies indicated which strategies are commonly used and which ones must be considered for the integration. The expert interviews provided potential organisational and project-level OSC and BIM integration strategies (Table 3.7). Strategies to address specific project-related problems allow versatility and improvisations in tackling them. Conversely, the organisational strategies are more formal and need upper management support.

The first identified strategy was accurate definitions and detailing, which is highly project outcome driven (Table 3.7). However, the literature found that early project phases are more significant for OSC and BIM integration. It is now understood that the conservative culture of the New Zealand industry has a significant impact. When it comes to the organisational level strategies like government intervention, two types of actions may affect the lower levels. One would be incentives, and the other mandatory regulations. This study's results corroborate the findings of a great deal of the previous work (Aburas, 2011; Jiang et al., 2021; Xu et al., 2020; Xue et al., 2021), as the experts believe the driving factors and mandatory regulations are both useful for OSC and BIM integration (Table 3.7). A critical strategy for any new technology is teamwork and collaboration with involved parties in projects. Working together from the early stages will help the stakeholders understand what will happen and what must be done to prevent duplications and errors. Contrary to expectations, this strategy still is not appropriately used in projects.

Previous studies showed that documenting information and data can be helpful for future projects as a lesson learned. Although projects are not repetitive, in OSC, mass production can be an economic advantage. Therefore, having a digital library or storing information allows the stakeholders to act with fewer mistakes. The results confirm the results of previous studies (Jiang et al., 2021; Jin et al., 2017), where having a source of data can facilitate the integration of OSC and BIM. The most significant challenges included lack of training, knowledge, and experience (Table 3.6). As a result, a strategy to deal with these challenges involves more training and further development of training content and relevant academic curricula. Consistent with the literature, the expert interview findings here indicate the collaboration with well-informed people and clarifying the relevance of training suppliers as another training strategies.

It has been identified that contract language and clause alterations are also necessary to support BIM collaboration with OSC (Jiang et al., 2021; Jin et al., 2017). What is striking are the changes in contracts and delivery systems during the last decades that allow the collaboration of different parties. Technology management is one of the strategies that, based on the findings of this study, is recommended but not currently used. (Table 3.7). While the lack of technology management strategy is not very encouraging; experts believe that using digital twin technology can facilitate the integration of OSC and BIM.

The New Zealand industry can take other countries like Singapore or UK which are pioneers in OSC and BIM as an example and adapt their procedures to the local culture and environment (BCA, 2017; Ramboll, 2020). Many countries have road maps provided by the high-level authorities, and industry must operate based on them. However, it is worthwhile to note that in New Zealand, projects have action plans in case of any problem. According to these data, authors can infer that many challenges of OSC and BIM which are in common will be reduced by applying combinations of these strategies. Therefore, the most significant common challenges have been chosen for the integration framework as the response to the last objective (Figure 3.6).

### 3.5.4 OSC and BIM Integration Framework

The developed OSC and BIM integration framework consisted of three components: the challenges, the identified strategy clusters, and the application level. Challenges obtained from literature and interview are the first part of the framework. As mentioned above a group of challenges for OSC and BIM have been identified through the SLR process (Tables 3.2 and 3.3). Some of these challenges were then confirmed via expert interview as the common challenges for New Zealand and other countries. Some challenges have been excluded as they were not confirmed by the interviewees to be applicable for New Zealand.

The remaining challenges in the framework are regarded as unique for the New Zealand construction industry (Tables 3.4 and 3.5). These challenges are demonstrated as packages in dashed lined boxes in Figure 3.6. The illustrated challenges are drivers and correspond to a series of strategies (Table 3.7); the strategies were identified from both previous literature and expert interview. The list of these strategies is shown in Tables 3.6 and 3.7. The challenges are linked to the strategies with green and blue arrows in Figure 3.6.

The above-mentioned process has also been carried out for OSC and BIM integration strategies. Initially the strategies were clustered into six categories identified from the literature review (Table 3.4) and further confirmed by expert interview findings. These strategy clusters are demonstrated in green in Figure 3.6. Two other strategy clusters were found in the expert interviews which were not identified in previous literature. These strategies are demonstrated in blue colour in Figure 3.6. The subset strategies are divided into two groups. One of these is the current strategies highlighted in yellow in Figure 3.6. The other is the recommended ones which are not in Figure 3.6 (Table 3.7, recommended column). In addition, the framework demonstrates that three of the identified strategy clusters are applicable at organisational level and five of them at project level. Groups of strategies are then linked together and shown as eight distinct clusters in the framework. These strategies are policy document, communication, documentation, accurate definition and detailing, government development, contract development, training and professional development, and technology management.

The framework provides a diagnostic tool for identifying appropriate strategies for the identified challenges. For instance, lack of periodic meetings, insufficient collaboration, and poor integration challenges can be mitigated by earlier planning and engagement. The early involvement permits the stakeholders from various project stages to cooperate, and result in a reduction of potential rework (Rashed & Mutis, 2021). This strategy belongs to the greater communication cluster, which is one of the recommended strategies stated in the interviews.

Engaging in the early stages require new forms of contract that enable the involvement of different parties. Contract development by its own is another identified strategy cluster in the framework illustrated in Figure 3.6. This also leads to a series of other strategies which can mitigate other challenges. Therefore, by looking at this example, it can be understood that identified challenges and strategies can be interrelated and have a systemic affect. This simply means that applying one strategy may help solve or mitigate other challenges. The presented framework (Figure 3.6) helps stakeholders find what can be a challenge to applying OSC and BIM, and how and at what level they should be solved.

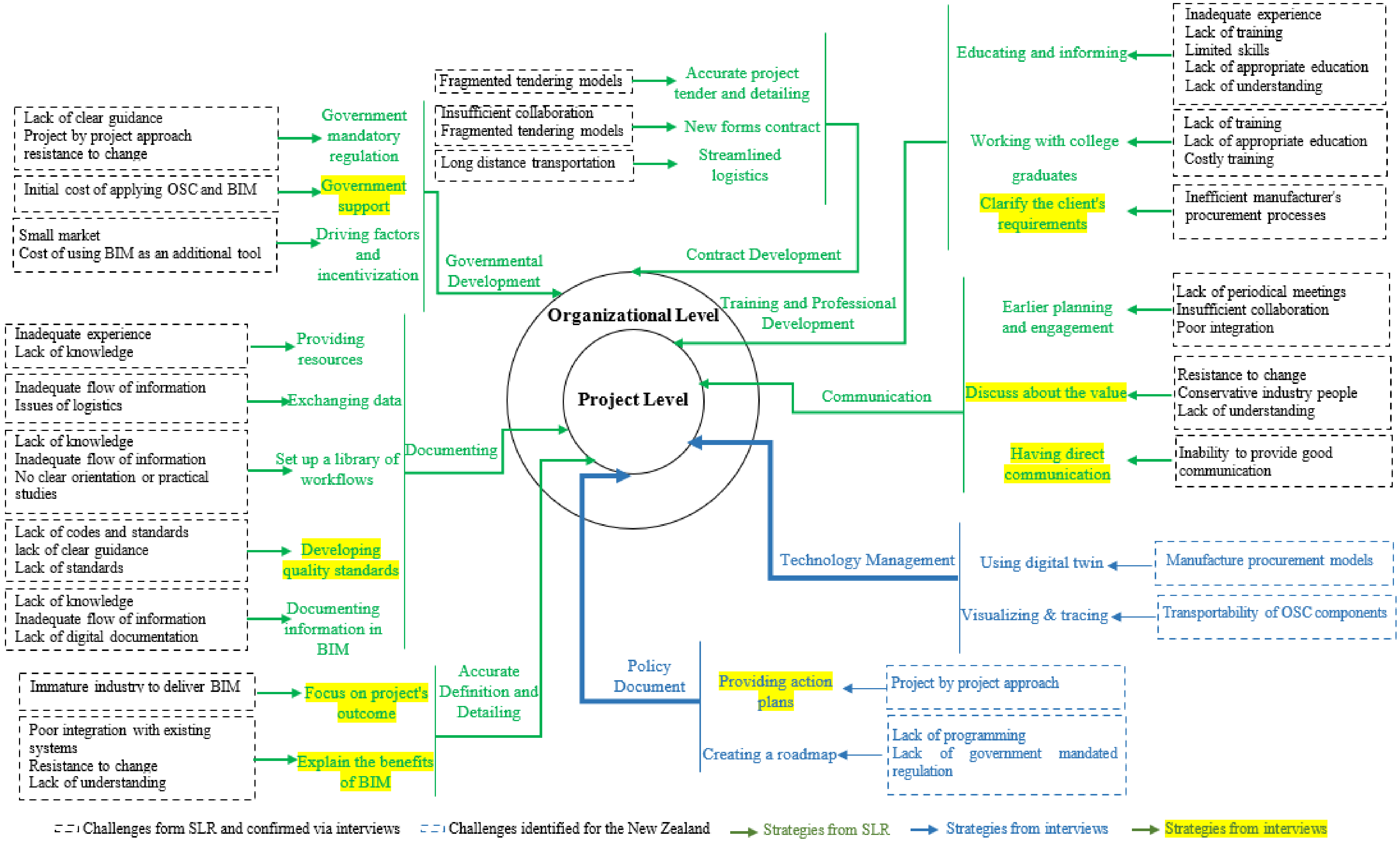


**Figure 3.6:** OSC and BIM Integration Framework

According to above figure, each branch consists of three parts, challenges (black and blue dashed boxes), strategies (demonstrated in green and blue texts) which are extracted from SLR and interviews with New Zealand experts, and the level of the strategy implementation; project or industry. Blue colour branches, mentioned by interviewees which indicate to the challenges and strategies related to New Zealand. Derived from SLR and interviews, strategies highlighted in yellow indicate strategies which are currently being used in OSC projects. Other strategies as the recommended strategies, are extracted from SLR and confirmed by interview as well.

## 3.6 Conclusion

This study aimed to develop a conceptual integration framework for OSC and BIM in the New Zealand construction industry at the organisational and project levels. This was done through investigating, structuring, and documenting strategies to facilitate the integration of OSC and BIM in New Zealand. This study used a triangulation rationale involving scientometric analysis, systematic literature review, and semi-structured interviews. The current state on OSC and BIM adoption and integration was investigated through scientometric analysis. The results of this stage assisted the authors to figure out the main papers which were the foundation of this study. The details of each section have been mentioned above (Figures 3.3, 3.4, and 3.5).

The next stage involved challenges and strategies for OSC and BIM integration. Transportation, training, and experiences, planning and designing, financial, collaboration and commitment, industry, innovation, and process were the six clusters of challenges identified from OSC literature (Table 3.1). From previous literature, lack of knowledge, human resources, financial, legal constraints, interoperability and collaboration, and lack of standardisation were identified as BIM implementation challenges (Table 3.2). Initially six integration strategy clusters were identified through a systematic review of previous literature (Table 3.3).

Interviews confirmed and complemented the findings of the SLR stage. Significant OSC and BIM implementation challenges were also identified and categorised through interviews (Tables 3.5 and 3.6). The categorised challenges were in line with the systematic review stage. However, policy documentation and technology management were two additional integration strategy clusters identified through the interview findings (Table 3.7).

Within the developed framework (Figure 3.6), challenges, strategies, and the strategy application levels have been demonstrated. Each cluster of strategies responds to groups of challenges identified from the literature and expert interviews. Three of the identified strategy clusters would apply at the organisational level and five can be applied at the project level. Identified challenges and strategies can be linked together, thus demonstrating that the application of a strategy could be beneficial for mitigating other challenges even if they are not directly linked.

The study findings confirm the knowledge gap found in the literature concerning the relatively under-developed OSC and BIM integration strategies, particularly in New Zealand, and emphasized the training of different stakeholders. Based on the systematic literature review and interview findings, this study identified eight main strategies as a guideline for mitigating existing and future challenges, and this resulted in an integration framework. The identification of OSC and BIM integration challenges and strategies expands the current body of knowledge, particularly for the efficient execution of OSC-based projects. The framework identified effective improvements arising from OSC, and BIM may serve as a guideline for both project level and organisation level activities and processes.

From a practical aspect, the framework as a diagnostic tool can help practitioners identify and understand OSC and BIM development and training integration in New Zealand. These findings are beneficial at a governance level for formulating policies and prioritising research in the implementation of OSC and BIM. Policymakers may apply this study to identify critical topics in OSC for future research and policymaking in order to enhance productivity. The limitations of this study are mainly the low level of expertise, cases and practices in BIM application in OSC. The framework presented in this study can be further applied in the OSC and BIM integration cases to develop the detailed actions in association with each strategy. Future research may concentrate on examining the correlations between the factors affecting integration issues and methods. Finally, it is essential to conduct additional quantitative and qualitative analyses to thoroughly examine the proposed framework. These analyses will help assess the validity of the findings from this study and ensure that the framework is robust and applicable in real-world scenarios.

# Chapter 4: Challenges for OSC and BIM Integration in New Zealand

***The current chapter is based on the following article:***

Ghalenoei, N. K., Jelodar, M. B., Paes, D., & Sutrisna, M. (2022, November). Exploring Offsite Construction and Building Information Modelling Integration Challenges; Enhancing Capabilities within New Zealand Construction Sector. In IOP Conference Series: Earth and Environmental Science (Vol. 1101, No. 4, p. 042008). IOP Publishing. doi:10.1088/1755-1315/1101/4/042008

## 4.1 Introduction

New Zealand's construction industry is a crucial driver of the national economy, contributing approximately 6% to the Gross Domestic Product (GDP) (PrefabNZ, 2018c). Despite its importance, the industry faces several persistent challenges, including high costs, low productivity, and limited innovation (Mirus et al., 2018b). Factors such as inefficient procurement practices, limited management capabilities, skill shortages, and poor workability have further hindered productivity and growth (Babaeian Jelodar et al., 2016). Addressing these issues is critical for ensuring the sustainability of the sector, particularly as the demand for housing and infrastructure continues to rise.

One of the most promising ways to improve productivity and overcome these challenges is through the adoption of modern tools and construction methods, such as digital technologies and offsite manufacturing techniques (Bell, 2019; Duncheva & Bradley, 2019; Eliwa et al., 2018; PrefabNZ, 2018c). Offsite Construction (OSC) refers to the process of manufacturing building components in a controlled, factory-like setting and assembling them on-site. This method has the potential to reduce construction time, minimise errors, and lower risks

(Babaeian Jelodar et al., 2016), while also promoting more sustainable construction practices(Hwang et al., 2018a; Mao et al., 2015).

Despite these recognised benefits, OSC still faces a number of significant challenges. These include technical difficulties, regulatory hurdles, and logistical constraints (Barkokebas et al., 2021). In recent years, Building Information Modelling (BIM) has emerged as a powerful tool to help overcome some of these challenges. BIM has been shown to enhance the efficiency and quality of prefabricated construction processes by streamlining information flow and supporting the use of digital technologies (Abanda et al., 2017; Cheng & Ma, 2020). Although its use in OSC is still relatively limited, BIM has the potential to transform the way offsite construction is managed and executed (Barkokebas et al., 2021).

The integration of BIM with OSC offers immense potential for improving the economic, environmental, and social sustainability of construction projects (Zhang et al., 2016). BIM-enabled OSC can facilitate collaboration, ensure compliance, improve knowledge sharing, detect clashes, and optimize design processes (Babaeian Jelodar & Shu, 2021; Gbadamosi et al., 2020a). However, to realise these benefits, the challenges associated with integrating these two technologies must be carefully examined and addressed.

Given the increasing pressure on New Zealand's construction industry to improve productivity, the integration of OSC and BIM is of paramount importance. This study is significant because it seeks to identify the key challenges hindering the integration of OSC and BIM in New Zealand. By addressing these challenges, industry stakeholders can improve the effectiveness and efficiency of construction projects, thereby contributing to the overall growth and sustainability of the sector. This research aims to investigate the challenges of integrating OSC and BIM in New Zealand's construction industry. The findings will provide valuable insights for project stakeholders, helping them to anticipate and mitigate potential obstacles. Ultimately, this study will contribute to enhancing the productivity of OSC projects in New

Zealand, while also providing a framework for the future adoption of advanced construction technologies.

## 4.2 Literature Review

This section reviews the relevant literature on the adoption and integration of OSC and BIM in the construction industry. It examines the benefits and challenges of OSC, particularly in the New Zealand context, and explores the role of BIM in enhancing the efficiency of OSC projects.

### 4.2.1 Potential of OSC in Construction

Offsite Construction (OSC) has demonstrated significant potential to enhance productivity within the construction industry compared to conventional site-built methods (Sacks et al., 2010a). This increased productivity results from OSC's application of manufacturing principles, which support the efficient production of high-volume, high-quality building components (Blismas et al., 2010). Despite these well-documented benefits, the adoption of OSC remains limited (Hosseini et al., 2016; Pan et al., 2012). Although some studies suggest that automation in offsite activities, particularly when supported by BIM, could further boost productivity (Goulding et al., 2012), significant challenges persist that limit the widespread implementation of OSC.

### 4.2.2 OSC in New Zealand: Challenges and Opportunities

In New Zealand, OSC has been identified as a crucial enabler for increasing the timely supply of housing (Page & Norman, 2014b). Despite this, OSC uptake remains low, with only 5–10% of newly constructed homes utilising offsite methods, compared to as much as 80% in certain European countries (Tso, 2018). The introduction of initiatives such as KiwiBuild and a renewed government focus on housing supply underscore the importance of understanding and mitigating challenges to OSC adoption. These challenges include regulatory processes, especially regarding resource and building consents (Bell, 2019).

Several studies have outlined challenges to the adoption of OSC, including inadequate access to advanced technology, logistical difficulties, and regulatory hurdles concerning resource and building consents (Abanda et al., 2017; Cheng & Ma, 2020; Hoover et al., 2017; Yin et al., 2019). Aylap and Ay (2020) and Lou and Kamar (2012) point to the shortage of trained operatives and educational programmes as critical obstacles. Furthermore, although OSC often requires higher initial capital investment. Furthermore, although higher initial capital investments are often required for OSC (Ayalp & Ay, 2020; Sutrisna et al., 2019), few studies provide a comprehensive analysis of how these costs impact decision-making among stakeholders, particularly within New Zealand's construction industry.

### 4.2.3 Comparison of BIM in Conventional Construction vs. OSC

The integration of BIM in conventional construction and OSC presents different challenges and benefits due to the inherent differences in their processes. Conventional construction often relies on site-based methods with less emphasis on pre-fabrication, which can lead to inefficiencies, such as delays, waste, and rework (Eastman et al., 2011; Nawari, 2012). While BIM has been successfully applied in convetional construction to enhance design coordination, reduce errors, and improve scheduling, its full potential is often limited by the conventional, fragmented nature of the construction process (Abanda et al., 2017).

In contrast, OSC, with its focus on prefabrication and assembly, aligns well with BIM's capabilities. BIM enhances OSC by improving the design, planning, and management of offsite processes. For example, through 3D modelling and simulations, BIM enables better coordination between offsite manufacturing and on-site assembly. The integration of BIM in

OSC can lead to more accurate prefabrication, reducing material waste, and improving quality control (Ezcan et al., 2013; Goulding & Arif, 2013). Furthermore, the collaborative nature of BIM supports the integration of various stakeholders in the offsite process, which is essential for the success of OSC projects (Sacks et al., 2010b).

While other technologies, such as advanced robotics, IoT, or AI, also offer potential benefits for the construction industry, the integration of BIM and OSC offers a unique advantage. BIM provides a digital framework for design and coordination, while OSC focuses on the physical production and assembly of building components offsite. The synergy between these two technologies facilitates the efficient and accurate translation of digital models into physical construction, which is not as seamlessly achievable with other emerging technologies alone (Akinade et al., 2015; Sabet & Chong, 2019). Additionally, OSC's reliance on prefabrication aligns well with BIM's ability to model and simulate these processes before they occur, creating a feedback loop that enhances decision-making and project outcomes. In contrast, other technologies may address specific aspects of construction, but the combined approach of BIM and OSC presents a more holistic solution to industry challenges (Tang et al., 2019a; Wu et al., 2022; Xu et al., 2018).

### 4.2.4 Integration of OSC and BIM: Benefits and Challenges

The effective implementation of OSC relies heavily on the sharing of practical knowledge among stakeholders, necessitating robust information management systems that leverage advanced technologies like BIM. While the integration of OSC and BIM is posited to facilitate mass customisation within the construction industry (Liu et al., 2019), the existing literature often lacks detailed exploration of the integration process. BIM is recognised for its ability to enhance collaboration among various parties involved in construction projects, thereby improving productivity and sustainability throughout the project lifecycle (Eastman et al., 2011). Many challenges across different stages of OSC can potentially be managed using BIM technology (Chong et al., 2017).

For instance, BIM can assist in identifying and correcting inefficiencies in on-site operations, which can lead to a reduction in rework (Bryde et al., 2013). However, the literature frequently overlooks the challenges associated with implementing BIM, including the need for adequate training, high costs, and unclear guidelines (Alazmeh et al., 2018; Jin et al., 2017; Lee et al., 2015). While these challenges are acknowledged, research rarely provides practical frameworks for addressing them. Despite significant advancements in BIM applications within conventional construction, its integration with OSC remains underexplored (Goulding et al., 2015; PrefabNZ, 2018b; Wang et al., 2020).

Current efforts towards integration often lack thorough documentation, and researchers like Abanda et al. (Abanda et al., 2017) suggest that more detailed investigation is needed. Although Tang et al. (Tang et al., 2019b) identified a correlation between BIM use and improved OSC performance, they did not provide specific insights into the challenges associated with integrating these two technologies in practice.

Overall, while the existing literature provides valuable insights into the benefits and potential of OSC and BIM, there are significant gaps, particularly in terms of identifying the key challenges that hinder their integration. This research aims to address these gaps by focusing on the specific challenges associated with OSC and BIM integration within the New Zealand construction industry. Understanding these challenges will provide the foundation for further research on how these technologies can be better utilised in the local context.

## 4.3 Research Methods

A combinational approach was undertaken for this study. First, a literature review identified OSC and BIM integration challenges, followed by interviews with New Zealand specialists to confirm the findings. The literature review examined the existing literature and prior findings in depth. The deductive literature review provided the research with the background knowledge to conduct the interviews. It assisted in identifying the difficulties in implementing BIM and OSC. The interviews offered a detailed and complimentary conceptualisation of the findings in the following stage (Fellows & Liu, 2009; Harden & Thomas, 2010; Van Eck & Waltman, 2014). Semi-structured interviews with New Zealand experts were undertaken during 2021 to identify potential challenges for OSC and BIM integration. However, due to the COVID-19 restrictions, the interviews were all conducted online.

The original pool of respondents consisted of experts with more than ten years of expertise in construction projects and a bachelor's degree or higher education level. Experts with experience in prefabrication, OSC, and BIM in New Zealand were also included in the selection process. The number of interviewees was decided based on theoretical saturation, and nine interviews were conducted. The term "theoretical saturation" refers to the point in the interview process when more interviews can no longer supply new information for the study's specific aim (Glaser & Strauss, 2017).

Each interview was digitally recorded and transcribed and lasted about 40-60 minutes. Interviews were prepared with core questions followed by additional questions about the study's goals for maximum tangibility and comprehension of responses (Chen & Partington, 2004). The interview transcriptions were analysed using NVivo20 to assist with the organisation and management of the qualitative data. While NVivo facilitated the process by helping to code, sort, and structure the data, it is important to note that the analysis and interpretation of the data were carried out by the researcher. NVivo is a valuable tool for managing large qualitative datasets, but it is the researcher's task to identify meaningful patterns and themes (Edwards-Jones, 2014).

For this study, thematic analysis (Braun & Clarke, 2006) was employed as the primary method of data analysis. This process involved familiarising oneself with the data, generating initial codes, searching for themes, reviewing themes, and finally defining and naming them. The coding was performed iteratively, allowing patterns and key themes to emerge from the interview data. This iterative process ensures that the analysis is grounded in the data while allowing the researcher to engage deeply with the material (Gibbs, 2017). The goal was to identify specific integration challenges for BIM and OSC. The interviewees' information is presented in Table 4.1.

**Table 4.1:** Interviewees Details

| Expert | Current role | Experience (years) |
| --- | --- | --- |
| R1 | Digital Assets & Engineering Lead | 11 |
| R2 | Digital Engineering Leader | 21 |
| R3 | Head of Product Design | 19 |
| R4 | Project Analyst and Planner | 19 |
| R5 | Head of Modular Design for Manufacture | 20 |
| R6 | Architectural Technician | 10 |
| R7 | Chief Executive Officer | 30+ |
| R8 | Consultant | 20 |

## 4.4 Findings and Discussion

The challenges associated with the integration of OSC and BIM in New Zealand grouped into four main categories: Human Resource, Documenting, Managerial, and Organisational challenges (Figure 4.1). This section explores each of these categories and discusses the findings from both the literature and the interviews.

*Human Resource Challenges*

One of the primary challenges to the successful integration of OSC and BIM is the lack of skilled and adequately trained personnel. The construction industry in New Zealand, as with many other regions, suffers from a shortage of workers who have the necessary knowledge and skills to implement these technologies effectively (Ayalp & Ay, 2020; Lou & Kamar, 2012). Interview findings confirmed this challenge, with participants indicating that the workforce lacks familiarity with OSC processes and BIM benefits. There is also a general lack of awareness regarding the technical aspects of these innovations.

Tang et al. (Tang et al., 2015) suggests that graduates with OSC and BIM expertise could save the industry training costs, but there are not yet enough educational programmes to fill this gap. Moreover, contractors often lack the experience required to successfully handle OSC projects, particularly in the private sector where expertise in designing, transporting, and installing prefabricated components is limited (Zhang et al., 2018). This lack of training and experience poses a significant challenge, as inexperienced contractors can lead to poor-quality prefabricated components and increased costs. Without a concerted effort to upskill the workforce, OSC and BIM integration may continue to be hindered.

*Documenting Challenges*

Effective documentation and information management are critical for the successful integration of OSC and BIM. However, one of the significant challenges identified in both the literature and interviews is the lack of digital documentation and archives in New Zealand's construction industry. According to the interviewees, the absence of a comprehensive digital database makes it difficult for stakeholders to retain institutional knowledge and learn from past projects. This leads to repeated mistakes and inefficiencies (Kordestani Ghalenoee et al., 2018a).

BIM offers the potential to address this issue by allowing data to be stored and shared across project stages, enabling stakeholders to access and learn from previous experiences (Abanda et al., 2017; Nawari, 2012). However, despite its potential, BIM is underutilised in this capacity. Interviewees noted that digital documentation practices are not widely adopted, and the lack of a centralised digital library means that valuable project information is often lost when staff leave or when project phases transition. The findings suggest that the implementation of a robust documentation system which integrates BIM into the workflow could significantly improve project outcomes by reducing rework, improving collaboration, and enhancing knowledge sharing.

*Managerial Challenges*

Managerial challenges represent another key barrier to OSC and BIM integration. Decision-makers, particularly those with non-technical backgrounds, often resist adopting new technologies, either due to a lack of understanding or reluctance to deviate from conventional methods (Mao et al., 2015; Zhang et al., 2018). The interviewees indicated that many financial managers and other decision-makers are hesitant to embrace OSC and BIM, despite their potential to improve productivity and reduce costs. This resistance often stems from a lack of belief in the benefits of these technologies or a failure to appreciate the long-term gains from upfront investment. Babaeian Jelodar et al. (2014) and Kordestani Ghalenoee et al. (Kordestani Ghalenoee et al., 2018b) have similarly observed this resistance in other research, noting that overcoming it requires considerable effort in educating stakeholders about the advantages of new technologies.

Additionally, the findings pointed to a lack of regular communication and collaboration among stakeholders. Interviewees stressed the importance of having regular meetings, seminars, and webinars to facilitate knowledge sharing and problem-solving throughout the project lifecycle. Without these, collaboration remains fragmented, and opportunities to address issues early on are missed (Vernikos et al., 2014; Wuni & Shen, 2020). Improving managerial support for OSC and BIM, through education and regular communication, is crucial for overcoming these barriers and ensuring that decision-makers are better equipped to support these innovations.

### *Organisational Challenges*

Organisational challenges are closely linked to the structural fragmentation of the construction industry in New Zealand. The industry is characterised by a project-based approach, where each stakeholder operates independently, making it difficult to foster the collaboration necessary for OSC and BIM integration (Xue et al., 2017). The findings suggest that this fragmentation leads to poor communication between stakeholders, contributing to inefficiencies and rework. Furthermore, many stakeholders in New Zealand's construction industry are resistant to change. Interviewees noted that some participants, particularly older stakeholders, are reluctant to adopt OSC because they fear it will stifle architectural creativity or because they are set in their conventional ways (Rahman, 2014). This reluctance to change is a major barrier to the wider adoption of OSC and BIM, as it inhibits innovation and collaboration.

Geographical isolation also compounds the organisational challenges. New Zealand's small market size and distance from international suppliers make importing prefabricated components expensive, limiting the feasibility of large-scale OSC adoption. These economic constraints are a significant factor for many stakeholders, who may be unwilling to invest in OSC and BIM due to the high upfront costs (Zhang et al., 2018). Addressing these organisational challenges requires a cultural shift within the industry, where collaboration, innovation, and openness to new technologies are prioritised. Organisational inertia must be overcome to fully realise the benefits of OSC and BIM in New Zealand's construction sector.

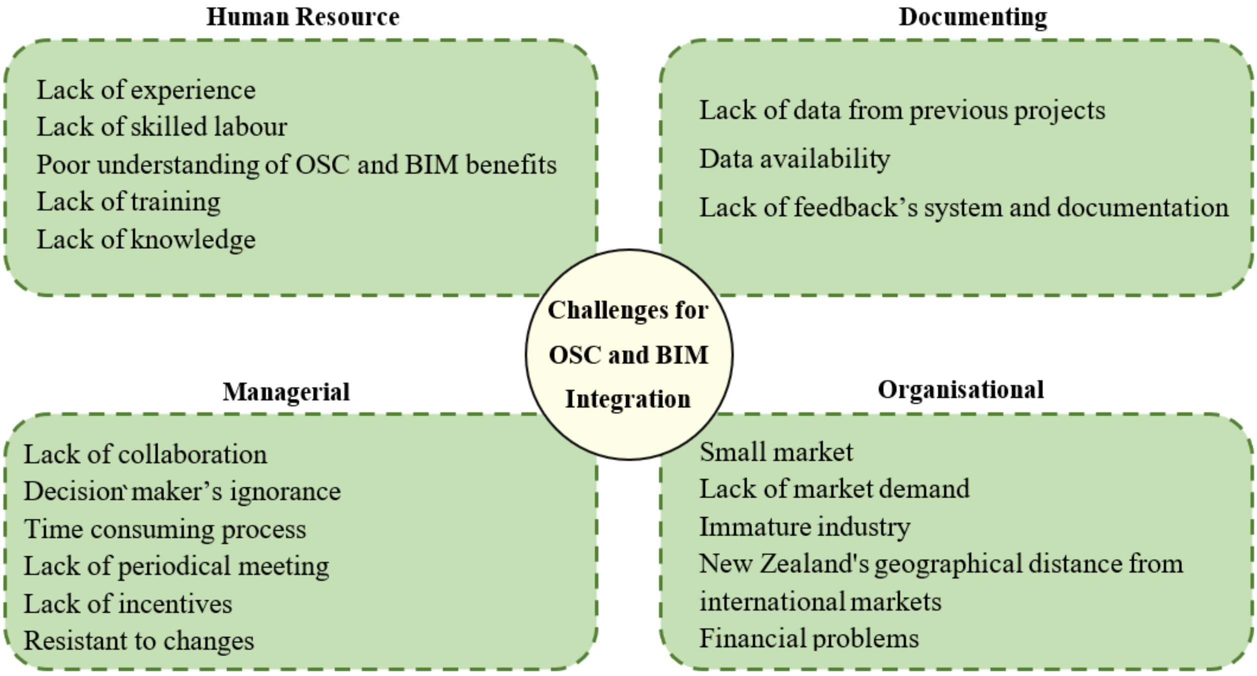


**Figure 4.1:** Challenges for OSC and BIM Integration in New Zealand

The integration of OSC and BIM in New Zealand's construction industry faces significant challenges across four key areas: Human Resource, Documenting, Managerial, and Organisational challenges. These issues range from a lack of skilled personnel and inadequate digital documentation practices to managerial resistance and structural fragmentation in the industry. Addressing these challenges is essential for improving collaboration, reducing project costs, and enhancing the overall productivity of the construction sector. By understanding these barriers, stakeholders can take steps to facilitate the integration of OSC and BIM, ultimately leading to more efficient and sustainable construction practices in New Zealand.

## 4.5 Conclusion and Future Research

This study aimed to identify the specific barriers to OSC and BIM integration through a literature review and interviews with industry experts. The research findings, supported by qualitative analysis using NVivo 12, categorised these challenges into four main groups:

Human Resource, Managerial, Documenting, and Organisational challenges. A critical issue is the shortage of skilled workers and insufficient training programs, making it difficult to find professionals who are well-versed in both OSC and BIM technologies. This lack of expertise slows the adoption process and undermines the effectiveness of these innovations.

In addition, decision-makers often lack the technical understanding and confidence needed to invest in OSC and BIM, which leads to resistance within organisations. This resistance is further complicated by the fragmented nature of the construction industry in New Zealand, where stakeholders typically operate independently, leading to poor collaboration. Another key challenge is the absence of robust digital documentation practices, resulting in inefficiencies and a lack of institutional knowledge retention. Without effective documentation systems, stakeholders fail to learn from past projects, leading to repeated errors.

These findings are valuable for industry practitioners, as they identify key areas where improvement is needed for OSC and BIM integration. By understanding the specific challenges, stakeholders can take proactive steps to develop solutions that support more seamless adoption. The research also provides a theoretical foundation for future studies, which can now build on the identified challenges to create strategies aimed at overcoming these barriers. While this study contributes to the understanding of OSC and BIM integration, it has some limitations. Access to industry experts with in-depth knowledge of both OSC and BIM in New Zealand was restricted, and Covid-19-related constraints made face-to-face interviews impossible. Despite these limitations, the findings are globally relevant and can be applied to other regions facing similar integration challenges.

Future research should focus on exploring and developing strategies to overcome the challenges identified in this study. Quantitative and qualitative analysis can be employed to test the effectiveness of these strategies in different project contexts. Additionally, case studies on successful OSC and BIM integration projects could provide further insights into best practices.

There is also a need for more research that looks into the long-term benefits of OSC and BIM integration, specifically how it impacts project costs, timelines, and sustainability outcomes. Finally, further work is necessary to assess how New Zealand's construction industry can adapt international standards for OSC and BIM integration while addressing local market and regulatory conditions.

# Chapter 5: The Factors of Integration

***The current chapter is based on the following article:***

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. Sutrisna, M. Rahmani, D (2024), "The Challenges and Strategies of BIM for Offsite Construction Delivery; the Factors of Integration" (Under Review).

## 5.1 Introduction

Compared to other industries, construction suffers from low productivity for years (Razkenari et al., 2020). In response to this deficiency, offsite construction (OSC) was introduced to improve productivity within the construction industry (Alsakka et al., 2023; Zolghadr et al., 2022). OSC involves manufacturing building components in a factory setting before being transported to the construction site for assembly. The approach aims to reduce construction time while improving quality and safety, and, ultimately, to enhance construction performance (Shahzad et al., 2022). Over the years, this process has developed to the point that advanced technology, such as Building Information Modelling (BIM), is becoming a significant tool in the delivery process (Olawumi, 2019).

OSC is a method for better delivery and can benefit usage of BIM as a digital tool to enables experts to collaborate in a virtual environment, thus improving communication and reducing clashes (Abanda et al., 2017). BIM integrates different data types as a building's digital representation and enables project stakeholders to collaborate in a virtual environment (Guignone et al., 2023). BIM has been shown to enhance project communication and coordination, resulting in fewer errors, less waste, and higher client satisfaction (Liu et al., 2021b; Ullah et al., 2019). BIM implementation in the OSC delivery process increased due to its ability to enhance stakeholder collaboration and facilitate clash detection during the design and construction phase (Hwang et al., 2018a). Based on the literature this process is integrating various features to increase overall performance and productivity (Mohammed & Ali, 2012). BIM and OSC integration enhance productivity by optimizing planning, communication and reducing errors in the construction industry (Liu et al., 2021a).

Although this integration delivers numerous advantages, there are challenges that require attention to employing BIM specifications in the OSC delivery process (Abanda et al., 2017; Gan et al., 2018a; Li et al., 2019). Integration challenges could be a result of lack of training, lack of skills and knowledge, transportation issues, and cost considerations. In addition, resistance to change, reluctance to invest in new technologies and the small market could be other challenges associated with OSC and BIM integration (Abanda et al., 2017; Porwal et al., 2023; Rashidian et al., 2023).

In order to reduce the impacts of these challenges, various strategies have been recommended, which include constant training and upskilling knowledge, stakeholder collaboration, standardisation, and mandating the use of BIM in OSC projects (Barkokebas et al., 2021; Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022). The strategies can help overcome cultural and organisational barriers, improve skills and knowledge, ensure compatibility, and effectively manage costs (Ayalp & Ay, 2020; Li et al., 2019). According to previous studies, OSC and BIM integration has not been fully realised in the construction industry of many countries. Although these studies have provided valuable insights by exploring the challenges and strategies influencing OSC and BIM integration, there has been no systematic and empirical exploration of the critical factors influencing these challenges and strategies (Brown et al., 2020; Tang et al., 2019a; Tang et al., 2019b; Ullah et al., 2019; Waqar et al., 2023; Yang et al., 2022). Therefore, these critical factors need to be determined and classified for further integration assessment, and finally, their root causes of their criticality should be identified.

The current study addresses the mentioned gap by achieving the following objectives: (1) explore the factors affecting OSC and BIM integration through the literature review; (2) explore the underlying variables for challenges, strategies, and integration factors through a questionnaire survey followed by a case study. This paper contributes to understanding OSC and BIM integration in the construction industry by establishing the underlying factors for challenges, strategies, and integration variables based on literature review findings.

## 5.2 Literature Review

This section examines the existing literature on the integration of OSC and BIM, focusing on the benefits, challenges, and strategies for improving their synergy. As the demand for faster, more efficient, and sustainable construction methods grows, OSC and BIM have gained increasing attention for their potential to revolutionise the construction industry (Makabate et al., 2021; Yin et al., 2019).

### 5.2.1 Benefits of OSC and BIM Integration

OSC offers several benefits regarding productivity, sustainability, and cost-effectiveness. As a system isolated from the construction site, OSC requires a high level of collaboration and efficiency in managing fragmented information exchanged among stakeholders (Phang et al., 2020). Several studies have explored the ability of BIM to enhance collaboration and provide accurate information at the right time and location, which is crucial throughout the lifecycle of OSC projects (Abanda et al., 2017). For example, BIM facilitates better decision-making during design, helps reduce rework during construction, and supports maintenance in the facility management phase.

Yin et al. (2019) pointed out that various investigations have explored the BIM and OSC separately throughout the lifecycle of OSC, including their roles in facility management, sustainability, and collaboration. However, these studies tend to examine the benefits of BIM and OSC integration in isolated stages, without offering a comprehensive approach that spans the entire lifecycle. For example, while Wang et al. (2020) focused on integrating lean construction principles with BIM technology to improve the precast design process, other stages such as construction and facility management are often underexplored.

Similarly, Liu et al. (2021b) investigated the integration of BIM with steel fabrication, showing how BIM can improve data interoperability and streamline information flow. However, despite the advantages identified in these studies, practical large-scale validations of these approaches remain limited. Many studies focus on theoretical benefits without testing them across real-world projects, which leaves gaps in understanding how OSC and BIM integration can truly impact efficiency and sustainability throughout the lifecycle.

### 5.2.2 Challenges for OSC and BIM Integration

Despite the recognised benefits, OSC and BIM integration faces significant challenges. A recurring issue in the literature is the shortage of skilled workers and lack of educational programmes to support the adoption of these technologies (Ayalp & Ay, 2020; Hwang et al., 2018b; Wong et al., 2017). While these barriers are frequently acknowledged, many studies merely highlight them without offering in-depth investigations into the root causes of these shortages. For instance, few studies examine why industry stakeholders are not investing in training programmes or how the current workforce's reluctance to adapt to new technologies impedes progress (Jang et al., 2022; Zou et al., 2022). The failure to critically explore these underlying causes represents a significant gap in the literature, leaving questions about how to effectively address workforce shortages unanswered.

Additionally, regulatory constraints, logistical issues, and design inflexibility are cited as further barriers to the adoption of OSC across different regions (Agapiou, 2022; Jang et al., 2021). However, many of these studies take a high-level approach to these challenges without providing detailed, context-specific solutions. For example, regulatory barriers are discussed broadly, but there is a lack of research exploring how specific regulations such as building codes or procurement processes impede OSC adoption in different countries. This lack of specificity limits the practical value of these studies, as they fail to offer actionable strategies to overcome such barriers.

Moreover, the complexity of integrating diverse stakeholders and managing fragmented information flows across different stages of construction is another major challenge (Goulding et al., 2015; Li et al., 2017). While BIM is often cited as a tool to improve communication and reduce schedule risks, the literature frequently overlooks the practical difficulties of implementing BIM in fragmented supply chains typical of OSC projects. The challenge of coordinating multiple stakeholders often spread across different locations adds layers of complexity to BIM adoption. The lack of a comprehensive, industry-wide integration framework that addresses these practical challenges has left BIM and OSC integration in a fragmented state.

### 5.2.3 Strategies for Overcoming Integration Challenges

Several strategies have been proposed to address these integration challenges, including improving communication, government intervention, streamlined logistics, accurate project definitions using 3D models, and innovative contracts (He et al., 2021; Jang et al., 2021; Nawari, 2012). However, while these strategies are promising in theory, they often lack empirical validation, limiting their applicability in real-world projects. For example, recommendations such as government intervention or streamlined logistics are frequently discussed without considering the institutional or market constraints that may make these strategies difficult to implement. The reliance on generalised strategies fails to acknowledge the complexities of local regulatory environments, which vary significantly between regions, further limiting the practicality of these strategies in different contexts.

Jiang et al. (2021) propose strategies such as new forms of contracts and early stakeholder involvement, which could theoretically foster better collaboration and integration. However, the lack of large-scale testing or pilot projects to evaluate the effectiveness of these strategies undermines their credibility. In the New Zealand context, Kordestani Ghalenoei et al. (Kordestani Ghalenoei et al., 2022a) conducted a systematic literature review and interviews to identify 35 challenges and 21 strategies specific to OSC and BIM integration. While their research provides valuable insights into the New Zealand construction industry, the heavy reliance on qualitative methods limits the generalisability of their findings. Without quantitative analysis to measure the impact of these challenges and strategies, it is difficult to determine which factors are most critical and how they interact. This reliance on qualitative data highlights a broader weakness in the literature, where in-depth, quantitative studies are needed to develop more actionable, scalable strategies that can be applied in diverse contexts.

### 5.2.4 Need for OSC and BIM Integration

While previous studies have provided insights into the integration of OSC and BIM, there is still a lack of quantitative research that could identify and structure the underlying factors that affect integration. Tang et al. (2019a) highlighted correlations between BIM adoption and OSC project performance but did not explore the specific barriers that prevent effective integration. Similarly, Kordestani Ghalenoei et al. (2022a) explored the integration challenges qualitatively, but quantitative data is necessary to guide the development of a structured roadmap for integration. In overall, while OSC and BIM integration offers considerable potential to transform the construction industry, the current literature presents several limitations. Most studies focus on isolated phases of the project lifecycle, without a comprehensive view of how integration can benefit the entire process. Additionally, while theoretical solutions are offered for overcoming integration challenges, there is a lack of practical frameworks and empirical evidence to support their effectiveness. Addressing these gaps through a data-driven, lifecycle-oriented integration roadmap will be essential for advancing the integration of OSC and BIM in the construction industry.

## 5.3 Research Methods

In this chapter, a mixed-methods approach (explanatory sequential design) was employed, integrating both quantitative and qualitative methods using an online questionnaire and a case study. This combination enables a comprehensive exploration of the research questions, addressing the limitations inherent in using either method in isolation (Gutiérrez Braojos et al., 2020). The online questionnaire served as the quantitative phase of the research, designed to gather numerical data on specific variables relevant to the study. This method facilitates the collection of data from a larger sample size, providing a broader perspective on the phenomena under investigation. The quantitative results help identify trends, patterns, and correlations that may not be evident through qualitative methods alone (Creswell et al., 2003; Ivankova et al., 2006).

Following this, the case study method was employed as the qualitative phase, providing an in-depth examination of specific instances of OSC and BIM integration. This approach captures the richness of participants' experiences and insights, allowing for a contextual understanding of the complexities and nuances involved in OSC and BIM practices. Through detailed interviews and observations within a real-world setting, the case study method enriches the quantitative findings with valuable qualitative data (Gutiérrez Braojos et al., 2020; Tashakkori, 1998). The rationale for this mixed-methods design is multifaceted. First, it enhances the robustness of the findings through complementarity; the quantitative data from the questionnaire provides a solid foundation of evidence that can be explored further with qualitative insights from the case study. Second, the study achieves triangulation, which increases the validity and reliability of the results by integrating findings from both methods to create a more comprehensive understanding of the challenges and strategies related to OSC and BIM integration (Johnson, 2017; Jonsen & Jehn, 2009a).

Additionally, the sequential nature of this design ensures that the initial quantitative findings inform the subsequent qualitative phase, guiding the focus of the case study and the types of questions posed during interviews. This approach not only maintains relevance but also grounds the research in the realities faced by practitioners in the field (Almeida, 2018). Ultimately, this mixed-methods approach allows for a holistic view of the research problem, leading to nuanced conclusions about OSC and BIM integration challenges and strategies. After a review of relevant studies to OSC and BIM integration, adopted the same 35 challenges and 21 strategies and semi-structured interview technique employed by Kordestani et al. (2022a).

To summarise and modify these factors, two rounds of the peer-review process were done by academic peers, and industry professionals involved in the OSC delivery process with BIM implementation in construction projects. Through this process, similar factors with similar themes were combined and unclear ones were modified for better clarity and understanding, resulting in a final list of 19 challenges and 16 strategies. In this context, “modified” refers to refining the wording or phrasing of factors to enhance clarity and ensure they are easily understandable. This process addressed any vagueness or overlap, resulting in more precise and consistent descriptions aligned with the research objectives. (Figure 5.1). The modified lists were the input data for creating the questionnaire used in this study.

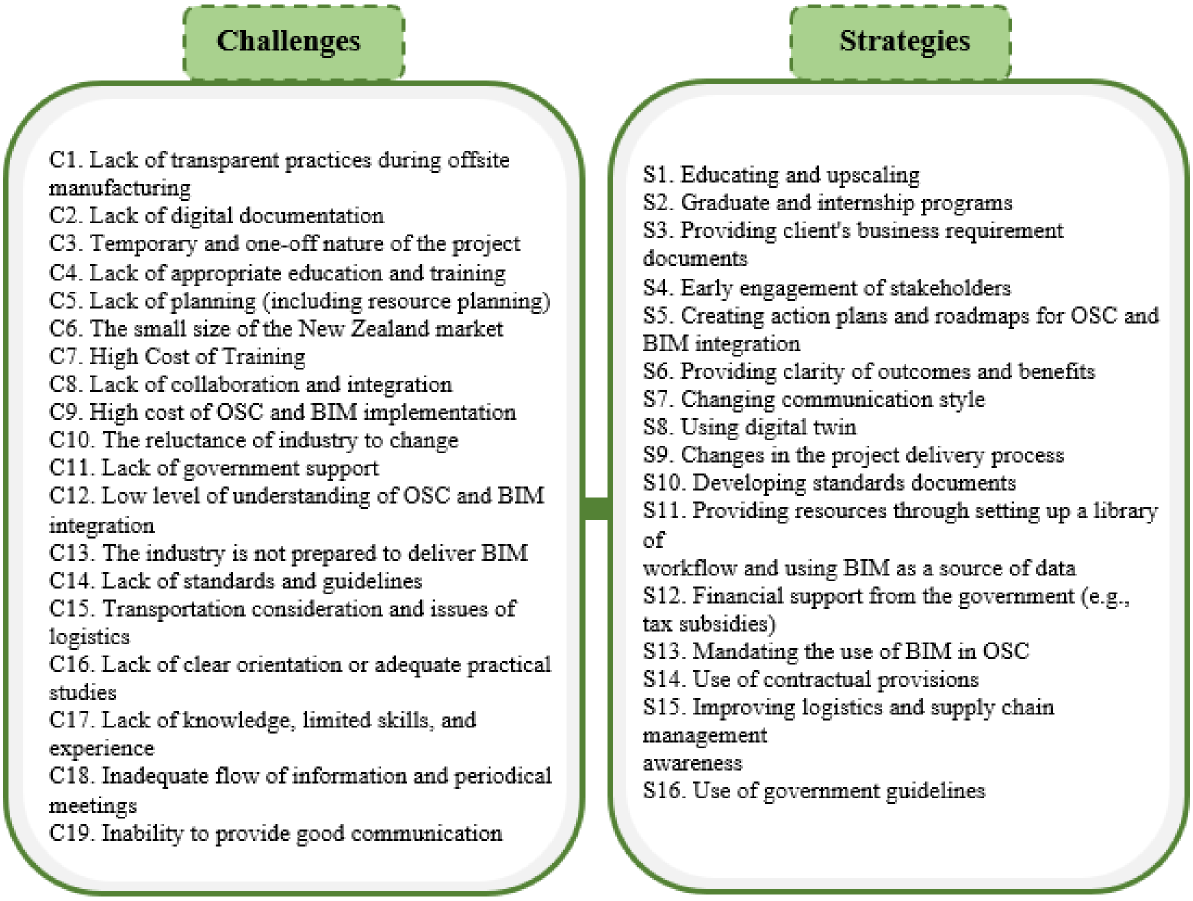


**Figure 5.1:** Challenges and Strategies for OSC and BIM Integration (Kordestani Ghalenoei et al., 2022a)

### 5.3.1 Survey

The questionnaire was designed based on the Figure 5.1 list, and questions were developed for measuring integration throughout the OSC delivery process, starting from the initial phase to close out (PMBOK, 2021). Several studies have employed questionnaires to rank the variables in construction management fields (Asadi et al., 2023; Kordestani Ghaleenoei, 2022; Kordestani Ghalenoei et al., 2021). This research applied an empirical and quantitative method to explore the OSC and BIM integration challenges and strategies and evaluated them by running an exploratory factor analysis. Thus, the factor analysis technique was employed to explore underlying factors that impact the OSC and BIM integration. Factor analysis reduces data and checks the results to see if multiple relationships exist among variables (Yap et al., 2018).

The questionnaire consisted of two parts: one focused on the demographic information, and the other aimed at measuring the participants' agreement with the importance of the three different factors (Appendix 5). First challenges they have experienced, second strategies they have applied to mitigate the challenges during project life cycle and finally questions related to measuring the integration. Participants were asked to rate the questions on a 7-point Likert scale, with scores ranging from 1, "Not at all important", to 7 ", Extremely important". The 7-point Likert scale allowed the respondents to state nuanced responses to the questions. The 7-point scale is likely more reliable than others because items are chosen based on the survey construct (Dawes, 2008; Joshi et al., 2015). Figure 5.2 presents the research methodology process used in the current study.

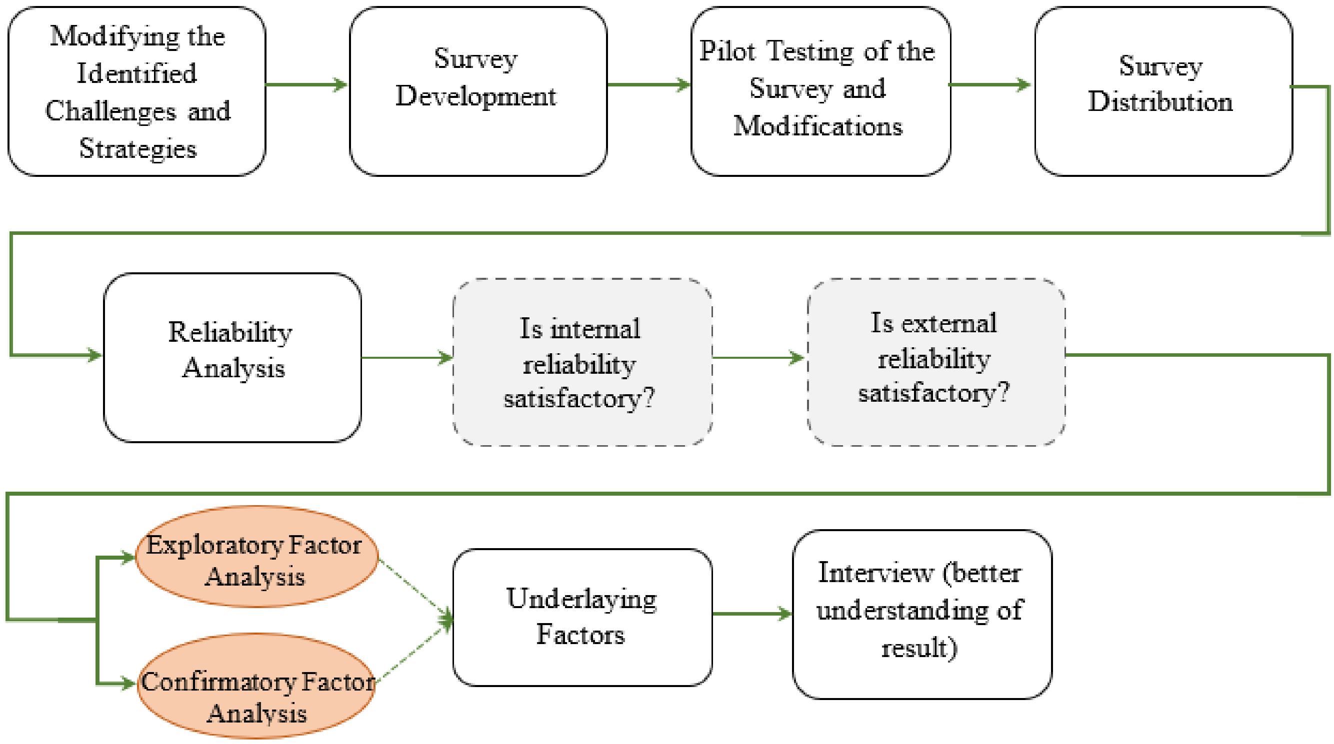


**Figure 5.2:** Research Design Process

A peer review process, with four experts from industry and academia, was conducted before survey distribution, followed by a pilot study with 30 randomly selected respondents. The questionnaire was then modified based on the expert's feedback and pilot study. Two rounds of peer review were sufficient because they addressed key validation objectives. The first round, involving feedback from four industry and academic experts, ensured the questionnaire's content was relevant and aligned with the study's objectives (Brace, 2018).

The second round, a pilot study with 30 respondents, tested the practical application of the survey (Dillman et al., 2014). Both rounds provided sufficient feedback for refinement, making additional iterations unnecessary. Data was collected from October 2022 to February 2023 using Qualtrics, a web-based survey tool. The questionnaire link was sent to construction companies, including clients, consultants and contractors who were identified based on their industry profile and activity in OSC projects, and implementation of BIM to facilitate the delivery process within the New Zealand construction industry.

The target respondents were project managers from contractors, clients, and consultant companies. Architects, draftspersons, and designers were also considered in the survey, as they employ BIM in their design process. Random sampling was conducted to select the target respondents from the BIMinNZ and OffsiteNZ, the leading organisations in New Zealand for BIM and OSC. Fifty-five key BIM user companies are registered with BIMinNZ (BIM Acceleration Committee, 2019) and 99 companies under OffsiteNZ (2023). Six out of 99 OSC companies operating in Australia were removed from the list because of the study scope. In total, 142 companies were selected. Based on the number of technical employees with the relevant specific roles listed in Table 5.1, 450 emails were emailed to the company employees. 116 valid responses were included in analysis out of 164 received responses; the rest were not considered for analysis due to their incompleteness.

The appropriate sample size for this study, considering a small population size based on the Cochran Formula, was estimated at 113 which is acceptable and reliable within +/- 8% margin of error at the 95% confidence level (Cochran, 1977). In addition, the sample size compares favourably with other studies having similar scopes and conditions, including studies in the New Zealand construction sector. This indicates that the sample size is acceptable the response rate for this research is around 36.4%, greater than the free parameters needed to provide a workable solution, and statistical analysis based on such a rate would be trustworthy (Asadi et al., 2023; Yap et al., 2020). Table 5.1 presents the demographics of study participants in the survey, representing diverse disciplines and varying years of experience. The range of participants helped the authors gain a comprehensive perspective on individuals with respect to both academic knowledge and industry experience.

**Table 5.1:** Demographic Information of Participants

| Description | % Of respondents | Years of Experience | Experience in Construction | Experience in OSC | Experience in BIM |
|---|---|---|---|---|---|
| Profession/job roles of participants | | | | | |
| Engineer | 41.4% | 0-5 years | 33.34% | 22.93% | 37.5% |
| | | 6-10 years | 25% | 66.66% | 47.93% |
| | | 11-15 years | 29.16 | 6.25% | 10.41% |
| | | 16-20 years | 6.25% | 2.08% | 4.16% |
| | | More than 20 years | 6.25% | 2.08% | |
| Architect | 6.9% | 0-5 years | 12.5% | 37.5% | 62.5% |
| | | 6-10 years | 37.5% | 62.5% | 25% |
| | | 11-15 years | 25% | | 12.5% |
| | | 16-20 years | 12.5% | | |
| | | More than 20 years | 12.5% | | |
| Planner | 2.6% | 0-5 years | 33.33% | 66.66% | 66.66% |
| | | 6-10 years | | 33.33% | 33.33% |
| | | 11-15 years | 66.66% | | |
| | | 16-20 years | | | |
| | | More than 20 years | | | |
| Project Management | 31.0% | 0-5 years | 22.22% | 33.33% | 42.22% |
| | | 6-10 years | 19.44% | 52.77% | 50% |
| | | 11-15 years | 25% | 8.35% | 2.78% |
| | | 16-20 years | 22.22% | 5.55% | |
| | | More than 20 years | 11.12% | | |
| Other | 18.1% | 0-5 years | 19.05% | 33.33% | 33.33% |
| | | 6-10 years | 28.58% | 52.38% | 38.09% |
| | | 11-15 years | 9.52% | 9.52% | 19.04% |
| | | 16-20 years | 23.8% | 4.76% | 9.54% |
| | | More than 20 years | 19.05% | | |
| 0-5 (A), 6-10 (B), 11-15 (C), 16- 20 (D), More than 20 (E) | | | | | |

### 5.3.2 Case Studies

A qualitative exploratory case study method was employed at this step to confirm the analysis result. Three cases from different New Zealand regions were chosen to cover diversity and unique characteristics (Snyder, 2012). Three criteria were considered while choosing the cases: usage of OSC components and BIM during the project lifecycle, accessibility to the project's data, and willingness of participants to attend the interview (Table 5.2). The case study employed a combination of document review and semi-structured interviews as the primary data collection methods. Design documents, published sources, and meeting notes were thoroughly reviewed to gather detailed information and gain a deep understanding of the selected projects. This process involved thematic analysis of these documents, with key themes extracted and organised using NVivo 20 software.

The interviews were conducted both in person and remotely via Microsoft Teams. The online option was necessary due to geographical distance between some participants and the researcher, enabling broader participation despite logistical challenges. A total of four interviews were conducted, with a mix of in-person and online sessions, depending on the interviewee's location and availability. Two design managers (one from a contractor/ manufacturer, and one form consultant), a BIM manager from the consultancy, and one draftsperson, also from the consultant. Each participant had over 10 years of industry experience, providing a depth of knowledge and practical insights critical to this research.

Triangulation was employed throughout the data collection process to ensure the reliability and validity of the findings. The study cross-validated information by integrating multiple sources—documents, meeting notes, and interviews from various stakeholders—strengthening the robustness of the conclusions drawn (Humble, 2009; Johnson, 2017). This multiple case study design also allowed for replication, reinforcing the insights obtained across different participants and contexts. The case study approach was holistic, focusing on the overall process of OSC and BIM integration. Instead of narrowing the focus to specific sub-units (as would be done in an embedded case study), the holistic approach was selected because BIM and OSC integration are deeply interconnected processes, requiring consideration of multiple stakeholders and phases throughout the project lifecycle. Examining the projects holistically provides a more comprehensive understanding of strategies and challenges (Yin, 2018).

NVivo 20 was used to analyse the qualitative data from the interviews (recorded and then transcribe into text). Although NVivo aided in structuring and organising the data, the actual analysis was carried out by the researcher, focusing on content analysis and cross-referencing key findings with interview data to ensure a comprehensive understanding of the case studies (Edwards-Jones, 2014; Gibbs, 2017). The case study method was chosen because it allows for comparing two or more empirical examples in numerous situations based on the study settings, with specific criteria chosen for this comparison (Yin, 2012). It also enables the collection of specific data that will aid in the study's discussion process, and will lead to a theoretical conclusion, the goal of this study (Meyer, 2001; Snyder, 2012). Finally, this methodology enables researchers to investigate study cases' operational and strategic involvement in a specific site or area (Snyder, 2012).

**Table 5.2:** Case Studies Description

| Project Description | Project Description | Location | Size |
|---|---|---|---|
| Case 1: Waikato River to Redoubt (R2R) | Waikato R2R is a Completed water project which spread through Waikato and Auckland regions. The Waikato R2R programme was implemented to increase the treated water supply by 50 million litres daily from the Waikato to Auckland. The R2R programme involved several Workfront, including Phase 1 in Tuakau and a Booster Pump Station in Papakura. | Waikato Region | Large-Infrastructure |
| Case 2: Noel Leeming Building | The second case study is an in-progress commercial building in the South Island's west. It is a single-story building located in Section 39 Block 1 Maori Reserve & Section 41 block, 1 Maori Reserve & Section 40 and Section 42 Block 1, Greymouth or Mawhera 21 Maori Reserve. | Greymouth-South Island | Medium-Commercial |
| Case 3: MPI-IPEQ Facility | The project aims to establish a specialised facility for the quarantine of imported plants in line with the bio-security regulations of New Zealand. The project involves designing and constructing several components, including 12 interconnected greenhouses, a headhouse, and the greenhouses, a mechanical plant room area. The greenhouses and the corridor cover an area of approximately 500 square metres, while the headhouse occupies an area of around 240 square metres. | Auckland | Medium-Building |

### 5.3.3 Factor Analysis

To identify the underlying factors influencing challenges, strategies, and the integration of OSC and BIM, this study employed factor analysis, a statistical technique frequently used in construction research to uncover patterns and relationships among observed variables. This approach has been applied in previous studies within the construction industry to categorise challenges, strategies, and integration factors, providing a more structured understanding of complex phenomena (Asadi et al., 2023; Harper et al., 2016; Kordestani Ghaleenoei, 2022; Kordestani Ghalenoei et al., 2021).

The survey results were then analysed using exploratory factor analysis (EFA) to identify factors in a set of observed variables, followed by confirmatory factor analysis (CFA) to confirm the factor structure and assess the goodness of fit of the model obtained from EFA (Chesney et al., 2006). IBM SPSS Statistics, version 28, was used for EFA. This software is widely used for statistical analysis and provides various tools for data exploration (Morgan et al., 2004). EFA aims to identify the latent constructs underlying the data set by reducing the observed variables to a smaller set of factors.

Following EFA, IBM Amos, version 26, was employed for CFA. Amos is specifically designed for structural equation modelling and provides a robust framework for testing hypotheses about relationships among observed and latent variables (Kline, 1998). CFA analysis tested the hypothesised factor structure derived from the EFA to confirm the validity of the factors identified. In total, questions 19, 16, and 15 were used to measure challenges, strategies, and integration, respectively. Through factor analysis, the factors for the three groups were reduced and categorised into eight groups, each with an underlying variable, providing a robust framework for understanding the complexities involved in OSC and BIM integration.

## 5.4 Findings

### 5.4.1 Survey Findings

In the current study, a correlation test employed to investigate related items among challenges, strategies, and integration variables a correlation test was performed. The initial number of components was extracted using two scree plots and Maximum Likelihood approaches. A value of more than .4 for detecting the significance in the level of factors was chosen (Ma et al., 2019; Olanipekun et al., 2017), and the eigenvalue of 1 was used as the standard cut-off condition for extracting the number of factors throughout the test (Ye et al., 2015). The factors with a magnitude of less than .40 and those with a significant cross-loading were eliminated (Mazzurco et al., 2020). The internal consistency of the remaining factors was then assessed using Cronbach's alpha and Composite Reliability (CR) to ensure both reliability and consistency.

The validity of the questions' consistency and the reliability of the data for subsequent analysis were verified using Cronbach's alpha and Composite Reliability (CR). When the questionnaire employs a Likert scale, this test is recommended for identifying validity (Ajayi, 2017). Additionally, convergent validity was tested using Average Variance Extracted (AVE), ensuring that all constructs exceeded the threshold of .5, confirming that more than half of the variance in the construct was explained by its items (Hair, 2009). Discriminant validity was also confirmed through the HeteroTrait-MonoTrait (HTMT) ratio, with values below .85, demonstrating that the constructs were sufficiently distinct from each other (Gaskin et al., 2019).

In this study, all the questions have a reliability greater than the normal level, which shows internal consistency, and is similar to the study done by Liu et al. (2022) (Table 5.3). The study also examined the "Cronbach alpha if item deleted" measures to identify any items that should be eliminated from the analysis. Based on this analysis, it was found that "Implementation costs" should be removed from the list of factors because it had a Cronbach's alpha of .632. However, removing it did not improve the reliability of the results, as Cronbach's alpha decreased from .890 to .883. Researchers concluded that it would be best to retain CH1 as the final factor because the other factors are related to this item. Table 5.4 lists the included items, the EFA factors, and the sums of square loadings for each factor.

**Table 5.3:** Means, standard deviations, and two-tailed Spearman's rho correlations

| Variables | α | N | Mean | SD | CH1 | CH2 | CH3 | ST1 | ST2 | INT1 | INT2 | INT3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CH1 | .636 | 116 | 5.2602 | .87597 | 1 | | | | | | | |
| CH2 | .761 | 116 | 5.1266 | .91727 | .515** | 1 | | | | | | |
| CH3 | .804 | 116 | 5.3256 | .94477 | .499** | .701** | 1 | | | | | |
| ST1 | .782 | 116 | 16.708 | .90347 | .345** | .515** | .612** | 1 | | | | |
| ST2 | .806 | 116 | 13.4515 | .92326 | .720** | .320** | .384** | .581** | 1 | | | |
| INT1 | .818 | 116 | 8.367 | .92402 | .465** | .145 | -.032 | .229* | .606** | 1 | | |
| INT2 | .836 | 116 | 10.3849 | .94162 | .418** | .137 | .322** | .483** | .335** | .513** | 1 | |
| INT3 | .845 | 116 | 11.3866 | .93893 | .357** | .254** | .311** | .483** | .322** | .495** | .737** | 1 |
| All factors | .890 | | | | | | | | | | | |

*Note. **: p < .01, *: p < .05, ** Correlation is significant at the 0.01 level (2-tailed).*

In order to decrease the chance of overlapping variables and enhance the quality of the final model, EFA permits the removal of any item that does not belong to the factor. EFA evaluates how well particular challenges, strategies, and integration correspond with factors (Juhari & Arifin, 2020; Ye et al., 2015). A test was necessary to ensure the data were sufficient for factor analysis before beginning the EFA analysis. As a result, the Kaiser-Meyer-Olkin (KMO) test was run to ensure the sampling was enough. The factor analysis would yield accurate results when used as part of the KMO test, which measures sample adequacy (Mazzurco et al., 2020).

The KMO test result was .794, which is more than the acceptable requirement of .5 (Assaad et al., 2023; Ye et al., 2015). The number demonstrates the factor analysis. There are enough variables in common for challenges, strategies, and integration. In addition, to check whether the data is eligible or not, the Bartlett sphericity test was performed which resulted in significance and was indicated by the p-value (Sig. .001), which was less than .05 (Juhari & Arifin, 2020). This revealed that the sample size was sufficient for EFA to extract the critical components (Yap et al., 2020). These pre-tests confirmed the internal validity of the model by ensuring that the constructs were well-suited for factor analysis.

The Promax method rotates the factors with high correlations to make the results easier to interpret (Umar et al., 2019). As the data were assumed to be correlated to each other, this method was employed for the rotation (Kline, 2013). Items with a loading factor less than 0.4

(Harper et al., 2016) or cross-loading greater than 75% between components (Mazzurco et al., 2020) were identified. Items with a high cross-loading factor between components must be evaluated further (Harper et al., 2016). In each rotation round, inconsequential items were deleted based on the chosen criteria, and the analysis was performed with the remaining elements. The maximum likelihood and Promax rotation method resulted in 33 factors with factor loadings ranging from .477 to .960 grouped into eight components with a total variance of 61.44%, as shown in Table 5.4. Maximum likelihood estimation allows authors to obtain meaningful results with a relatively small sample sizes (Kline, 2013). A minimum of 60% is required for the constructions to be valid (Yap et al., 2018). The scree plot produced the same result, with the curve flattening off after the fourth component.

After deleting 17 items from the EFA model (8 from challenges, five from strategies, and four from integration), a follow-up CFA on the remaining items produced an excellent model fit: $\chi2(224) = 346.832$, $p < .001$, CFI = .090, SRMR = .05, RMSEA = .069, PClose = .018. Final categories were then named based on the content, theory, and literature. Items removed from CFA are denoted by R (a shorthand for "removed") in Table 5.4. Table 5.4 shows the factor loading of the remaining elements in the CFA. Convergent validity was confirmed by AVE values greater than .5, and discriminant validity was supported by HTMT ratios below the acceptable threshold of .85. The revised scale's reliability, convergent and discriminant validity were also assessed. Face validity of the data was done by experts who have knowledge in the area. Cronbach's alpha, construct reliability, and maximum reliability (MaxR(H)) were all more than .7 for each component, indicating appropriate reliability for the included constructs (Hair et al., 2014).

Each component's name can be chosen based on the highest factor loading or a broad phrase that describes the variable notions (Yap et al., 2020). Each component has been labelled to identify the substance of the underlying factors. Table 5.4 displays the results and includes eight named and aligned components with the underlying factors. Two of these items were loaded on challenge (CH) 1, three on challenge 2, and four on challenge 3. Three items are loaded for strategy (ST) 1, and four items are loaded for strategy 2. Integrations (INT) 1 and 2 had two and three items, respectively, and integration 3 had three items. CH1 (Implementation Costs), CH2 (Integrated Knowledge Deficit), CH3 (Competency and Preparedness Deficit), ST1 (Integration Facilitators), ST2 (External Support and Policy Regulation), INT1 (BIM-Driven OSC Readiness), INT2 (BIM-Enabled Collaboration and Facilitation), and INT3 (BIM-Enabled OSC Enhancement) are further addressed in the discussion section.

In overall, the internal validity of this study was reinforced by conducting pre-EFA correlation tests, Cronbach's alpha, and Composite Reliability (CR) to ensure that the constructs consistently measured the intended items. Additionally, convergent validity was confirmed through AVE values greater than .5, and discriminant validity was validated through the HTMT ratio, ensuring that each construct was distinct. The use of expert reviews before data collection ensured face validity, while Bartlett's sphericity test and KMO test confirmed the data's suitability for factor analysis. These steps together ensured the internal consistency and validity of the findings throughout the factor analysis process.

The external validity of the study, or its generalisability, is supported by including industry experts from the New Zealand construction sector, providing a real-world representation of OSC and BIM integration challenges. However, external validity may be limited due to the specific context of New Zealand's construction industry and regulatory environment, making the results potentially less generalisable to larger international contexts. Nevertheless, the findings may still be applicable.

**Table 5.4:** EFA and CFA structural factor loading matrix for variable study items

| Factors | | Items | EFA 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | CFA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CH1 | C7 | High cost of training | | | | | | | | .528 | .60 |
| | C9 | High cost of OSC and BIM implementation | | | | | | | | .733 | .79 |
| CH2 | C1 | Lack of transparent practices during offsite manufacturing | | | | | .477 | | | | .62 |
| | C3 | Temporary and one-off nature of the project | | | | | .496 | | | | R |
| | C4 | Lack of appropriate education and training | | | | | .688 | | | | .76 |
| | C5 | Lack of planning | | | | | .79 | | | | R |
| | C18 | Inadequate flow of information and periodical meetings | | | | | .541 | | | | .80 |
| CH3 | C12 | Low level of understanding of OSC and BIM integration | | | .681 | | | | | | R |
| | C13 | The industry is not prepared to deliver BIM | | | .531 | | | | | | .48 |
| | C14 | Lack of standards and guidelines | | | .835 | | | | | | .83 |
| | C16 | Lack of clear orientation or adequate practical studies | | | .752 | | | | | | .78 |
| | C17 | Lack of knowledge, limited skills, and experience | | | .632 | | | | | | .83 |
| ST1 | S1 | Educating and upscaling | | | | .478 | | | | | R |
| | S4 | Early engagement of stakeholders | | | | .908 | | | | | .68 |
| | S5 | Providing clarity of outcomes and benefits | | | | .534 | | | | | .77 |
| | S6 | Changing communication style | | | | .768 | | | | | R |
| | S8 | Creating action plans and roadmaps for OSC and BIM integration | | | | .542 | | | | | .64 |
| ST2 | S2 | Graduate and internship programmes | | .638 | | | | | | | .67 |
| | S12 | Financial support from the government | | .728 | | | | | | | .73 |
| | S13 | Mandating the use of BIM in OSC | | .696 | | | | | | | .77 |
| | S14 | Use of contractual provisions | | .57 | | | | | | | .69 |
| | S16 | Use of government guidelines | | .92 | | | | | | | R |
| INT1 | IN1 | Projects have a high readiness level for facilitating OSC through BIM | | | | | | | .565 | | .82 |
| | IN2 | There is a high level of understanding of BIM functions for OSC implementation | | | | | | | .96 | | .85 |
| INT2 | IN3 | Using BIM software facilitated OSC compliance to design | .796 | | | | | | | | .88 |
| | IN5 | Collaboration on a cloud-based BIM facilitated the design | .697 | | | | | | | | .78 |
| | IN7 | Collaboration on a cloud-based BIM facilitated transportation | .596 | | | | | | | | .71 |
| | IN9 | Collaboration on a cloud-based BIM facilitated installation | .481 | | | | | | | | R |
| | IN14 | Applying BIM facilitated project monitoring | .829 | | | | | | | | R |
| | IN15 | Overall execution time is reduced proportionally to the applied level of BIM | .702 | | | | | | | | R |
| INT3 | IN11 | Applying BIM facilitated the identification of OSC requirements | | | | | | .774 | | | .86 |
| | IN12 | Applying BIM facilitated collaboration between manufacturing and installation | | | | | | .559 | | | .79 |

| | | | |
|---|---|---|---|
| IN13 | Applying BIM facilitated the management of OSC constraints | .629 | .77 |

Extraction Method: Maximum Likelihood, Rotation Method: Promax with Kaiser Normalization. Note. ***: $p < .001$; (R): The item was later removed during CFA to establish the model fit, C: Challenge, S: strategy, I: Integration

The data analysis revealed key insights into the challenges, strategies, and integration variables of OSC and BIM integration, aligning with the study's objectives to explore factors through both a literature review and data collection. Implementation Costs, Integrated Knowledge Deficit, and Competency and Preparedness Deficit were identified as the primary challenges. Specifically, high costs of training and implementation, insufficient education, and unclear guidelines emerged as significant challenges to effective integration. These findings highlight the critical factors that influence OSC and BIM integration, addressing the first objective of the study.

In response to these challenges, two key strategies were identified. Integration Facilitators, which fosters clear communication and understanding of project outcomes. External Support and Policy Regulation which particularly happens through government policies and funding. Government support, including mandates for BIM use, was recognised as a significant enabler of successful integration. These strategies directly address the second objective, providing insights into how challenges can be mitigated through strategic interventions.

Additionally, integration mechanisms such as BIM-Driven Readiness and Cloud-Based Collaboration were found to improve project execution and streamline coordination, demonstrating the potential for BIM to support OSC. These factors not only enhance collaboration between teams but also facilitate more efficient management of project constraints. The constructs in the analysis showed strong internal consistency, with Cronbach's alpha and Composite Reliability (CR) scores exceeding .7, confirming the reliability of the findings. Validity tests further supported that the constructs were distinct and well-suited for analysis, ensuring the robustness of the conclusions drawn.

### 5.4.2 Case Study Findings

The following insights summarize the factors in three construction projects. These findings highlight how various factors influenced the implementation and effectiveness of OSC and BIM across different project contexts. In Case 1, the Implementation Cost Factor was significant, with high expenses for technology, hardware, and training. Despite these costs, the project excelled in Integration Facilitators by involving stakeholders early, clarifying project goals, and creating actionable plans. BIM-Driven OSC Readiness was strong, as a skilled team effectively utilised BIM and OSC processes. The project successfully improved BIM-Enabled Collaboration and Facilitation through a cloud-based BIM platform, reducing misunderstandings and enhancing integration.

BIM-Enabled OSC Enhancement was achieved with accurate BIM models, leading to better collaboration, fewer errors, and increased efficiency. While in in Case 2, Implementation Costs were high due to extensive training needs and data management expenses. The project faced challenges with Integrated Knowledge Deficit due to poor manufacturer transparency and insufficient training, impacting quality and increasing costs. The Competency and Preparedness Deficit was also noted, with a lack of clear standards and industry guidelines. However, Integration Facilitators helped mitigate some risks through early stakeholder engagement and effective planning. The project struggled with BIM-Driven OSC Readiness as adapting to new technologies proved challenging, affecting overall efficiency.

Case 3 encountered substantial Implementation Costs involving technology and external consultants. Integrated Knowledge Deficit issues arose from inadequate transparency from manufacturers. Competency and Preparedness Deficit were observed due to unclear standards and limited investment in training. Despite these challenges, the project benefited from Integration Facilitators through detailed action plans and external support, including government mandates for BIM use. BIM-Driven OSC Readiness improved over time, and

BIM-Enabled Collaboration and Facilitation was enhanced through a cloud-based BIM platform, which helped in better coordination and reduced errors. BIM-Enabled OSC Enhancement was realised through effective BIM modeling, optimizing logistics and improving overall project efficiency. Overall, the case study shows that while some factors, such as implementation costs and the role of integration facilitators, are common challenges across all projects, the specific impacts of knowledge deficits, competency issues, and BIM readiness differ, reflecting the unique contexts and strategies of each project.

## 5.5 Discussion

The factor analysis has revealed that underlying factors significantly impact the integration of OSC and BIM in the construction industry. In essence, these underlying factors can significantly affect the integration process, and they are closely related to the challenges and strategies associated with the integration. Effective management of these factors can lead to better integration, by reducing the impact of the challenges through using strategies.

***CH1: Implementation Cost Factor***

As the latent variable, the Implementation Costs factor represents the hidden costs related to adopting and implementing OSC and BIM in the construction industry. These costs can be attributed to various factors, such as the need for extensive training, technology costs, redesign, implementation, and data management costs (Liu et al., 2020). Training costs could be the first factor contributing to the high implementation costs because OSC and BIM technologies require significant knowledge and training to be effectively used by construction professionals. Case 1 BIM manager and one architect from Case 2 mentioned that lack of knowledge is a challenge for implementing OSC and BIM, and more training needs to be done before and during the process (Cases 2&3). Architects, engineers, and builders must be trained to use these technologies to their fullest potential. This training can be time-consuming and require additional resources, such as trainers, training materials, and software licenses (Gbadamosi et al., 2020a; Liu et al., 2020).

In addition to training costs, implementing OSC and BIM requires purchasing hardware, software, and other equipment, which can be very costly. Furthermore, new software needs to be maintained, which can increase the cost (An et al., 2020b). However, experts believe that when it comes to cost and quality, stakeholders should pick quality over cost. For example, spending more money on better computers to run the software may be necessary. Moreover, it is essential to consider how much money is being wasted in other areas. By implementing these changes, the client can avoid costly mistakes and save money in the long term" (Case 3).

Another factor is data management for construction processes, which must be revamped to integrate OSC and BIM technologies effectively. This includes modifying workflows, roles, and responsibilities of construction professionals. Implementing BIM in OSC delivery generates considerable data that has to be managed, stored, and maintained effectively. In Case 2, delivery team developed a centralised shared file called the Digital Engineering Platform, which could be accessed by all the people involved in the project and updated constantly. The cost of data management can be significant, particularly as data volumes increase. Furthermore, implementing OSC and BIM technologies requires hiring consultants, contractors, and subcontractors to help with implementation. These professionals bring additional costs, including fees, salaries, and other expenses (Kluck & Choi, 2023; Waqar et al., 2023).

***CH2: Integrated Knowledge Deficit Factor***

The manufacturer and the building site crew must communicate accurately throughout the delivery process to guarantee that the components have the necessary requirements and standards. Manufacturing faults and inconsistencies can cause delays and extra expenses if there is a lack of transparency (Nguyen et al., 2022; Ribeiro et al., 2022). The main issue stated during the interviews (Projects 2&3) is the coordination between what is manufactured in the plant and what needs to be made on-site. The lack of manufacturer transparency made it challenging for stakeholders to decide on the appropriate OSC components for their projects. Stakeholders may be reluctant to accept OSC if they lack access to accurate information on the performance, quality, and reliability of OSC products, which could delay the adoption of OSC.

When BIM is used as a new technology, "the situation can be worsened" (Cases 1, 2, and 3). Lack of instruction and training in OSC and BIM integration necessitates the development of specialised knowledge and abilities, such as reading and understanding technical drawings and using digital tools for design and communication (Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022).

According to the project review (Cases 2 and 3), workers may lack the skills to use these technologies and practises successfully without the proper training and education, leading to poor quality, waste, and excessive expenditures. Finally, misunderstandings might result from an inadequate information flow and infrequent interactions among pertinent players. One participant claimed that "close communication" was necessary for a better problem-solving outcome. Additionally, OSC and BIM practises include numerous stakeholders, including designers, manufacturers, builders, and clients, so collaboration and communication are crucial for successful integration (Law et al., 2022; Nguyen et al., 2022; Yazıcıoğlu, 2021). However, a lack of communication and collaboration can result in errors and delays (Case 2).

***CH3: Competency and Preparedness Deficit Factor***

Based on analysis of the collected data, the lack of industry-wide standards and guidelines for BIM and OSC presents a severe challenge to the construction sector. An architect from Project 2 stated that businesses have difficulty comprehending what is expected of them and how to carry out projects to the necessary standard. The integration of BIM and OSC in construction projects is greatly hampered by a lack of direction, helpful research, and precise orientation. Companies could lack the knowledge required to implement these successful practices. According to Jiang et al. (2021) and Wuni & Shen (2020), the industry might lack the knowledge, experience, and training required to combine BIM and OSC. Lack of investment in new technologies, education, and training may also contribute to the industry's overall unpreparedness from the manufacturer's perspective (Case 2).

The industry needs to develop and adopt standards and guidelines for BIM and OSC practices to mitigate these challenges. Appropriate documents can help companies to better understand their responsibilities, have the same perspective, and provide the necessary knowledge and skills to perform projects better. To achieve this, as mentioned before, investing in training and education is necessary. The industry should consider improving the adoption and implementation of these practices and new technologies to enhance project efficiency and quality (BIM manager, Case 1).

***ST1: Integration Facilitators Factor***

Integration facilitators are critical as latent variables in facilitating the successful implementation of OSC and BIM integration. The term involves the engagement of all relevant stakeholders, including clients, design teams, contractors, and suppliers in planning and decision-making. Early engagement of stakeholders is a crucial aspect of integration, as it ensures that all parties involved have a shared understanding of the project's objectives, scope, and requirements from the outset (Cases 1&2). Involving stakeholders in the planning phase can identify and address potential challenges early, thus minimizing the risk of delays and cost overruns (Kordestani Ghalenoee et al., 2018a). Another crucial component of this factor is to provide clarity regarding the results and advantages. It outlines the project's aims and objectives and the anticipated advantages of integrating OSC and BIM. This guarantees that everyone involved in the project is aware of its value and will be dedicated to attaining its goals (Case 1).

Creating action plans and roadmaps is another element of integration facilitators. It involves developing detailed plans and timelines for implementing OSC and BIM integration, including adopting appropriate technologies, training, and support. By creating clear and achievable plans, stakeholders can work together towards achieving the project's objectives in a coordinated and efficient manner (Kordestani Ghalenoei et al., 2022a). BIM managers from cases 1 and 3 said integration facilitators are also critical in successfully implementing OSC and BIM integration. If stakeholders are engaged early, outcomes and benefits are clearly stated, and actionable plans and roadmaps are created, all parties involved can work together towards achieving the project's objectives collaboratively and efficiently.

***ST2: External Support and Policy Regulation***

Financial support from the government through tax subsidies can incentivize companies and institutions to adopt new technologies and practices. This support can be used to fund training programmes, research, and the development of new technologies, and to offset the costs of adopting new practices (Kordestani Ghalenoei et al., 2022a; Xu et al., 2020). Tax incentives can be in the form of deductions, credits, or exemptions and can be targeted to specific industries or technologies. For example, in New Zealand, the government offers a tax credit for research and development activities, which can help companies invest in new technologies and practices (Cases 1,2 & 3).

Mandating the use of BIM in OSC can promote modernization by encouraging the implementation of more efficient and effective building practices. BIM as a digital tool can be used to improve functional properties of construction processes, reduce errors, and increase stakeholder collaboration. By mandating BIM use, governments and industry organisations can promote the adoption of a standardised technology that can improve construction outcomes. The BIM manager from case 1 stated that in New Zealand the Ministry of Business, Innovation and Employment (MBIE) has created a BIM Acceleration Committee, which is promoting the use of BIM in the construction industry; however, its work still in the early stages and requires more attention. In Case 3, a governmental facility, the use of BIM for coordination and collaboration is mandatory; however, for Case 2, BIM is not required.

Using contractual provisions for OSC and BIM integration can promote modernization by creating a more collaborative and integrated construction process. By including contractual provisions for integration, construction projects can be planned and executed in a more integrated and coordinated way (Jiang et al., 2021). Case 1 has developed a standard form of contract for modular construction, including BIM and OSC provisions. This contract is designed to help promote modern building practices and increase stakeholder collaboration.

***INT1: BIM- Driven OSC Readiness***

This factor includes various elements that are critical for implementing BIM-OSC processes effectively. It is necessary that the project team have an in-depth understanding of BIM functions and OSC processes; they then will be able to develop effective BIM-OSC workflows. The created workflow will facilitate achieving project goals and will maximise the benefits of using BIM for OSC. Case 1 organisation developed a digital engineering team from young graduates who are most familiar with new technologies. The young graduates start their career journey with company, and the training process gives them a rich understanding of the workflow.

Moreover, the project team must understand BIM and OSC integration's challenges and limitations, like the need for standardisation, lack of necessary skills, and transportation issues

(Hwang et al., 2018b). Although the team must know the challenges, understanding the benefits, such as increased productivity, better quality control, and reduced waste, is also necessary. By understanding these benefits, the team can develop BIM-OSC workflows that maximise these advantages and mitigate challenges (Gan et al., 2018a; Gan et al., 2018b).

Furthermore, the project team must be ready to implement BIM-OSC processes. In Case 3, BIM in OSC delivery is being employed for the first time; thus, the design team's learning and readiness process took longer than expected. Having the required software, hardware, shared resources, and an understanding of the project's objectives creates a high readiness level, leading to effective OSC and BIM workfellow. Additionally, roles must be clearly defined, and the team must be able and willing to implement OSC and BIM processes effectively. Case 2, regarding innovation culture and a well-trained workforce, had some difficulties as some people in their organisation were reluctant to use new technologies.

***INT 2: BIM-Enabled Collaboration and Facilitation Factor***

The BIM-Enabled Collaboration and Facilitation factor measures how much BIM software is utilised to enhance stakeholder cooperation and communication in the construction process. This factor consists of three parts: firstly, OSC conformity to design was facilitated by cooperation on a cloud-based BIM platform, and collaboration on a cloud-based BIM platform facilitated transportation for OSC and BIM integration. Secondly, the use of BIM software to ensure that the design fits the OSC criteria is referred to as OSC compliance to design.

This includes using BIM to visualise the design in 3D, identify potential clashes and conflicts, and optimize the design for offsite fabrication and assembly (Liao et al., 2019). And thirdly, collaboration on a cloud-based BIM platform facilitated the design process, which refers to using BIM software to enable collaboration among all stakeholders involved in the design process. In all three projects, the use of BIM helped to reduce misunderstanding and unnecessary duplications among architects, engineers, contractors, and subcontractors, who can all work together on the same BIM model, share information and ideas, and make real-time changes to the design.

In Case 1, due to the use of asbestos under the ground level where the beams had to be installed, the team used a cloud-based BIM platform to check the transportation and installation of the components. The literature showed that BIM could be effectively used to plan logistics, coordinate transportation, and ensure that offsite components are appropriately integrated into the construction process (Law et al., 2022; Lim et al., 2022). Overall, the BIM-enabled collaboration and facilitation factor represents how BIM software facilitates collaboration and communication among stakeholders, ensures OSC compliance, and optimizes the design and construction process.

***INT3: BIM-Enabled OSC Enhancement Factor***

A better OSC and BIM integration enhancement entails several factors. BIM can help manufacturing and installation teams collaborate through consistent communication and information exchange. By using BIM to create and share detailed 3D models of building components, both teams can better understand the design intent and coordinate their efforts more effectively. In cases 1 and 3, BIM models allow the project team better to understand the project, potential errors, and construction process. However, the logistics and transportation of building components in OSC can be complicated, and mistakes can be costly. By providing specific information on the size and weight of construction components and the sequence in which they must be transported and installed, BIM can help optimize the transportation and logistics process (Boyd et al., 2013; Razkenari et al., 2020).

BIM was used in case 1 to create highly accurate 3D models of building components, which can help minimise errors during the installation. By having components that fit together well, construction teams can reduce waste, improve quality control, and speed up the construction process. If OSC has been optimized by BIM, construction teams can achieve greater efficiency and reduce the overall construction time. BIM allows for identifying and addressing potential issues before they arise, thus reducing delays and the need for rework (Liu et al., 2021a; Wuni & Shen, 2020). Construction personnel needed on the job site can be reduced by manufacturing building components offsite, and this can increase construction site safety by having fewer workers exposed to potential hazards (Abanda et al., 2017). Moreover, apart from improved safety on the construction site, projects can gain various benefits by improving collaboration, logistics and transportation coordination, accuracy and quality control, higher efficiency, and lower construction time.

Figure 5.3 can act as a visual summary of the underlying factors discussed above. These factors can be considered by project managers and decision-makers while implementing BIM in the OSC delivery process from the initial stages. Thus, projects will most likely experience fewer challenges and have improved integration. The results demonstrated that integration has various aspects, which might be affected by different challenges and strategies that need more investigations. using BIM in the OSC delivery process is growing, and stakeholders noticed the benefits of using BIM in their projects based on the case study results; however, several challenges impeded the full integration.

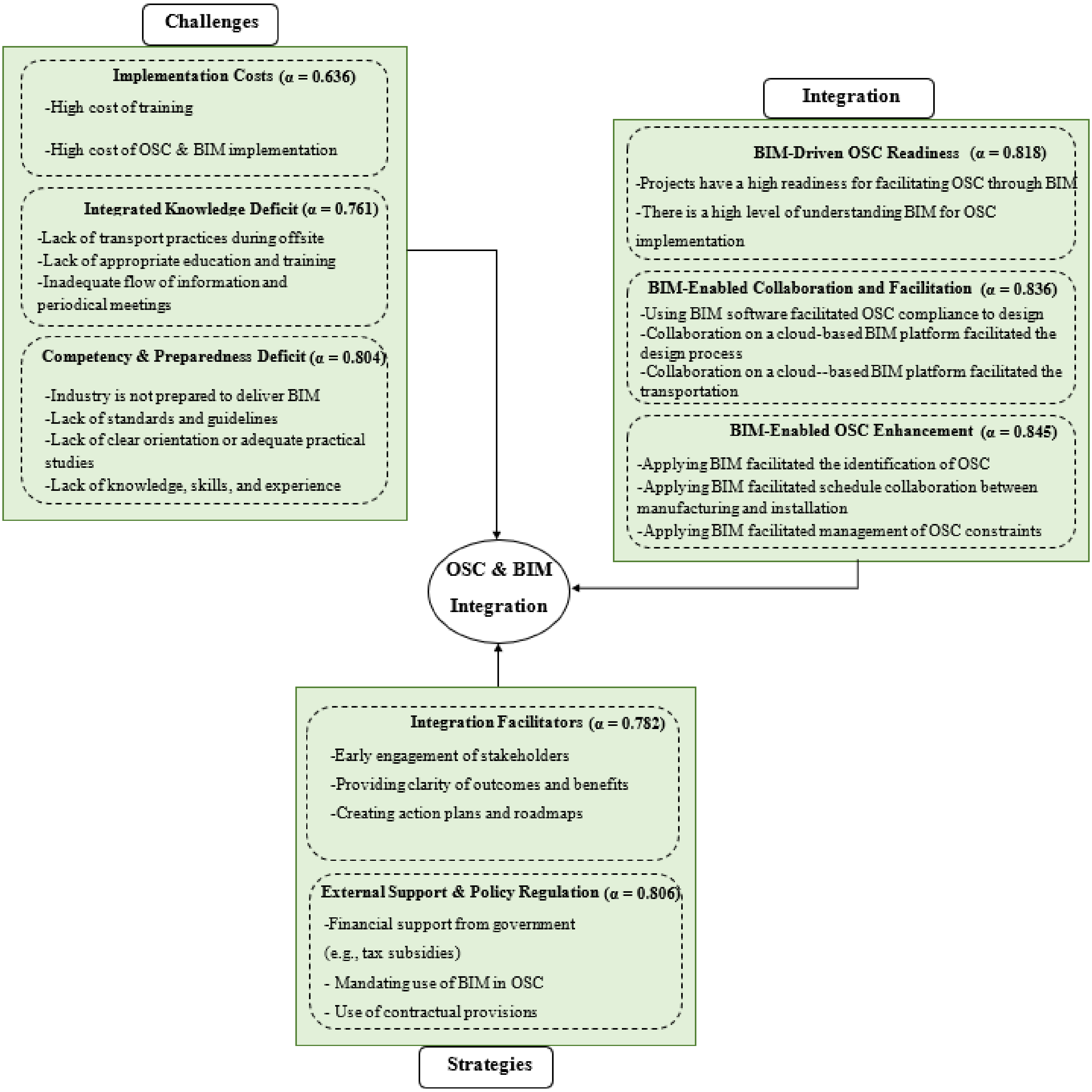


**Figure 5.3:** OSC and BIM Integration Underlying Factors for Challenges, Strategies, and Integration

## 5.6 Conclusion

This study has been conducted to understand the relationship between challenges, strategies, and integration. The findings contribute valuable data for subsequent analysis of the way these factors' impact on OSC and BIM integration in construction. The study assessed the key challenges and strategies that affect integration while exploring underlying strategy factors mitigating the integration challenges. Eight categories for challenges, strategies, and integration, including CH1 (Implementation Costs), CH2 (Integrated Knowledge Deficit), CH3 (Competency and preparedness deficit), ST1 (Integration facilitators), ST2 (External Support and Policy Regulation), INT1 (BIM-Driven OSC Readiness), INT2 (BIM-Enabled Collaboration and Facilitation), and INT3 (BIM-Enabled OSC Enhancement) were determined from the study.

The findings were then confirmed through case studies, and the results demonstrated that although integration has many challenges, companies are interested in continuing to implement BIM in the OSC delivery because benefits clear from several aspects. It can be concluded from the results that for each integration factor a project or organisation focuses on, different challenges and mitigation strategies need to be considered. Moreover, level of the integration also varies based on the project's characteristics, location, size, and type.

The research has added to existing knowledge by employing a quantitative methodology to confirm the challenges and strategies' OSC and BIM Integration in construction projects. The primary findings from the literature revealed a direct correlation between challenges, strategies, and integration, highlighting challenges as a factor that consistently affects integration (Li et al., 2019; Ullah et al., 2019). To improve the understanding of OSC and BIM integration, study categorised challenges, strategies, and integration items under eight underlying factors. However, previous studies investigated challenges such as transportation issues (Jiang et al., 2021), lack of knowledge (Abanda et al., 2017), and lack of skilled workforce (Ayalp & Ay, 2020). Outcomes of the study can also be helpful for providing the mitigation strategies. Since the questionnaire survey assessed OSC and BIM integration in construction, the study's results are valid for improving a preliminary guideline for better OSC and BIM integration. Although, the results cannot be generalized for other sorts of projects, the applied methodology is replicable to projects in other countries worldwide.

In addition to the academic implications, construction practitioners could benefit from the findings as well. During the initial phases of projects, this study's findings will help professionals address three identified challenges and factors that relates to low level integration. Thus, professionals can focus on strategies options like training and developing action plans instead of having to identify challenges. Presenting the primary factors of OSC and BIM integration challenges and strategies that can be used to improve relevant guidelines is the main practical implication of this study. Furthermore, the study provides a clear relationship between challenges, strategies, and integration. This will help stakeholders to understand the connection between factors and use targeted strategies to improved integration. The paper's findings show how the construction industry can use BIM in OSC delivery to make automation quicker and better, thus helping companies save money, work safely, and stay competitive.

The research has certain limitations that should be considered. The data were collected from OSC construction projects in New Zealand, and as a result, its relevance may differ in other countries. However, the applied methodology can be adapted for a similar analysis of integration in other countries. Furthermore, while the sample size meets the general requirements for conducting factor analysis, additional complementary data is needed to construct more comprehensive models. This step could involve employing confirmatory factor analysis or structural equation modelling to explore other challenges and strategies.

# Chapter 6: Evaluation of Factors Influencing Integration

***The current chapter is based on the following article:***

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D.  Sutrisna, M. Rahmani, D (2024), "A Comprehensive Evaluation of Factors Influencing Offsite Construction and BIM Integration in the Construction Industry ", Engineering Construction and Architectural Management.

## 6.1 Introduction

The construction industry has struggled with low productivity (Getuli et al., 2021) for a long time. The leading causes of the issue include ineffective collaborative processes and a lack of rich information exchange (Bakhshi et al., 2022). Offsite construction (OSC) has been deemed as one of the most effective construction methods over the last few decades by experts in architecture, engineering, construction, and operations (Kolo et al., 2014). OSC simplifies the manufacturing process by lowering the number of components and linkages (Shahzad et al., 2022); However, this technique presents a variety of challenges, defined as difficulties or obstacles that hinder progress or achievement of a goal (Jasti BR et al., 2019), particularly in collaboration between project stakeholders, including the architect, contractor, and client. These challenges arise due to the intricate and distinctive interface requirements of OSC (Nguyen et al., 2022).

Moreover, an increased number of production locations (prefabrication plants and sites) can give rise to additional challenges in managing the construction process (Kordestani et al., 2022), particularly when it comes to logistics (Bataglin et al., 2020). By enhancing data visualisation and clash detection, data-driven technologies such as Building Information Modelling (BIM) have improved decision-making during the early stages (Akinade et al., 2015). BIM has the potential to improve sustainability and effectiveness in all phases of a construction project (Latiffi et al., 2016), redefining client/end-user participation, cooperation, and collaboration (Sarvari et al., 2020). The use of BIM can significantly enhance project design and construction (Likita et al., 2023). However, this involves additional investment in new technology, training, and the creation of new forms of cooperation. As such, BIM is not yet the industry norm and, as a result, construction partners will probably be unable to use BIM models if they do not adopt BIM software (Waqar et al., 2023).

In particular, using BIM in the OSC delivery process presents several challenges. The construction industry's fragmented nature complicates the integration of BIM across various stakeholders involved in OSC projects. Additionally, the limited adoption of BIM in OSC and the need for standardisation create challenges in ensuring consistent integration of prefabricated components from different manufacturers. Interoperability issues and data exchange complexities further hinder the effective implementation of BIM, while supply chain management and cost considerations pose additional challenges for stakeholders (Bakhshi et al., 2022; Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022). Overcoming these challenges requires a collaborative approach and industry-wide strategy for the adoption of BIM in OSC (Jiang et al., 2021).

Whittington's (2006) Strategy as Practice (SAP) further shifts attention to the micro-level actions and decisions involved in strategy-making, highlighting how strategy is not only about planning at the organisational level but also about the day-to-day actions and decisions made by individuals. A strategy can be defined as a deliberate course of action designed to achieve specific objectives, typically in response to challenges or obstacles that hinder progress (Jasti BR et al., 2019). However, creating a collaborative environment can be challenging due to the involvement of multiple stakeholders and various phases in OSC delivery, and the implementation of BIM may further complicate this process (Ghannad et al., 2019).

Therefore, detailing the relationships and dependencies among challenges and strategies and their impact on integration enables stakeholders and decision-makers to comprehend the root causes of how to mitigate them effectively, what challenges could affect different aspects of integration and finally, which strategies could be helpful. Moreover, identifying specific challenges that need attention will ease the mitigation approach (Bakhshi et al., 2022; Kordestani et al., 2022).

Reviewing the literature showed that no single study investigated the challenges, strategies, and relationships for OSC and BIM integration and considered the various aspects of integration. Understanding the relationships between challenges and strategies is vital to enhancing collaboration, improving efficiency, reducing costs, ensuring quality control, and managing time effectively in the construction industry (Abanda et al., 2017; He et al., 2021). Therefore, this study focuses on filling the existing gap by achieving the following objectives: (1) To explore the factors affecting OSC and BIM integration through the literature review.(2) To explore the underlying variables for challenges, strategies, and integration factors through a questionnaire survey. (3) To investigate the relationships and effects of factors affecting integration in the New Zealand construction industry.

In Chapter 5, the focus was on identifying the underlying factors affecting OSC and BIM integration, specifically using EFA and CFA. These factors including challenges, strategies, and integration variables were validated using real-world case studies, providing a foundational understanding of the variables at play. In contrast, this chapter (Chapter 6) builds upon those findings by shifting from identification to examining the relationships and effects of these factors on integration. Using Structural Equation Modelling (SEM), this chapter explores how the identified challenges and strategies interact and influence OSC and BIM integration within the New Zealand construction industry. While Chapter 5 focused on validation, Chapter 6 offers a deeper, more analytical understanding of how these factors impact integration outcomes. This distinction allows for a more comprehensive evaluation of the integration process, providing insights into the causal effects of the factors identified in the previous chapter.

## 6.2 Literature Review

This section explores the integration of OSC and BIM, examining how these digital technologies enhance the construction industry. It begins by reviewing studies that focus on the integration of digital technologies in OSC, followed by research on the implications of BIM in various domains. Finally, it explores specific studies that address the integration of OSC and BIM, highlighting the benefits and challenges of this integration.

### 6.2.1 Digital Technology Integration in OSC

One study done by Yang et al. (2024) explores human-robot collaboration in timber prefabrication, which aims to enhance flexibility and productivity. This research identifies both challenges and opportunities, constructing a framework based on existing theories and human labor perspectives to guide future research on robotic integration in OSC. This approach enhances the prefabrication process by combining automation with human expertise, demonstrating potential for increased efficiency.

Similarly, Yi et al. (2023) explored optimizing the stacking of precast slabs in prefabricated construction using mathematical programming techniques. Their research focused on reducing slab reshuffling and minimizing stack area while considering practical factors like stability and dunnage positions. The proposed method led to a 16.56% improvement in efficiency. This work exemplifies how mathematical models can aid in refining prefabrication processes in OSC. In another study, Zou et al. (2023) employed augmented reality (AR) and object detection models to reduce manual labor involved in AR map development. Using YOLOv8x and bounding box predictions, their approach demonstrated an efficient method for generating accurate AR map components. This development has significant implications for improving interactive features in AR systems used in prefabrication, contributing to greater precision and reduced labor in construction processes.

### 6.2.2 BIM Integration in Various Construction Domains

BIM used in many areas including project lifecycle, risk management, waste, and supply chain management for construction industry (Hijazi et al., 2023; Moshtaghian & Noorzai, 2023; Zheng et al., 2023). Research done by Zheng et al (2023) investigated four different methods of integrating BIM with Life Cycle Assessment to evaluate the environmental impact of constructed assets. These methods include conventional, parametric modelling, plug-in, and industry foundation classes- based integration. Results suggest that each integration approach has its strengths and weaknesses. The plug-in approach performs well in development and calculation time, while the conventional method excels in result validity. The parametric modelling approach surpasses the IFC-based method in various aspects, although the IFC-based method demonstrates validity with a minimal error rate of approximately 1%.

Hijazi et al (2023) addressed the challenges of identifying valuable construction supply chain data and reconciling disparate information by proposing a data model integrating blockchain technology with BIM, thus offering a solution to enhance digital engineering and ensure trusted data management in the construction industry. Moreover, BIM and risk management integration explored by Moshtaghian and Noorzai (2023) to enhance project optimization and mitigate issues arising from the disjointed integration of 3D, 4D, and 5D modelling with execution data in construction projects, emphasizing the importance of adopting BIM technologies to prevent delays and mismanagement.

### 6.2.3 Integration and System Integration

In practice, integration activities are essential throughout the entire project lifecycle. In the early phases, project teams must focus on integrating market demands, stakeholder needs, and system requirements. This early integration is crucial because a well-designed project begins with a comprehensive understanding of what stakeholders expect and require. It involves not only meeting functional requirements but also addressing non-functional demands, such as safety, sustainability, and usability. By ensuring these aspects are considered during the concept design phase, the project sets a solid foundation for cohesive and efficient progression (Kossiakoff et al., 2011; Rajabalinejad et al., 2020).

As the project moves into the detailed design phase, the focus shifts to integrating components to ensure they collectively deliver the desired functionalities. At this stage, system integration—bringing together components, subsystems, or human interactions to form a cohesive whole—becomes critical. This type of integration emphasizes the technical aspects, such as how components, interfaces, and human interactions work together to meet the project's objectives (Rajabalinejad et al., 2020).

In the construction industry, the complexity of projects, the different phases of the project lifecycle, and the involvement of multidisciplinary teams—owners, architects, engineers, contractors, and suppliers—make systems integration vital. These teams often use various heterogeneous systems, creating challenges in communication and collaboration. Effective systems integration ensures that these diverse systems and stakeholders can work together seamlessly, fostering collaboration across the project (Liu et al., 2021b; Sanvido & Medeiros, 1990).

Ultimately, systems integration is about achieving interoperability, which is key to improving productivity and efficiency in construction. In an industry often characterised by fragmentation and siloed operations, the ability to integrate systems and teams is a critical enabler of streamlined workflows and better outcomes. Improved collaboration through systems integration helps reduce delays, resolve conflicts, and enhance (Rajabalinejad et al., 2020).

### 6.2.4 OSC and BIM Integration; Challenges and Mitigation Strategies

Integrating OSC and BIM has generated several benefits and addressed challenges in the construction industry. Previous studies have highlighted the results of this integration, including the early identification of long completion times, which allows for proactive measures to mitigate delays. Furthermore, the integration restructures procurement schedules by facilitating information exchange and stakeholder coordination. Another significant outcome is the exploration of design constraints for fabricators (Agapiou, 2022; Khan et al., 2022; Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022).

By implementing BIM, fabricators can comprehensively understand design intent, identify potential challenges like lack of knowledge, experience, and collaboration in the fabrication process, and optimize construction accordingly (Bakhshi et al., 2022; Barkokebas et al., 2021; Wuni & Shen, 2020; Yin et al., 2019). This integration also reduces differences between design and manufacturing models, enhancing accuracy and efficiency in fabrication process through applying strategies such as continues education and training, developed standards and guidelines, and updating contract's regulations (Hwang et al., 2018b; Jiang et al., 2021; Wuni & Shen, 2019).

In addition, integrating OSC and BIM reduces the fabrication cycle time by increasing OSM and BIM coordination. This allows project teams to enhance production, minimise waste, and achieve faster project delivery. Coordination errors are minimised through improved communication and collaboration enabled by BIM, reducing clashes and conflicts during construction (Mostafa et al., 2020). Integration between OSC and BIM has been researched in different studies. A framework for integrating BIM and OSC, emphasizing the digitalisation of premanufacturing phases, has been previously proposed. The system relies on BIM as the principal source of project-related data and integrates lean principles to recognise and reduce waste. The proposed framework focuses on improving planning, information exchange, and quantifying improvements (Barkokebas et al., 2021).

Li et al. (2019) conducted a study that presented an integrated BIM and prefabricated housing conceptual framework. The framework introduced components such as the smart BIM platform, innovative work packages, and smart Prefabricated Housing Production objects, aiming to enhance the integration of BIM in the prefabrication process. This approach facilitates efficient communication, information exchange, and coordination among stakeholders in prefabricated housing projects.

As previous studies have shown, integrating BIM in OSC poses significant challenges and several strategies were recommended to mitigate their effects. For instance, the fragmented structure of construction projects, lack of training and understanding among project workers, financial ramifications, and the requirement for standardised standards and contract language are some of the challenges for integrating OSC and BIM (Ayalp & Ay, 2020; Hwang et al., 2018b; Jiang et al., 2021; Razkenari et al., 2020; Wuni & Shen, 2020). To deal with these challenges, strategies such as government assistance, constant education and training, uniform legislation, and teamwork have been identified (Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022).

Kordestani et al. (2022) explored the challenges and potential benefits of integrating OSC and BIM in New Zealand's construction sector. The research identified challenges such as misalignment between offsite manufacturing processes and BIM workflows, limited standardisation, inadequate training, and resistance to change. The study recommends promoting collaboration, developing standardised processes, investing in training, fostering innovation, and creating incentives to enhance capabilities within the sector. In another study by Kordestani Ghalenoei (2022a), the challenges of integrating OSC and BIM in New Zealand have been investigated. It identifies challenges specific to OSC and BIM implementation, such as limited adoption, lack of expertise, and the need for standardisation. The study proposes a framework emphasizing technology, processes, and collaboration to address these challenges.

Addressing transportation issues through precise definitions and detailing (Yin et al., 2019), incentivizing OSC and BIM integration through regulations and incentives (Aburas, 2011; Jiang et al., 2021; Xue et al., 2021), and encouraging cooperation and teamwork among stakeholders (Jiang et al., 2021; Jin et al., 2019) are other examples of strategies recommended by previous studies. While existing literature has explored the challenges and potential strategies to counter their adverse effects, a notable gap exists in comprehending the interaction between these challenges and strategies, particularly in relation to their collective influence on integrating OSC and BIM.

Furthermore, what are the key causes which could influence integration aspects? Consequently, this research embarks on a comprehensive exploration of this unexplored terrain, aiming to elucidate these complex dynamics. By addressing this gap, the study contributes valuable insights to empower relevant stakeholders to enhance integration among these concepts within the dynamic construction industry framework. In order to find out the list of challenges and strategies, a comprehensive literature conducted and finally the factors were chosen from scientific studies explored the integration of OSC and BIM (Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022). Figure 6.1 illustrates challenges and corresponding strategies inherent in the context under study.

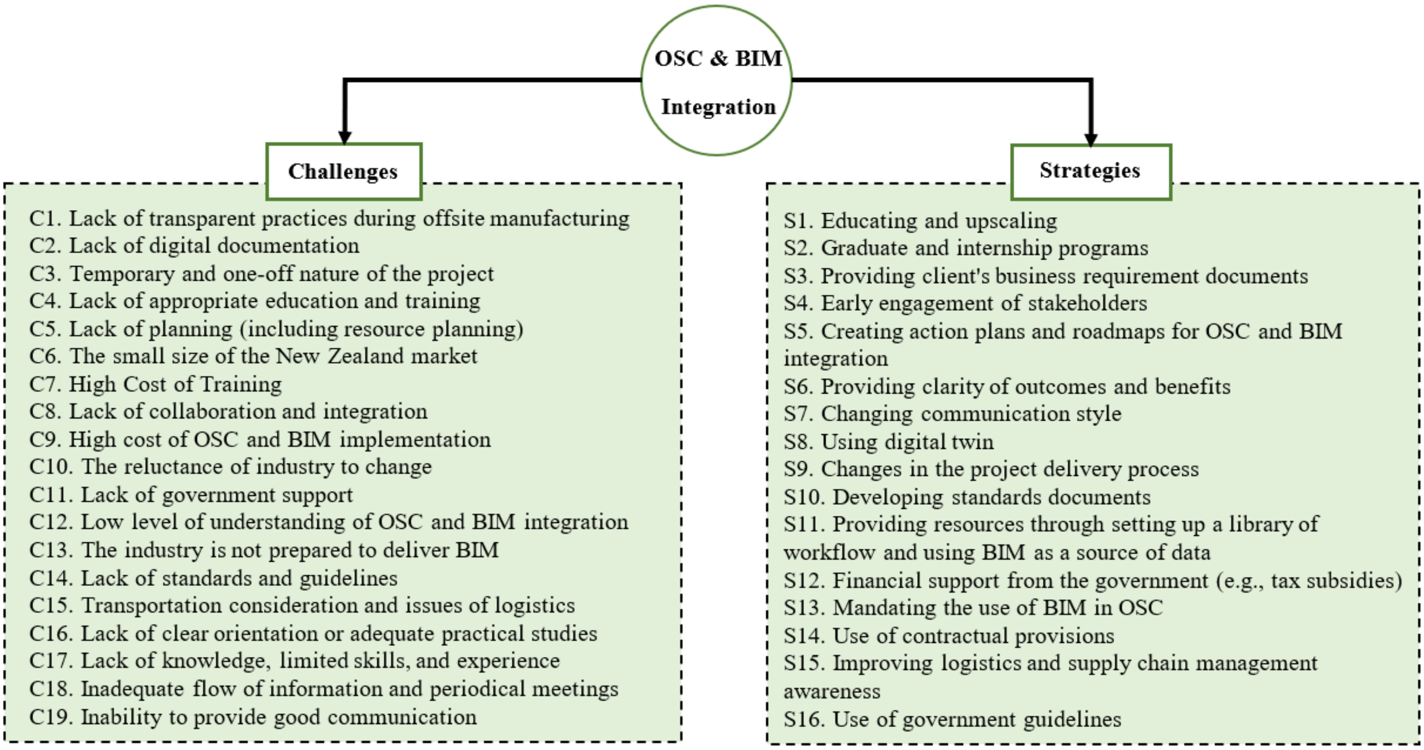


**Figure 6.1:** OSC and BIM Integration Challenges and Strategies (Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022)

The challenges and strategies presented in Figure 6.1 are derived from previous studies that utilised comprehensive research methodologies. These studies initially explored factors through a systematic literature review from various sources, all of which were from high-ranked journals, and then confirmed and validated them via semi-structured interviews, identifying 35 challenges and 21 strategies. Therefore, the challenges and strategies used in this study are the result of extensive literature review. To adapt this data for the current study, several peer review sessions with industry experts and academics were held to refine the list. During these sessions, items with similar themes were consolidated, unclear aspects were clarified, and the language was simplified to ensure it was understandable for industry stakeholders. Ultimately, after these adjustments, 19 challenges and 16 strategies were identified as the foundation for this research, reflecting the most significant and actionable considerations for OSC and BIM integration.

## 6.3 Research Methods

This research employs a quantitative approach to examine the challenges and strategies related to OSC and BIM integration through a survey focusing on 19 challenges and 16 strategies. The questionnaire survey encompasses participants' demographic information and level of agreement about the importance of challenges, strategies, and factors for OSC and BIM integration in the New Zealand construction industry. Participants rated the items on a 7-point Likert scale, ranging from 1 ("Not important at all") to 7 ("Extremely important") (Appendix 5). This scale allows respondents to express nuanced attitudes and provides greater independence for capturing precise responses. Studies have demonstrated that the 7-point scale provides high levels of reliability, reaching its upper limits (Allen & Seaman, 2007). Experts generally advise using instruments like Likert to utilise a wide range of options on the scale whenever possible. As a result, the responses can be condensed into narrower categories during analysis (Dawes, 2008; Joshi et al., 2015).

Before survey distribution, a peer review process involving four experts from industry and academia was conducted, followed by a pilot run with 30 randomly selected respondents. A project manager and a digital engineering manager from the industry with more than 15 years of construction experience and working with BIM and OSC for more than five years were selected to review the survey questions. Two rounds of peer review were adequate to meet the study's validation needs. The initial round, with input from four experts in industry and academia, ensured that the questionnaire content was appropriate and aligned with the research goals (Brace, 2018).

A second round, conducted as a pilot study with 30 participants, confirmed the practicality and usability of the survey (Dillman et al., 2014). These two rounds provided enough feedback to refine the instrument, eliminating the need for further iterations. Initially, the demographic section was located at the beginning of the survey. However, based on the peer review results, it was deemed better to move it to the end of the survey. These types of questions do not require much thought, as respondents can simply mark their answers.

Moreover, the challenge question was rephrased to make it clearer and more aligned with the research scope. The original question, “Based on your experience, which of the following OSC and BIM integration challenges exist in your projects?” was revised to, “Please indicate your level of agreement with each integration challenge you encountered, based on your recent direct or indirect project experience in OSC and BIM.” Then data collection occurred between October 2022 and February 2023 using Qualtrics, a web-based survey tool. The questionnaire link was shared with construction companies, including clients, consultants, and contractors involved in OSC projects that implemented BIM in project delivery.

Project managers from contractors, clients, and consultants were the targeted respondents. The poll included architects, drafters, and designers because they use BIM in their design process. Simple random sampling was used to choose the targeted respondents from BIMinNZ and OffsiteNZ, the leading BIM and OSC organisations in New Zealand. There were 55 companies registered with BIMinNZ (BIM Acceleration Committee, 2019) and 99 companies registered with OffsiteNZ (OffsiteNZ, 2023) from various industrial positions. Six Australian companies were not included since they were not within the scope of the study, and a total of 142 companies with 450 respondents were chosen as the population size for the study. As a result, 450 emails were sent to the company respondents.

The appropriate sample size for this study, considering a small population size based on the Cochran Formula, was estimated at 113, and it was acceptable and reliable within +/- 8% margin of error at the 95% confidence level. The sample size aligns well with other research conducted under similar objectives and circumstances, including investigations within the New Zealand construction sector (Assaad et al., 2023; Ramachandra & BamideleRotimi, 2015). Out of the 164 responses, 116 valid ones—represented a 34.6% response rate. As a result, more than the needed minimum of 100 respondents compared to other studies were used in this research (Bagözzi & Yi, 2012; Xia et al., 2016). The response rate for this study was similar to a previous study conducted by Omer et al. (2022), which had 106 valid responses. Incomplete responses were not eligible for inclusion in the final sample size, as specific questions that had not been answered were disqualified (Asadi et al., 2023; Yap et al., 2020).

Most respondents (56%) were employed at consultancy companies, approximately 9% were on the client side, and 35% worked as contractors. Regarding experience, 24% of respondents had 0-5 years, 25% had 6-10 years, and the remaining 50% had more than 11 years of experience, with around 25% having up to 15 years of experience. Notably, most participants had 0-5 years of experience in OSC and BIM projects, indicating the infancy of these concepts in New Zealand. Only a small percentage of participants (2.5% and 5%) reported having more than 16 years of experience in OSC and BIM projects. Figure 6.2 illustrates the methodology process of this research.

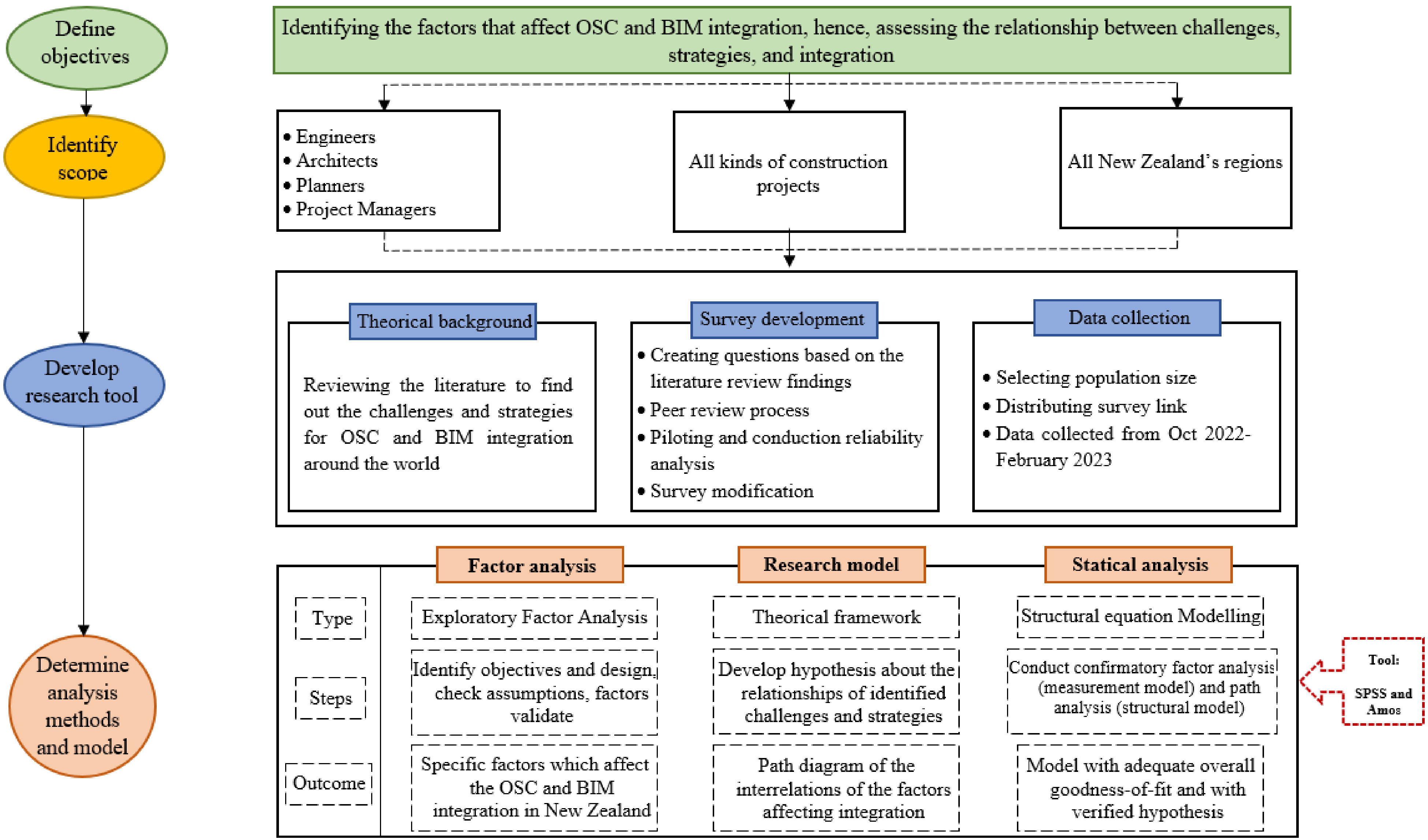


**Figure 6.2:** Research Design Process

Research design figure illustrates the process by which the current study achieved its objectives, consisting of four main components: defining objectives, identifying scope, developing research tools, and determining analysis methods and models. The study's scope encompasses eligible participants from engineering, architecture, planning, and project management fields across all regions of New Zealand. The research tool was shaped through comprehensive literature review, followed by the development of surveys and data collection methods. The final step involves selecting the appropriate methods and applying steps, along with their outcomes, including categorizing factors and constructing path diagrams using IBM SPSS and AMOS.

Besides the factors for challenges and strategies various criteria were considered to develop integration questions. Initially, it was essential for the questions to span the entire project delivery lifecycle. By incorporating both broad and detailed inquiries for each phase. Moreover, the study aimed to address all aspects of integration, including collaboration, comprehension, and facilitation processes using different questions. The questions undertook multiple peer review sessions to ensure clarity and relevance for stakeholders. Initially, 23 questions were developed, but following the peer review process, 15 questions were considered suitable for inclusion in the survey as illustrated in Table 6.1.

**Table 6.1:** Developed questions for OSC and BIM integration measurement factors

| OSC and BIM Integration Factors |
| --- |
| IN1. Projects have a high readiness level for facilitating OSC through BIM. |
| IN2. There is a high level of understanding of BIM functions for OSC implementation. |
| IN3. Using BIM software facilitated OSC compliance to design. |
| IN4. Using BIM software facilitated OSC. |
| IN5. Collaboration on a cloud-based BIM platform facilitated the design process. |
| IN6. Collaboration on a cloud-based BIM platform facilitated the OSC manufacturing process. |
| IN7. Collaboration on a cloud-based BIM platform facilitated the transportation. |
| IN8. Collaboration on a cloud-based BIM platform facilitated real-time change management. |
| IN9. Collaboration on a cloud-based BIM platform facilitated installation process. |
| IN10. 3D modelling facilitated the design process. |
| IN11. Applying BIM facilitated the identification of OSC requirements. |
| IN12. Applying BIM facilitated schedule collaboration between manufacturing and installation. |
| IN13. Applying BIM facilitated management of OSC constraints (e.g., maximum size, transport schedule) |
| IN14. Applying BIM facilitated project monitoring process. |
| IN15. Overall execution time reduced proportional to the applied level of BIM (Level 0-4). |

## 6.4 Findings and Analysis

This section begins with an analysis conducted through factor analysis, followed by the presentation of the initial model for Structural Equation Modelling (SEM) via three distinct path models. Subsequently, the findings derived from the SEM models are elaborated upon.

### 6.4.1 Measurement Validation

In the current study, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were carried out to assess the validity and reliability of the measurement. EFA was employed because previous research has not established the underlying structure of the relationships between challenges, strategies, and integration factors in OSC and BIM. This method helps uncover hidden structures in the data and develop constructs for creating measurement scales. Additionally, CFA was used to examine the relationships between observed variables and their underlying latent constructs (Asadi et al., 2023; Kordestani Ghaleenoei, 2022).

Before EFA, a correlation test was performed to identify related items among challenges, strategies, and integration variables. Items with correlation values lower than 0.4 were eliminated (Ma et al., 2019; Olanipekun et al., 2017). The Kaiser-Meyer-Olkin (KMO) test was also conducted to ensure the suitability of the data for factor analysis, resulting in a value of .794, which exceeds the accepted minimum threshold of.5(Assaad et al., 2023; Ye et al., 2015). This ensures that the sample is adequate for factor analysis, thus supporting the internal validity of the data. The Promax method rotation was chosen because it allows results to be interpreted more easily (Umar et al., 2019). This method was employed for the rotation as an assumed correlation among variables. Maximum likelihood estimation was applied because it produces meaningful results even with relatively small sample sizes (Kline, 2013). In each round of rotation, based on the criteria, items that contributed little to the factor structure were removed. In total, 17 items were eliminated during the EFA analysis: 8 items from challenges, 5 from strategies, and 4 from integration variables.

The internal validity of the constructs was rigorously tested. Cronbach's alpha was used to assess the internal consistency of the remaining factors, and all variables displayed reliability greater than the generally accepted threshold of .7 (Ajayi, 2017). Additionally, Composite Reliability (CR) was calculated, with all values above 0.6, further supporting the reliability of the constructs (Hair et al., 2014). Table 6.2 presents the remaining factors' means, standard deviations, and two-tailed Spearman's rho correlations.

**Table 6.2:** Means, standard deviations, and two-tailed Spearman's rho correlations

| Variables | N | Mean | SD | CH1 | CH2 | CH3 | ST1 | ST2 | INT1 | INT2 | INT3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CH1 | 116 | 5.2602 | .87597 | 1 | | | | | | | |
| CH2 | 116 | 5.1266 | .91727 | .515** | 1 | | | | | | |
| CH3 | 116 | 5.3256 | .94477 | .499** | .701** | 1 | | | | | |
| ST1 | 116 | 16.708 | .90347 | .345** | .515** | .612** | 1 | | | | |
| ST2 | 116 | 13.4515 | .92326 | .720** | ` | .384** | .581** | 1 | | | |
| INT1 | 116 | 8.367 | .92402 | .465** | .145 | -.032 | .229* | .606** | 1 | | |
| INT2 | 116 | 10.3849 | .94162 | .418** | .137 | .322** | .483** | .335** | .513** | 1 | |
| INT3 | 116 | 11.3866 | .93893 | .357** | .254** | .311** | .483** | .322** | .495** | .737** | 1 |

| | |
|---|---|
| N | Represents the number of observations or samples for each variable |
| Mean | Indicates the average value of the variable across the sample |
| SD | Standard Deviation, which measures the dispersion or variability of the variable's values around the mean. |
| CH: Challenges variables, ST: Strategies variables, INT: Integration variables | |

The maximum likelihood and Promax rotation method resulted in 33 items with factor loadings ranging from .477 to .960 grouped into eight latent variables with a total variance of 61.44%, as shown in Table 6.3. Two of these items were loaded on challenge CH1, three on challenge 2, and four on challenge 3. Three items are loaded for strategy ST1, and four items are loaded for strategy 2. Integrations INT1 and 2 had two and three items, respectively, and integration 3 had three items. After this stage, CFA analysis was then conducted on the remaining items, and they were named according to their nature by either considering the highest factor loading or by using a general phrase that captures the variable concepts from the literature, aiming to add triangulation (Yap et al., 2020).

CH1 (Implementation Costs), CH 2 (Integrated Knowledge Deficit), CH 3 (Competency and Preparedness Deficit), ST1 (Integration Facilitators), ST2 (External Support and Policy Regulation), INT1 (BIM- Driven OSC Readiness), INT2 (BIM-Enabled Collaboration and Facilitation), and INT3 (BIM-Enabled OSC Enhancement) are further addressed in the discussion section. CH1 includes the items related to the cost of implementing both OSC and BIM and their required training. CH2 involves items representing the lack of knowledge, and items related to skills and understanding of the concepts are included in CH3. Integration facilitators encompass the items that demonstrate the tools to improve the integration, while ST2 shows strategies from outside the projects or organisations. INT1 related to the items showing overall understanding and preparedness of integrating OSC and BIM. INT2 is named after the collaboration and facilitation provided by using BIM in the OSC delivery process, and INT3 includes items related to the improvement of OSC.

To establish an acceptable model fit, two items from CH2, one from CH3, two from ST1, one from ST2, and three from INT2 factors were removed ($\chi2(224) = 346.832$, $p < .001$, CFI = .90, SRMR = .05, RMSEA = .069, Pclose = .018). According to accepted thresholds for model fit, the statistics from the CFA were evaluated. Values in the following ranges suggest an excellent fit: CMIN/DF between 1 and 3, CFI > .95, SRMR < .08, RMSEA < .06, and Pclose > .05. Alternately, "if a fit falls within the range of CMIN/DF between 3 and 5, CFI between .90 and .95, SRMR between .08 and .1, RMSEA between .06 and .08, and Pclose between- .01 and .05, it is considered acceptable" (Hu & Bentler, 1999).

To ensure the construct validity of the model, both convergent and discriminant validity were tested. The convergent validity of the latent variables was evaluated using the Average Variance Extracted  measure, which exceeded .5 (Hair, 2009). Construct Reliability values above .6 are recommended for validity. To "assess discriminant validity, a test of the HeteroTrait-MonoTrait  ratio of correlations was conducted using a plugin for AMOS" (Gaskin et al., 2019). None of the correlations showed more than the threshold of .85, supporting discriminant validity (Hair, 2009). Furthermore, the revised scale's reliability and convergent and discriminant validity were evaluated.

Based on CFA results, the measurement model, which examines the relationship between a factor and its variables, can be refined to create the best-fit model (Ahmed, 2010). Cronbach's alpha for all variables was above .7, indicating that the included constructs exhibited appropriate reliability (Hair et al., 2014) (Table 6.4). The study also evaluated "Cronbach alpha if item deleted" metrics to pinpoint potential candidates for exclusion from the analysis. This evaluation determined that "Implementation Costs" ought to be excluded from the roster of factors due to its Cronbach's alpha value of .632 (Table 6.4). Nevertheless, eliminating this item did not enhance the reliability of the result; Cronbach's alpha shifted marginally from .890 to .883. Given the interrelatedness of this item with other factors, the researchers thus concluded that retaining CH1 as the ultimate factor would be the optimal course of action.

The external validity of the findings, or their generalisability to a broader context, was also considered. The sample included industry experts from New Zealand’s construction sector, ensuring that the results are reflective of real-world practices in the region. However, some limitations to external validity arise from the small market size of New Zealand and the country's unique regulatory environment, which may limit the generalisability of these findings to larger international markets. While the study was focused on New Zealand, the challenges and strategies identified in OSC and BIM integration may be relevant to other regions facing similar construction industry issues. Future research can explore these challenges in different contexts to confirm the broader applicability of the findings.

**Table 6.3:** EFA and CFA structural factor loading matrix for variable study items

| Factors | | Items | Factors | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | EFA | | | | | | | | CFA |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| CH1 | C7 | High cost of training | | | | | | | | .528 | .60 |
| | C9 | High cost of OSC and BIM implementation | | | | | | | | .733 | .79 |
| CH2 | C1 | Lack of transparent practices during offsite manufacturing | | | | | .477 | | | | .62 |
| | C3 | Temporary and one-off nature of the project | | | | | .496 | | | | R |
| | C4 | Lack of appropriate education and training | | | | | .688 | | | | .76 |
| | C5 | Lack of planning (including resource planning and scheduling) | | | | | .79 | | | | R |
| | C18 | Inadequate flow of information and periodical meetings | | | | | .541 | | | | .80 |
| CH3 | C12 | Low level of understanding of OSC and BIM integration | | | .681 | | | | | | R |
| | C13 | The industry is not prepared to deliver BIM. | | | .531 | | | | | | .48 |
| | C14 | Lack of standards and guidelines | | | .835 | | | | | | .83 |
| | C16 | Lack of clear orientation or adequate practical studies | | | .752 | | | | | | .78 |
| | C17 | Lack of knowledge, limited skills, and experience | | | .632 | | | | | | .83 |
| ST1 | S1 | Educating and upscaling | | | | .478 | | | | | R |
| | S4 | Early engagement of stakeholders | | | | .908 | | | | | .68 |
| | S5 | Providing clarity of outcomes and benefits | | | | .534 | | | | | .77 |
| | S6 | Changing communication style | | | | .768 | | | | | R |
| | S8 | Creating action plans and roadmaps for OSC and BIM integration | | | | .542 | | | | | .64 |
| ST2 | S2 | Graduate and internship programmes | | .638 | | | | | | | .67 |
| | S12 | Financial support from the government (e.g., tax subsidies) | | .728 | | | | | | | .73 |
| | S13 | Mandating the use of BIM in OSC | | .696 | | | | | | | .77 |
| | S14 | Use of contractual provisions | | .57 | | | | | | | .69 |
| | S16 | Use of government guidelines | | .92 | | | | | | | R |
| INT1 | IN1 | Projects have a high readiness level for facilitating OSC through BIM | | | | | | | .565 | | .82 |
| | IN2 | There is a high level of understanding of BIM functions for OSC implementation. | | | | | | | .96 | | .85 |
| INT2 | IN3 | Using BIM software facilitated OSC compliance to design. | .796 | | | | | | | | .88 |
| | IN5 | Collaboration on a cloud-based BIM platform facilitated the design process | .697 | | | | | | | | .78 |
| | IN7 | Collaboration on a cloud-based BIM platform facilitated transportation. | .596 | | | | | | | | .71 |
| | IN9 | Collaboration on a cloud-based BIM platform facilitated installation process | .481 | | | | | | | | R |
| | IN14 | Applying BIM facilitated project monitoring process | .829 | | | | | | | | R |
| | IN15 | Overall execution time is reduced proportionally to the applied level of BIM | .702 | | | | | | | | R |
| INT3 | IN11 | Applying BIM facilitated the identification of OSC requirements | | | | | | .774 | | | .86 |
| | IN12 | Applying BIM facilitated collaboration between manufacturing and installation. | | | | | | .559 | | | .79 |
| | IN13 | Applying BIM facilitated the management of OSC constraints. | | | | | | .629 | | | .77 |

Extraction Method: Maximum Likelihood, Rotation Method: Promax with Kaiser Normalization. Note. ***: $p < .001$; I: The item was later removed during CFA to establish the model fit, C: Challenge, S: strategy, I: Integration

### 6.4.2 Proposed Factors for OSC and BIM Integration Model

This research presents a model for OSC and BIM integration, including challenges, strategies, and related factors. The proposed model consists of (1) challenges-related factors, (2) strategies-related factors, and (3) integration-related factors. This study also controls for the effect of the experience in construction, OSC projects and BIM. Thus, three control variables have been added to the model. The following research questions are presented to be explored to achieve the research objective:

What is the impact of challenges on the integration of OSC and BIM within the context of New Zealand?

What is the impact of strategies on the integration of OSC and BIM within the context of New Zealand?

In this study, the authors examined the challenges through the lens of three factors, strategies with two factors, and ultimately integration with three factors. To achieve this, three distinct models were developed for each integration factor. The same challenges, strategies, and control variables are consistently presented in each model for analysis and evaluation. The following figure (Figure 6.3) presents the proposed model for the current study.

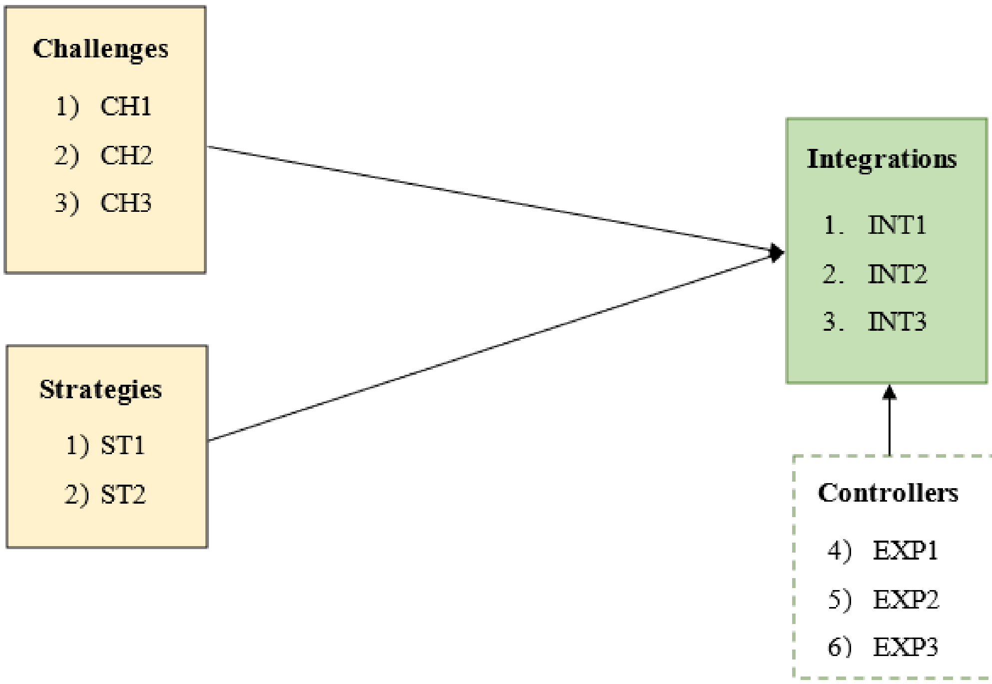


**Figure 6.3:** Initial Research Model For OSC and BIM Integration in Construction

### 6.4.3 Path Analysis Models

In the next step, three Structural Equation Models (SEM) were developed and tested to analyse the impact of latent and observed variables on integrating OSC and BIM (Path models 1, 2, and 3) using IBM SPSS AMOS version 26. In this research, SEM is employed to investigate the hypotheses regarding the relationship between observed and latent variables. This method is preferred over multiple regression, particularly when dealing with poorly measured variables (Fornell & Larcker, 1981). The theoretical study model, as depicted in Figure 6.3, illustrates the relationships among the variables.

Three path models demonstrated excellent model fit. CH1, CH2, CH3, ST1, and ST2 as observed exogenous variables, Exp1 (Experience in the construction industry), Exp2 (Experience in OSC), and Exp3 (Experience in BIM) as observed exogenous control variables, and INT1, INT2, and INT3 as observed endogenous variables were entered into the model. The first model (INT1) showed excellent fitness, $\chi2(12) = 15.52$, $p < .001$, CFI = .99, SRMR = .05, RMSEA = .05, PClose = .44. Second model (INT2) resulted in excellent fitness, $\chi2(11) = 16.39$, $p < .001$, CFI = .98, SRMR =.05, RMSEA = .06, PClose = .31. Last model (INT3) presented excellent fitness, $\chi2(13) = 19.26$, $p < .001$, CFI = .986, SRMR = .05, RMSEA = .06, PClose =.3. A summary of model validation and measurements of the CFA and SEM can be found in Table 5.4.

**Table 6.4:** Validity and Invariance Measurements of the Study Models

| | Model Invariance Tests | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CMIN (p-value) | | DF | | CMIN/DF | | CFI | SRMR | RMSEA | | PClose | |
| Path Model 1 | 15.52 | | 12 | | 1.29 | | .99 | .05 | .05 | | .44 | |
| Path Model 2 | 16.39 | | 11 | | 1.49 | | .98 | .05 | .06 | | .31 | |
| Path Model 3 | 19.26 | | 13 | | 1.48 | | .98 | .05 | .06 | | .3 | |
| | Construct Validity Measurements | | | | HTMT Measurements | | | | | | | |
| | α | CR | AVE | MSV | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| CH1 | .63 | .49 | .36 | .68 | .700 | | | | | | | |
| CH2 | .76 | .79 | .56 | .5 | .486*** | .751 | | | | | | |
| CH3 | .8 | .82 | .55 | .5 | .487*** | .712*** | .744 | | | | | |
| ST1 | .7 | .77 | .5 | .31 | .317** | .437*** | .478*** | .735 | | | | |
| ST2 | .8 | .80 | .51 | .36 | .607*** | .262* | .338*** | .561*** | .717 | | | |
| INT1 | .81 | .82 | .69 | .29 | .367** | .126 | -.019 | .215* | .545*** | .834 | | |
| INT2 | .83 | .83 | .63 | .43 | .415*** | .210* | .347*** | .535*** | .389*** | .484*** | .795 | |
| INT3 | .84 | .84 | .65 | .43 | .350** | .361*** | .455*** | .503*** | .327** | .430*** | .658*** | .807 |

Note: CMIN: Minimum Discrepancy; DF: Degree of Freedom; CFI: Comparative Fit Index; SRMR: Standard Root Mean Square Residual; RMSEA: Root Mean Square Error of Approximation; PClose: Probability of Close fit; α: Cronbach's Alpha; CR: Construct Reliability; AVE: Average Variance Extracted; MSV: Maximum Shared Variance; HTMT: HeteroTrait-MonoTrait Ratio of Correlations; *: $p < .05$

### 6.4.4 Path Analysis Models Findings

In this section the findings from three path analysis model are presented measuring three different integration variables.

***Path analysis model 1***

The analysis of the first path model revealed significant effects. Implementation Costs showed insignificant positive effects on New Zealand integration (βstandardised = .10, βunstandardised = .10, p = .42). However, Integrated Knowledge Deficit (βstandardised = .32, βunstandardised = .31, p = .004) and Competency and Preparedness Deficit (βstandardised = -.55, βunstandardised = -.53, p = .001) had a significant effect on BIM-Driven OSC readiness. The former had a negative effect, while the latter had a positive effect, both at a threshold of $p < .001$. Integration Facilitators (βstandardised = -.03, βunstandardised = -.03, p = .75) were not found to be significant.

In contrast, External Support and Policy Regulation (βstandardised = .61, βunstandardised = .60, p = .001) on BIM-Driven OSC Readiness demonstrated a significant positive effect on BIM-Driven OSC readiness $p < .001$. The negative effect of years of experience in construction was significant at a threshold of $p < .1$ (βstandardised = -.15, βunstandardised = -.11, p = .057). Years of experience in OSC showed a significant positive effect on BIM-Driven OSC Readiness (βstandardised = .05, βunstandardised = .07, p = .01). Years of experience in BIM did not significantly affect BIM-Driven OSC Readiness (βstandardised = -.18, βunstandardised = -.21, p = .44), despite two other control variables being significant.

***Path analysis model 2***

The analysis of the second path model revealed significant effects. Implementation Costs had a significant positive effect on BIM-Enabled Collaboration & Facilitation in New Zealand (βstandardised = .57, βunstandardised = .61, $p = .001$). In contrast, Integrated Knowledge Deficit showed a negative effect on integration and was found to be significant (βstandardised = -.48, βunstandardised = -.47, $p = .001$). Competency and Preparedness Deficit (βstandardised = .12, βunstandardised = .12, $p = .29$) had a positive effect but was not significant. Integration Facilitators demonstrated a significant positive effect (βstandardised = .74, βunstandardised = .73, $p = .001$) while External Support and Policy Regulation had a significant negative effect (βstandardised = -.30, βunstandardised = -.31, $p = .009$) on BIM-Enabled Collaboration and Facilitation. Among control variables, only years of experience in OSC indicated a significant negative effect, while the rest were not found to be significant. Years of experience in construction (βstandardised = .06, βunstandardised = -.04, $p = .43$) had a positive effect, while years of experience in BIM (βstandardised = .02, βunstandardised = -.03, $p = .77$) had a negative effect.

***Path analysis model 3***

The analysis of the last path model revealed significant effects. Implementation Costs (βstandardised = .28, βunstandardised = .29, $p = .03$) had a significant positive impact on BIM-Enabled OSC Enhancement in New Zealand. Integrated knowledge deficit (βstandardised = -.13, βunstandardised = -.13, $p = .27$) had a negative effect, while Competency & Preparedness Deficit (βstandardised = .22, βunstandardised =.21, $p = .073$) only had a significant negative effect at a threshold of $p < .1$. Integration Facilitators (βstandardised =.54, βunstandardised = .54, $p = .001$) had a positive effect, whereas External Support & Policy Regulation (βstandardised = -.22, βunstandardised = -.22, $p = .093$) showed a significant negative effect on BIM-Enabled OSC enhancement in New Zealand. The negative effect of years of construction experience was not significant (βstandardised = -.3, βunstandardised = -.2, $p = .708$), and the control variable years of experience in OSC indicated a positive significant effect on BIM-Enabled OSC Enhancement (βstandardised = .11, βunstandardised = .14, p = .006). However, years of experience in BIM with a negative effect were not significant (βstandardised = -.22, βunstandardised = -.27, p = .14). A summary of the findings for both path models can be found in Table 6.5.

**Table 6.5:** Specific Direct Effects

| Research Finding | Path | Unstandardised Estimate | Standardised Estimate |
|---|---|---|---|
| **Path Model 1** | | | |
| Implementation Costs | → BIM-Driven OSC Readiness | .10 | .10 |
| Integrated Knowledge Deficit | → BIM-Driven OSC Readiness | .31 | .32** |
| Competency and Preparedness Deficit | → BIM-Driven OSC Readiness | -.53 | -.55*** |
| Integration Facilitators | → BIM-Driven OSC Readiness | -.03 | -.03 |
| External Support and Policy Regulation | → BIM-Driven OSC Readiness | .60 | .61*** |
| Years of experience in construction | → BIM-Driven OSC Readiness | -.11 | -.15† |
| Years of experience in OSC | → BIM-Driven OSC Readiness | .07 | .05* |
| Years of experience in BIM | → BIM-Driven OSC Readiness | -.21 | -.18 |
| **Path Model 2** | | | |
| Implementation Costs | → BIM-Enabled Collaboration & Facilitation | .61 | .57*** |
| Integrated Knowledge Deficit | → BIM-Enabled Collaboration & Facilitation | -.47 | -.48*** |
| Competency and Preparedness Deficit | → BIM-Enabled Collaboration & Facilitation | .12 | .12 |
| Integration Facilitators | → BIM-Enabled Collaboration & Facilitation | .73 | .74*** |
| External Support and Policy Regulation | → BIM-Enabled Collaboration & Facilitation | -.31 | -.30** |
| Years of experience in construction | → BIM-Enabled Collaboration & Facilitation | .04 | .06 |
| Years of experience in OSC | → BIM-Enabled Collaboration & Facilitation | -.29 | -.23** |
| Years of experience in BIM | → BIM-Enabled Collaboration & Facilitation | -03 | -.02 |
| **Path Model 3** | | | |
| Implementation Costs | → BIM-Enabled OSC Enhancement | .29 | .28** |
| Integrated Knowledge Deficit | → BIM-Enabled OSC Enhancement | -.13 | -.13 |
| Competency and Preparedness Deficit | → BIM-Enabled OSC Enhancement | .21 | .22† |
| Integration Facilitators | → BIM-Enabled OSC Enhancement | .54 | .54*** |
| External Support and Policy Regulation | → BIM-Enabled OSC Enhancement | -.22 | -.22† |
| Years of experience in construction | → BIM-Enabled OSC Enhancement | -.2 | -.3 |
| Years of experience in OSC | → BIM-Enabled OSC Enhancement | .14 | .11** |
| Years of experience in BIM | → BIM-Enabled OSC Enhancement | -.27 | -.22 |
| Note: †: p <.1, *: p < .05; **: p <.01; ***: p < .001 | | | |

## 6.5 Discussion

This section discusses the three integration factors—BIM-Driven OSC Readiness, BIM-Enabled Collaboration & Facilitation, and BIM-Enabled OSC Enhancement—and examines the impact of the measured factors on each integration outcome. The discussion explores how challenges, strategies, and external factors influence these integration pathways, highlighting key relationships, significant findings, and their implications for improving OSC and BIM integration in the construction industry.

### 6.5.1 BIM-Driven OSC Readiness

The analysis results from model path 1 demonstrated that Integrated Knowledge Deficit and Competency and Preparedness Deficit significantly impact integration. β coefficient demonstrated that although the Integrated Knowledge Deficit is a challenge for integration, it can also be an advantage that helps organisations enhance their knowledge and readiness for better integration. On the other hand, the project-based nature of construction projects causes integration challenges (Eriksson, 2015). Knowledge creation and interchange are fundamental to the innovation process (Lindgren et al., 2018), and an ineffective flow of knowledge is an innovation challenge (Rundquist et al., 2013). Therefore, based on the results, knowledge sharing with stakeholders is required to improve integration within the construction industry.

The findings depicted Competency and Preparedness Deficits as a significant stakeholder challenge for successful OSC and BIM integration. The outcomes emphasize addressing the challenge because of its negative effect, which could enhance the integration of the mentioned context in construction. It means that while the challenge decreases, the integration will increase; thus, if projects deal with this challenge better, they could have an upper level of integration. Literature mentioned the need for skilled and knowledgeable people who can navigate the complexities of BIM tools and OSC workflows, leading to better integration and implementation (Evans et al., 2023; Olawumi, 2019).

The External Support and Policy Regulation standardised coefficients significantly correlate with integration. The beneficial outcome implies that the outputs could improve integration by implementing the approach and utilising BIM in the OSC delivery process. Stakeholders could strengthen the integration of OSC and BIM with External factors, including governmental backing, financial incentives, and changing legislation. According to New Zealand Ministry of Business Innovation and Employment (MBIE, 2021), developing building code regulations may lessen integration challenges.

The experience of OSC specialists can strongly impact successful integration in the construction sector. Their expertise, problem-solving skills, communication, and risk management capabilities all help to make the integration process more efficient. Stakeholders with more knowledge of both practices can make better decisions since they have a deeper comprehension of them. Conversely, as the OSC experience grows, stakeholders' perspectives change as they see the advantages of using more creative approaches. However, the outcome shows that years of construction expertise have a negative impact (Li et al., 2019).

### 6.5.2 BIM-Enabled Collaboration & Facilitation

The standardised coefficient of -.15 implies that BIM-Driven OSC Readiness declines as the standard deviation in years of building experience rises. This can be due to more expert professionals' resistance to adopting new technologies. Implementation cost's significant positive effect on BIM-Enabled Collaboration and Facilitation (model path 2) in the construction industry highlights the significance of investment in adopting BIM in OSC. The adoption will enhance collaboration and communication among diverse stakeholders from different disciplines (Nguyen et al., 2022). Although the initial cost is high, the long-term benefits will lead to saving costs due to early issues identifying and improving project quality and sustainability through implementing advanced technology (Kordestani Ghalenoei et al., 2022a).

The next challenge affecting integration is the Integrated Knowledge Deficit with a negative relationship. The negative impact depicts that if the challenge increases, the integration will increase; thus, it is critical to mitigate consideration for a challenge to have better integration. Organisations that struggle with high levels of integrated knowledge may face challenges in implementing successful integration strategies, potentially leading to inefficiencies and inconsistent outcomes. This shows that the lack of integrated knowledge influences the degree of integration (Evans et al., 2023; Rundquist et al., 2013).

The findings show that, despite the considerable beneficial influence that Integration Facilitators have on BIM-Enabled Collaboration and Facilitation, External Support and Policy Regulation have the opposite, detrimental effect. Enhancing Integration Facilitators will likely increase collaboration and facilitation inside organisations, facilitating effective stakeholder communication and coordination. However, the negative impact of the challenge raises the possibility that the factor may require careful control to prevent overly strict rules or insufficient external support from impeding the potential advantages of collaboration BIM offers (Evans et al., 2023; Lindgren et al., 2018). Integration Facilitators act as a bridge between various stakeholders, promoting efficient coordination, knowledge sharing, and communication. The literature backs up these findings by emphasizing the critical role of facilitation in overcoming challenges in construction projects (Lindgren et al., 2018). Notably, the significant negative effect of years of experience in OSC on BIM-Enabled Collaboration and Facilitation suggests a subtle relationship.

### 6.5.3 BIM-Enabled OSC Enhancement

The results for path model 3 showed that challenges significantly impact BIM-Enabled OSC Enhancement as an integration factor. The benefit of implementation cost shows that greater expenditure in resolving the issue resulted in more significant improvements in construction methods. This research shows that organisations that assign more resources and energy to address Implementation Costs will probably benefit from integration, even though causality cannot be conclusively shown. This finding is consistent with the idea that making financial sacrifices to address integration issues like costs can lead to better implementation and results in the larger literary context (Barkokebas et al., 2021).

The strong positive impact of Competency and Preparedness Deficits on BIM-Enabled OSC Enhancement demonstrates a boost in integration due to raising the challenge. Individuals or groups are defined as inadequately prepared for the tasks, challenges, or adjustments that a project or endeavour demands by the challenge. These results are consistent with previous research highlighting the importance of organisational expertise, preparation, and preparedness for applying innovative construction techniques like BIM and OSC (Evans et al., 2023; Rundquist et al., 2013). The findings point to the necessity for focused strategies to improve readiness and expertise while capitalizing on the benefits of integration issues to create an environment more favourable for BIM-driven improvements in OSC projects.

While Integration Facilitators significantly influence BIM-Enabled OSC Enhancement, the second strategy to mitigate integration challenges- External Support and Policy Regulation- has a negative impact. Findings show that significant improvements in using BIM for OSC are associated with the strategic use of Integration Facilitators, including collaboration processes, communication protocols, and coordination techniques between different stakeholders. The results support previous literature that emphasizes the contribution of these facilitators to efficient integration and workflows by highlighting their critical importance in encouraging a consistent approach to construction projects (Shaikh et al., 2020). According to the result, supporting Integration Facilitators can dramatically increase the uptake of BIM-Enabled OSC, providing tangible benefits for accuracy, project efficiency and stakeholder engagement.

The findings revealed a somewhat unexpected pattern, wherein External Support and Policy Regulation negatively affected BIM-Enabled OSC Enhancement, as indicated by the moderate standardised and unstandardised coefficients. However, it is essential to note that the statistical significance of these negative effects was not firmly established, suggesting the need for cautious interpretation. Potential factors contributing to the unexpected negative effects could be rooted in the unique dynamics of the construction landscape, whereby the implementation of External Support and Policy Regulation might interact with multifaceted variables.

The results inspire policymakers and practitioners to re-evaluate their approaches to promote BIM-Enabled OCS Enhancement, even though they enable precision in directly applying External Support and Policy Regulation requirements. Years of experience significantly affect BIM-Enabled OCS Enhancement, highlighting the link between growing OSC experience and integration. This result supported the study that emphasized the critical importance of industry experience in promoting technological acceptance and innovation within the construction industry (Rundquist et al., 2013).

As Figure 6.4 shows, integration is a complex process influenced by numerous factors, with challenges and strategies playing a critical role in its success or failure. These challenges and strategies are not static but evolve, positively or negatively impacting integration. What makes this process even more complicated is the interconnected relationships between these factors, ultimately affecting the integration level. Stakeholders engaged in integration initiatives must be cautious and adaptable, acknowledging the dynamic nature of challenges and strategies and considering how different challenges and strategies could assist them in improving the level of integration in their projects.

It is confirmed from the study findings that integration is not only one factor; it has various aspects that structure the integration together. It should be considered that these integration factors are related but, on the other hand, separate from each other, affected by various challenges and strategies. INT 1 is affected by CH2 and CH3, and by applying ST2, the integration level will change, distinct from the effect of ST2 on INT2 or INT3. Four factors, including two challenges and two strategies, impact INT2, whereas only CH3 influences INT3. These findings will help stakeholders use the proper strategies when facing specific challenges and pursuing different integration objectives.

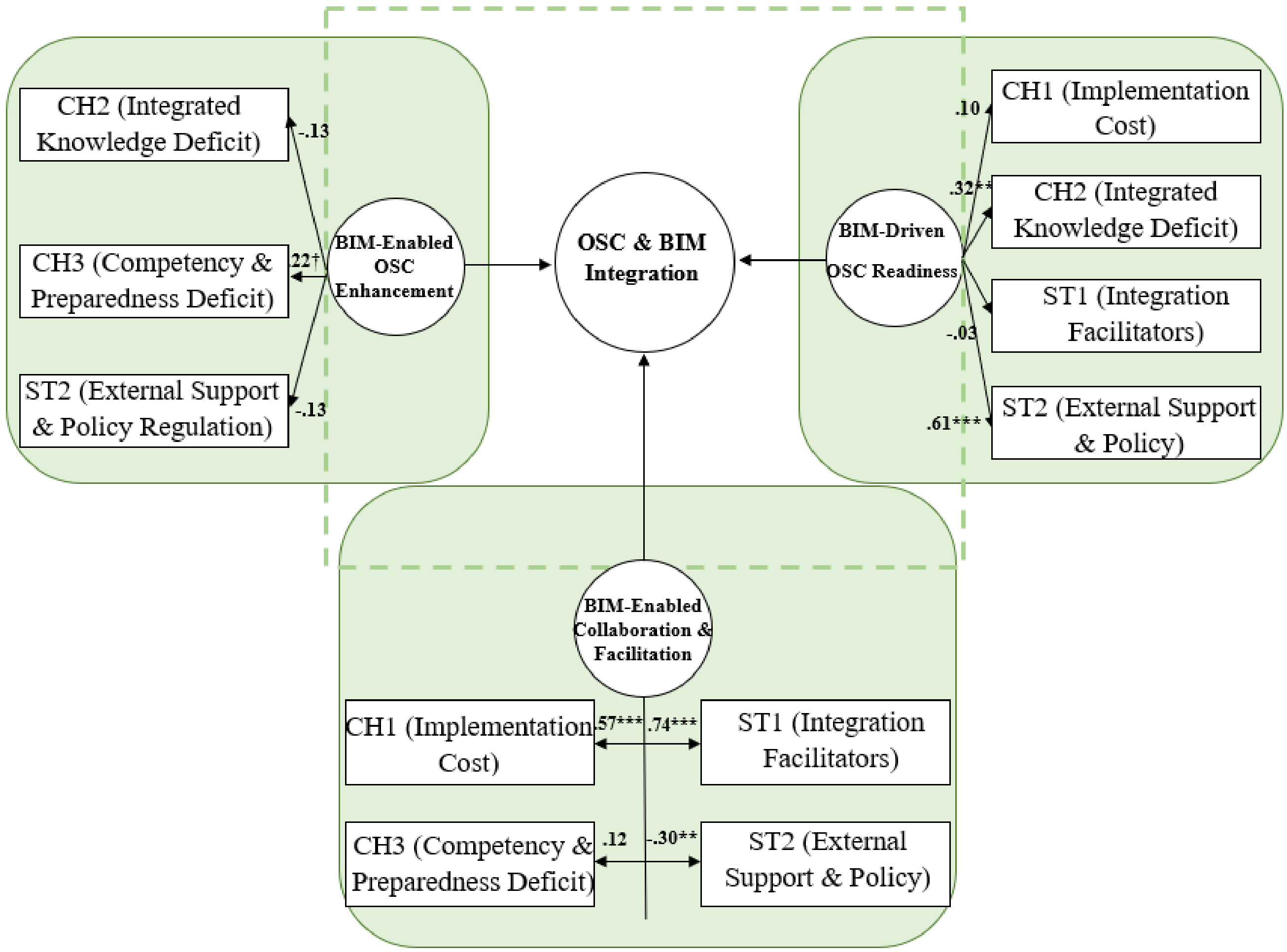


**Figure 6.4:** Path Models for Factors affecting OSC and BIM integration in construction

The inclusion of standardised estimates within Figure 6.4 aids in enhancing understanding of the model by illustrating the strength and direction of variable relationships. These estimates, which show the standardised sizes of the relationships between variables, make it easier to see which paths in the model are more important and how they compare to each other. In the models provided, different paths have different levels of importance in explaining how variables are related. For example, in Path Model 1 (BIM-Driven OSC Readiness), Integrated Knowledge Deficit and External Support & Policy Regulation have the highest standardised estimates, meaning they contribute a lot to explaining the model. In Path Model 2 (BIM-Enabled Collaboration & Facilitation), Integration Facilitators and Implementation Costs are most important, and in Path Model 3 (BIM-Enabled OSC Enhancement), Integration Facilitators and Implementation Costs are also key factors.

## 6.6 Conclusion

This study identified the influencing factors on OSC and BIM integration, providing the basic integration framework in construction projects. The study assessed how challenges and strategies affect integration in construction projects, and underlying factors for better understanding have been discussed. Initially, a comprehensive literature review was conducted to identify the challenges and strategies necessary for developing survey questions.

The survey was then created and modified through a peer review process and pilot study before final distribution. EFA, CFA, and SEM were employed as the data analysis methods for the survey data. To classify items EFA used and resulted in eight categories for challenges, strategies, and integration, including CH1 (Implementation Costs), CH2 (Integrated Knowledge Deficit), CH3 (Competency and Preparedness Deficit), ST1 (Integration Facilitators), ST2 (External Support and Policy Regulation), INT1 (BIM-Driven OSC Readiness), INT2 (BIM-Enabled Collaboration and Facilitation), and INT3 (BIM-Enabled OSC Enhancement).

CFA was then employed to confirm the EFA result, and SEM followed this step to investigate the factors that affect integration through three different model paths. Findings demonstrated that Implementation Costs and Competency and Preparedness Deficits significantly positively and negatively affect BIM-Driven OSC Readiness. External Support and Policy Regulation as a strategy showed a significant positive effect on integration. Although years of experience in BIM were insignificant, two other control variables (years of experience in construction and OSC) depicted negative and positive significant effects on BIM-Driven OSC Readiness, respectively. Model path 2 considered BIM-Enabled Collaboration and Facilitation as the second integration variable. CH1 and CH2 found significant positive and negative effects; the same pattern happened for the strategies. Only years of experience in OSC among control variables indicated a significant negative effect on the BIM-Enabled Collaboration and Facilitation variable.

For the previous models, challenges appeared with both negative and positive relationships on integration variables. CH1 and CH3 had significant positive effects. Integration Facilitators with a significant positive effect at $p < .001$ significantly affected BIM-Enabled OSC Enhancement. Finally, only years of experience in OSC were identified as significant in model path three. Through a quantitative methodology, this research adds to the body of knowledge by establishing the effects of challenges and strategies on OSC and BIM Integration in construction projects. The first section of the data displayed a significant connection between integration, challenges, and strategies. Secondly, this study provided knowledge of integration in OSC and BIM by classifying a wide range of challenges, strategies, and integration factors under eight fundamental groups.

The findings reveal that underlying factors which are not initially visible could play a significant role in achieving improved integration and require careful consideration. Revealing the challenges and strategies in relationships can clarify the internal connections between these concepts. The study contributes to academic by establishing a basic integration framework for construction projects and identifying challenges and strategies that impact integration. This framework, coupled with the use of rigorous methodologies such as EFA, CFA, and SEM, enhances the robustness of the study's findings, providing a solid academic foundation. Additionally, the study categorises challenges, strategies, and integration factors into eight fundamental groups, facilitating a more systematic understanding of the complexities involved in OSC and BIM integration.

Study findings can help the construction industry uncover hidden challenges and understand why they occur. By doing so, the industry can prevent or solve problems before they become serious, making projects run more smoothly and avoiding delays. Additionally, the insights gained from understanding these challenges and strategies can help create standard guidelines for integrating different aspects of construction. This will make construction processes more organised and efficient, benefiting everyone involved. This study has some limitations that should be considered. First, as the data were gathered from a sample of New Zealand construction projects, the measures' application in other countries and regions may differ.

However, the approach taken in this case can be adapted similarly to look at the integration practices utilised in other nations. Although the 116-participant sample size also satisfies the general standards for factor analysis, more complementary data are required to develop more comprehensive models. In future studies, attention could be directed towards exploring the roles and responsibilities of stakeholders in addressing challenges, as well as investigating potential differences in their perspectives. Additionally, it would be beneficial to examine how challenges may vary across different project lifecycle stages. Challenges encountered in the early stages of a project may differ from those experienced later, suggesting the need for diverse approaches. Therefore, investigating challenges based on the project lifecycle could assist stakeholders in efficiently allocating resources and minimizing duplications.

# Chapter 7: Offsite Construction and BIM Integration: Stakeholder's Perspective

***The current chapter is based on the following article:***

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. Sutrisna, M. Rahmani, D (2024), "Offsite Construction and BIM Integration Challenges in New Zealand: Stakeholder's Perspective", The Australasian Universities Building Education Association (AUBEA), November 2023, in press.

## 7.1 Introduction

Offsite construction (OSC) is an industrialised construction method involving transportable manufactured components installed onsite, improving efficiency and quality, and reducing carbon emissions (Abanda et al., 2017; MacAskill et al., 2021; Sutrisna et al., 2022). Revealing real knowledge is crucial for effectively implementing OSC in the construction industry, and this process may involve digital transition technologies like BIM (Hosseini, 2016). Building Information Modelling (BIM) is a tool that enables experts to collaborate in a virtual environment, improving communication and reducing clashes (Abanda et al., 2017).

OSC and BIM integration in the construction industry involves using digital technologies for the whole project lifecycle from design to demolition (Kordestani Ghalenoei et al., 2022a; Sutrisna et al., 2022; Zou et al., 2022). Integration has gained more attention in recent years due to its benefits for projects like improving the project quality and collaboration among stakeholders and reducing cost (Jayawardana et al., 2023; Kordestani et al., 2022). However, OSC and BIM integration adoption has been slow in New Zealand compared to other developed countries, which may be because of different stakeholders' perspectives on these concepts (Brown et al., 2020; Kordestani et al., 2022; Zou et al., 2022). Their integration has various challenges, including additional training and knowledge, lack of transparency in the manufacturing process, and high cost of implementing OSC and BIM (Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022).

The challenges may vary based on the project's phases or stakeholders (Wu et al., 2021). Due to the complexity of the OSC and BIM integration process, which involves multiple stakeholders, including clients, consultants, and contractors, effective collaboration and partnering are necessary, and it will develop their understanding of project success and allow them to deal with existing challenges (Kordestani Ghalenoei et al., 2022a; Sari et al., 2023). Based on previous studies, different stakeholders may be reluctant to any changes, be conservative and finally find new methods disruptive (Kordestani Ghalenoei et al., 2022a; Rahman, 2014; Sari et al., 2023). Additionally, many studies stated that although OSC and BIM gained popularity worldwide, their integration remained immature; therefore, more attention is required for this matter (Abanda et al., 2017; Liu et al., 2019; Liu et al., 2021b).

A comprehensive study has been conducted to identify challenges for OSC and BIM integration (Kordestani Ghalenoei et al., 2022a). However, this was limited to identifying the challenges, whilst additional research is required to assess stakeholders' perceptions of integration challenges, examining how different construction industry groups perceive the challenges of integrating OSC techniques with BIM in New Zealand. By identifying and addressing each stakeholder's challenges, this research will provide valuable insights that can be leveraged to facilitate the integration of OSC and BIM, thereby improving project outcomes and maximising project success. The perception is that the challenges may differ from various perspectives; however, tests and investigations are required to provide the related information regarding these differences.

## 7.2 Literature Review

### 7.2.1 An Overview of OSC in the Construction Industry

OSC has gained global recognition for its ability to enhance construction efficiency, improve quality, and support sustainability. By prefabricating components in controlled environments, OSC reduces on-site construction time and mitigates risks associated with conventional methods (Abanda et al., 2017; Hussein et al., 2021). In New Zealand, OSC is seen as a potential solution to address housing shortages and improve project delivery, driven by government initiatives and industry innovation (Zou et al., 2022).

Globally, OSC has been widely adopted in countries such as Sweden, Finland, the UK, and the US. Scandinavian countries have long utilised modular and panelised systems for residential projects, benefiting from high-quality outputs and streamlined processes. The UK's government-led initiatives promoting MMC have accelerated OSC adoption, particularly in public sector projects (Alazmeh et al., 2018; Ramboll, 2020). The US has also embraced OSC, especially in urban areas where labour shortages and tight project timelines necessitate faster construction methods (Pan et al., 2012; Pan & Goodier, 2012).

In New Zealand, OSC adoption is growing, spurred by the need for affordable housing and more efficient construction practices. Government initiatives, including pilot projects, have demonstrated OSC's potential to deliver quality housing at scale (Mirus et al., 2018a; PrefabNZ, 2018b). However, challenges such as high initial investment costs, logistical complexities, and a limited pool of skilled professionals present challenges to broader implementation (Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022). Despite these challenges, local manufacturers are developing expertise in OSC systems, with panelised and hybrid approaches being particularly prominent (Shahzad et al., 2022).

The three primary types of OSC in New Zealand are panelised systems, volumetric modular systems, and hybrid systems. Panelised systems involve prefabricating wall, floor, and roof panels for on-site assembly, making them suitable for low- to mid-rise residential projects. Volumetric modular systems construct entire modules off-site, ideal for complex elements like bathrooms and kitchens. Hybrid systems combine both methods, offering flexibility for project-specific needs (PrefabNZ, 2018b; Tookey, 2021). Panelised systems are especially prevalent due to their adaptability to New Zealand's varied terrain and remote locations, where efficient transport and assembly are crucial. Hybrid systems also support diverse project requirements, aligning with the country's construction goals (Eglinton, 2013).

OSC offers numerous benefits, including reduced construction time, enhanced quality control, and improved safety. Factory-controlled environments minimise defects and exposure to adverse conditions, ensuring higher-quality outputs (Zolghadr et al., 2022; Zou et al., 2022). Concurrent off-site and on-site activities shorten project timelines, a critical factor in addressing New Zealand's housing demands. OSC also supports sustainability by reducing waste and optimizing resource use. Safety improvements are notable, as off-site fabrication reduces on-site risks, enhancing worker conditions (Ribeiro et al., 2022; Sutrisna et al., 2022).

Challenges to OSC adoption include high initial costs for establishing manufacturing facilities and logistical complexities, particularly in transporting large, prefabricated components (Peiris et al., 2022; Ribeiro et al., 2022). The construction industry's resistance to change and a shortage of skilled professionals further hinder implementation. Additionally, a lack of standardisation and insufficient regulatory frameworks creates uncertainty for stakeholders, complicating planning and coordination efforts (Gan et al., 2018b; Shahzad et al., 2022). Despite these challenges, drivers such as government support, market demand for faster project delivery, and sustainability goals fuel OSC adoption (Jiang et al., 2021).

### 7.2.2 An Overview of BIM in the Construction Industry

BIM has revolutionised the AEC industry by enhancing collaboration, design accuracy, and project management. Globally, BIM adoption is driven by its ability to improve project outcomes and reduce costs. The UK is a leader in BIM implementation, with mandates requiring its use in public projects (Waqar et al., 2023). The US and other countries, such as Australia and Singapore, have also embraced BIM across various sectors, supported by government policies and industry standards (Kassem et al., 2013).

In New Zealand, BIM adoption is steadily increasing, driven by initiatives such as the BIM Acceleration Programme. The programme aims to raise awareness and encourage the use of BIM in construction projects. Despite progress, challenges such as high software costs and limited expertise remain challenges. However, growing demand for digitalisation and efficiency in project delivery continues to drive BIM adoption (BIM Acceleration Committee, 2019).

BIM offers several benefits, including enhanced visualisation and coordination. By creating a digital representation of a project, stakeholders can identify potential issues early and make informed decisions, reducing errors and rework. BIM also facilitates collaboration by providing real-time updates through a centralised model, improving project outcomes and cost efficiency (Gao & Pishdad-Bozorgi, 2019; Tang et al., 2019a). Its ability to perform simulations and analyses, such as energy performance and clash detection, further supports sustainable and efficient designs. BIM's data-rich environment also aids lifecycle management, enabling effective maintenance and operations (Azhar, 2011).

However, BIM faces challenges related to high implementation costs and the industry's reluctance to adopt new technologies. Data ownership, interoperability, and a lack of standardisation add complexity to collaborative projects (Yazıcıoğlu, 2021). Despite these challenges, drivers such as government mandates and the demand for improved project efficiency continue to promote BIM adoption. BIM's integration with emerging technologies, including artificial intelligence and the Internet of Things, enhances its value proposition, making it an essential tool for modern construction practices (Darko et al., 2020; Ghaffarianhoseini et al., 2017).

### 7.2.3 Integrating OSC and BIM in Construction Projects

The integration of OSC and BIM has the potential to revolutionise construction projects by combining the strengths of both technologies. OSC's modular construction methods benefit from BIM's digital platform, enhancing planning, coordination, and collaboration. BIM supports the design and simulation of OSC components, allowing stakeholders to visualise the construction process and anticipate potential issues before they arise. This integration enables better coordination between off-site and on-site activities, improving efficiency and reducing the likelihood of errors (Abanda et al., 2017; Razkenari et al., 2020).

Despite the advantages, integrating OSC and BIM is not without challenges. The complexity of aligning both technologies, the lack of industry-wide standards, and the need for specialised expertise can pose significant challenges. For OSC projects, where the construction process is distributed across multiple locations, coordinating the use of BIM to track and manage the production and assembly of components can be difficult (Yin et al., 2019). Furthermore, resistance to new technologies, high implementation costs, and the need for cross-disciplinary collaboration all need to be addressed for successful integration (Wang et al., 2020; Wang et al., 2022). To fully leverage the potential of OSC and BIM integration, it is essential to consider the roles of stakeholders in the process. The integration requires collaboration between various actors, including designers, contractors, clients, and suppliers, who must be aligned in their use of technology and working practices (Luo et al., 2019; Nguyen et al., 2022).

### 7.2.4 Stakeholder Perspectives on OSC and BIM Integration

Stakeholders' roles are critical in shaping the successful integration of OSC and BIM. Several studies have examined how different stakeholders (clients, contractors, suppliers, and consultants) perceive and influence the adoption of OSC and BIM in construction projects. These studies highlight various challenges and facilitators, but there remains a significant gap in understanding how stakeholders' varying interests, power dynamics, and levels of engagement impact the integration process (Luo et al., 2019; Nguyen et al., 2022; Yazıcıoğlu, 2021).

Research by Gan et al. (2018a) explored how stakeholders' perceptions influence the adoption of both OSC and BIM in the construction industry, finding that clients typically focus on cost-effectiveness, while contractors emphasize technical feasibility. However, this study does not provide a detailed analysis of how these differing priorities create conflicts or synergies during project implementation. Saito and Ruhanen (2017) similarly highlighted that stakeholders' power and interests shape their involvement in OSC and BIM integration but did not explore the ways in which power imbalances among stakeholders could hinder collaboration, especially in complex projects where multiple stakeholders with competing interests are involved.

A comprehensive review by Wu et al. (2021) examined stakeholder engagement in construction projects using BIM, finding that early engagement was critical for aligning stakeholder expectations. While the study acknowledged the importance of training and knowledge sharing, it did not investigate how each stakeholder group's knowledge, or lack of it, influences the integration process of OSC and BIM. Yazicioglu (2021) also discussed how different construction disciplines, such as design, procurement, and construction management, influence OSC and BIM adoption, but did not specifically address the nuances of stakeholder collaboration across different phases of the project lifecycle, which could significantly affect the integration of OSC and BIM.

Despite these insights, several gaps remain in the literature regarding stakeholders' roles in OSC and BIM integration (Kordestani Ghalenoei et al., 2022a). One key gap is the lack of research on how conflicting interests between stakeholders affect decision-making processes. For example, clients may prioritise cost savings at the expense of BIM implementation, while contractors may resist changing established workflows to accommodate OSC. This lack of in-depth exploration into power imbalances presents a missed opportunity for understanding how stakeholders' interests can be aligned for more effective integration (Luo et al., 2019; Nguyen et al., 2022; Wu, 2021).

Additionally, the literature fails to address how stakeholder collaboration evolves across the various stages of the project lifecycle, from design to post-construction. Each stage may present unique challenges and understanding how stakeholder roles change at each phase could inform strategies to overcome integration challenges (Tan et al., 2024). Moreover, while some studies briefly mention the role of training, there is insufficient examination of how differing levels of expertise among stakeholders affect OSC and BIM adoption. The lack of expertise, especially in BIM technology, may create resistance to adopting integrated solutions, but the specific challenges these differences create and how they can be addressed remain under-explored in the literature (Luo et al., 2019; Ninan et al., 2019; Yazıcıoğlu, 2021).

Overall, while considerable research has been conducted on the role of stakeholders in OSC and BIM integration, there is a clear need for further studies to explore how power dynamics, stakeholder collaboration across project phases, and levels of expertise influence the success of integration. Addressing these gaps could provide critical insights for developing targeted strategies to enhance stakeholder engagement and facilitate smoother integration of OSC and BIM in construction projects.

## 7.3 Research Methods

This study utilised a survey research method to investigate 19 challenges related to integrating OSC and BIM faced by clients, contractors, and consultants as the three main stakeholders in construction projects in New Zealand. The survey data were obtained from previous work, which included a comprehensive study using mixed methods, resulting in the identification of 35 challenges for OSC and BIM integration. After several rounds of peer review with industry experts and modification, 19 challenges were selected as the final input for this study.

The study population consisted of individuals with experience in OSC and/or BIM in the New Zealand construction industry who work on OSC projects by using BIM in the delivery process, and 116 valid responses out of 164 were used for analysis. The survey comprised two sections, one for demographics and the other for measuring participants' level of agreement with the importance of the challenges they have experienced in their projects. Participants were asked to rate the challenges on a 7-point Likert Scale ranging from "Not at all important" to "Extremely important" (Appendix 5). The 7-point Likert scale offers the respondents more choices to state their nuances attitudes and more independence to capture the exact answer. The 7-point is likely more reliable because items are chosen based on the survey construct (Dawes, 2008; Joshi et al., 2015).

Before the final distribution, a pilot study was used to demonstrate validity, but reliability can only be demonstrated after the collected data. A sample of 30 individuals was randomly asked from the population to participate in the pilot study, and the results were used to modify the survey. Data were collected from October 2022 to February 2023, and participants were asked to complete the online survey questionnaire through Qualtrics, a web-based survey tool. The survey link was sent through social media pages like LinkedIn and email to get more responses. After two weeks, follow-up emails were sent to ensure a high response rate, reduce non-response, and finally ensure the participant that their responses are valuable to research. Figure 7.1 presents the research process that has been taken for this study. The sample size and the specific population limit the study. Therefore, the generalisation of the findings to other populations may be limited.

One hundred sixteen valid responses were gathered from 164 received responses. Some of the questionnaires were excluded due to non-completion. The response rate of this study with 19 challenges is like the study done by Omer et al. (2022), with 106 valid responses. Most respondents (56%) work at the consultancy's companies; around 9% are on the client side and 35% work as contractors. 24% and 25% of respondents have 0-5 years and 6-10 years of experience, respectively. Participants with more than 11 years of experience cover the other fifty per cent with around 25% up to 15 years of experience. Most respondents had between 0-5 years of experience in OSC and BIM projects, which may show that these concepts have grown recently in New Zealand. Only 2.5% and 5% of the participants had more than 16 years of experience in OSC and BIM projects.

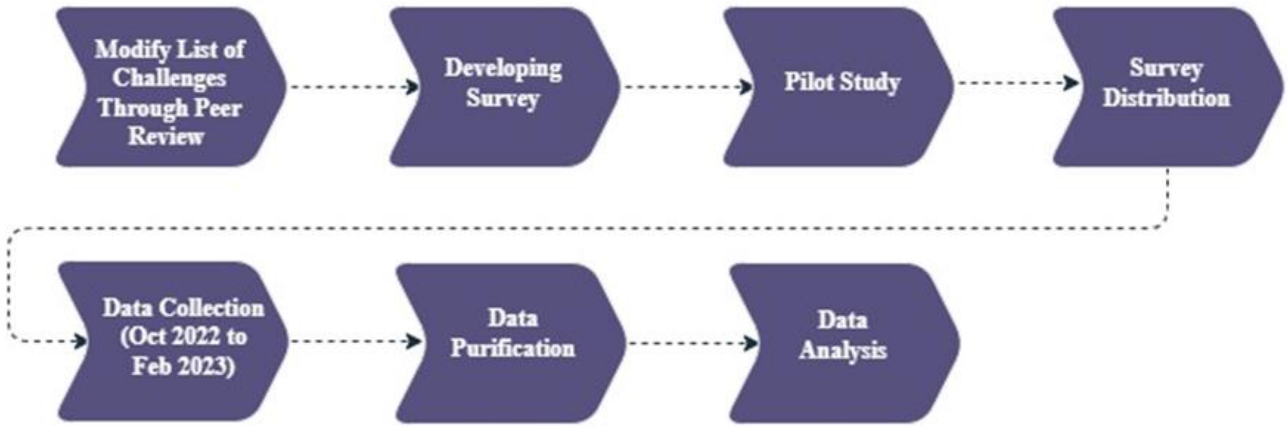


**Figure 7.1:** Research Methodology Process

## 7.4 Findings and Discussion

In the current study, the margin of error was calculated to be approximately 9.4% and determined using the formula:

Margin of error = 1.96 x (sqrt (0.5*(1-0.5)/116)) ≈ .094 or approximately 9.4% (Equation 7.1)

The margin of error means that if the survey was repeated with the same sample size, the outcome might vary by up to 9.4% in either direction. Analysis of variance (ANOVA) statistics employed to evaluate stakeholders' effects on the challenges. The test was analysed using SPSS version 29 software, and α smaller than .05 was considered for the data significance. Respondent groups (clients, contractors, consultants) are the independent variables, and the challenges obtained from the previous study are the dependent variables (Figure 7.2).

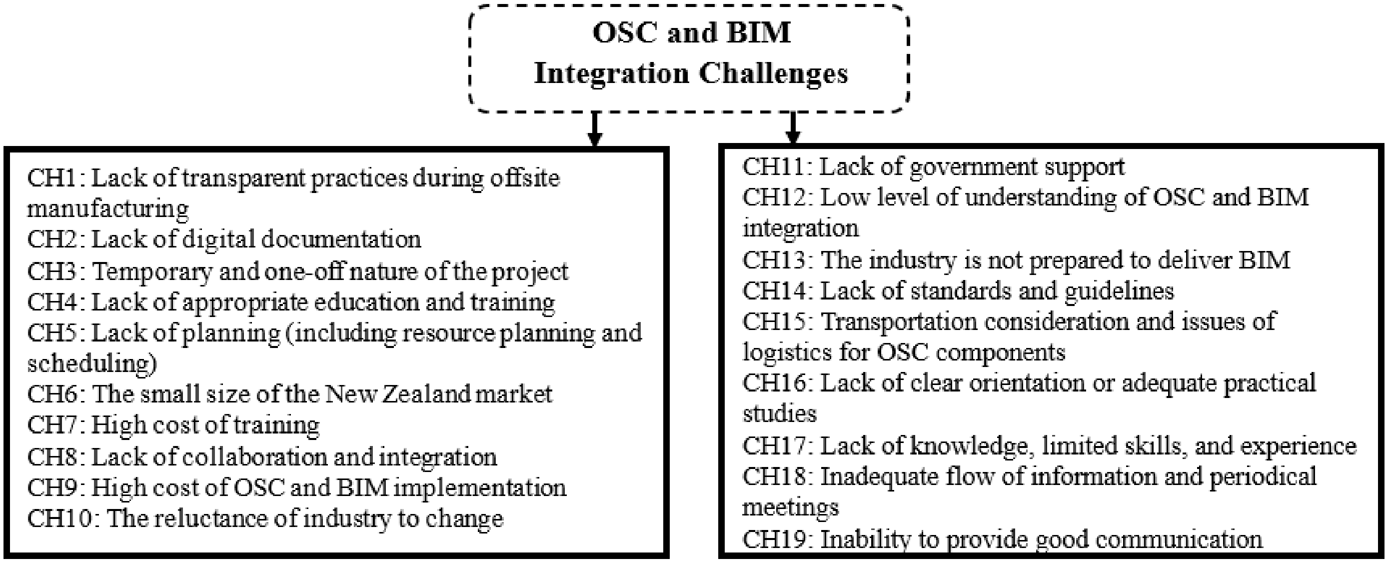


**Figure 7.2:** OSC & BIM Integration Challenges

From Table 6.1, it can be concluded that one-way ANOVA evaluated the impact of clients, contractors, and consultants on the challenges. The one-way ANOVA also indicated that for CH1, CH3, CH15, and CH19, the between-group variability is significantly greater than the within-group variability, as indicated by the F-statistics (3.593, 3.253, 3.953, and 3.195 respectively) and p-values (.31, .042, .022, and .045 respectively). The output shows a significant difference in the mean score of these indicators between the groups.

As mentioned, there is a statistically significant difference in mean values for CH1, CH3, CH15, and CH19 for at least two groups, while no significant difference was observed for the remaining challenges. One-way ANOVA for CH1 yielded a statistically significant result of (F (2,113) = [3.593] = .031). For CH3, the outcome of the test was (F (2,113) = [.742] = .042), while the statistical significance in the mean for CH15 was (F (2,113) = [3.953] = .022). Finally, for CH 19, the mean value is (F (2,113) = [3.195] = .045).

**Table 7.1:** Evaluation of clients, contractors, and consultants' perspectives on the challenges

| Challenges | | Sum of Squares | DF | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| CH1 | Between Groups | 26.001 | 2 | 13 | 3.593 | .031 |
| | Within Groups | 408.862 | 113 | 3.618 | | |
| | Total | 434.862 | 115 | | | |
| | Within Groups | 429.124 | 113 | 3.798 | | |
| | Total | 453.828 | 115 | | | |
| | Total | 349.198 | 115 | | | |
| CH3 | Between Groups | 24.704 | 2 | 12.352 | 3.253 | .042 |
| CH15 | Between Groups | 28.427 | 2 | 14.213 | 3.953 | .022 |
| | Within Groups | 406.263 | 113 | 3.595 | | |
| | Total | 434.69 | 115 | | | |
| | Total | 383.172 | 115 | | | |
| CH19 | Between Groups | 21.311 | 2 | 10.655 | 3.195 | .045 |
| | Within Groups | 376.862 | 113 | 3.335 | | |
| | Total | 398.172 | 115 | | | |

Furthermore, to perform multiple comparisons, Tukey's HSD Test was applied, and the results indicated that the mean value of CH1 (Lack of transparency in the OSC manufacturing process) differed significantly between consultants and contractors (p=.035, 95% C.I.= [-1.58, -.05]). Similarly, for CH3 (Temporary and one-off nature of the project), the mean value differed significantly different between the same group (p=.033, 95% C.I.= [.07, 1.91]).

Moreover, for CH15 (Transportation consideration and issues of logistics for OSC components), the mean value between contractors and consultants differed significantly (p=.018, 95% C.I.= [.15, 1.95]). Out of four challenges with a significant difference in mean value, only inability to provide good communication (CH19), there was a significant difference between clients and contractors (p=.038, 95% C.I.= [-3.13, -.07]). No statistically significant mean value was observed between clients, consultants, and contractors for the remaining challenges.

According to previous studies, it can be concluded that all the challenges are critical for stakeholders. However, some may be more important than others based on stakeholders' expectations, responsibilities, and objectives. Consultants are usually hired to provide professional guidance, best practices, and support for the overall project lifecycle (Law et al., 2022).

Contractors mainly complete the physical works and must finish them within the specific budget, time, and scope, which can impact their expectations differently. Clients mainly consider the project's time, quality, and cost-effectiveness more; therefore, they may have a different overview from other project stakeholders (Law et al., 2022; Sari et al., 2023).

From the test result employed in this study, 4 out of 19 challenges significantly differed between the two stakeholder groups. These four challenges are lack of transparency in the OSC manufacturing process, temporary and one-off nature of the project, transportation consideration and logistics issues for OSC components, and inability to provide good communication. From the contractor's perspective, a lack of transparency in the OSC manufacturing process (CH1) can impact the project completion date and cause delays, increasing the project cost. Additionally, it may prevent the adequate providing flow of information for regular progress updates (Lu & Liska, 2008). On the other hand, consultants may focus on the quality of the work, and the lack of clear transparency from manufacturers affects the required information they need to put in their BIM models. Both groups have essential roles in the projects, but applying different strategies to deal with each group may be required when mitigating the challenges.

The project's temporary and one-off nature is the next challenge, which is the significant difference between the two groups of stakeholders. Consultants may look at the projects with a long-term overview and implications of OSC and BIM in the construction industry. Contractors are primarily hired to assemble, and the one-off nature of the project may not be a big concern for them as the OSC and BIM integration helps them to improve efficiency, increase productivity and reduce waste.

Regarding transportation and logistics issues (CH15), the contractors may have concerns about delivering the components to the site in good condition and then being installed properly.

Conversely, consultants may look at the challenges differently and focus on the bigger picture of the issue, like the impact of the challenge on the projects' objectives and mitigation strategies (Lou et al., 2022; Wu et al., 2021). A study done by Law et al. (2022) also found the transport constraint in terms of size and weight of the OSC components as one of the challenges which differ between stakeholders in the projects. Finally, for clients and contractors, the inability to provide good communication (CH19) can be related to the different communication ways they usually apply their expectations, which cause disputes and misunderstandings. Overall, it is crucial to identify the best way to communicate and collaborate, especially in the OSC projects that need more collaboration.

## 7.5 Conclusion and Further Research

The primary purpose of the current research was to determine the differences between the challenges for OSC and BIM integration from a stakeholder's perspective in the New Zealand construction industry. Nineteen challenges from the previous author's study were examined by surveying clients, contractors, and consultants with experience working in OSC and/or BIM projects. The outcome of One-way ANOVA (Table 7.1) indicated that four challenges significantly differed among the two stakeholder groups. Three of the challenges named lack of transparency in the OSC manufacturing process (CH1), temporary and one-off nature of the project (CH3), and transportation and logistics issues (CH15) were significantly different from consultants' and contractors' points of view, which may occur due to their roles, objectives, and expectations. The inability to communicate well (CH19) was the other challenge that significantly differed between clients and contractors.

The challenges presented in Figure 7.2 could belong to the project, organisation, and industry levels. The four mentioned challenges belonged to the project and organisation level, which differ in the nature and approaches to mitigate them. However, mitigating these challenges requires a multi-dimensional approach involving collaboration and coordination among primary stakeholders at different levels. The findings of this study can be applied to develop strategies for targeted stakeholders to address specific challenges. The study is expected to play a significant role in enhancing understanding of the current state and identifying the most effective ways to improve the OSC and BIM integration in New Zealand.

# Chapter 8: Integration Maturity Assessment Framework

***The current chapter is based on the following article:***

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D.  Sutrisna, M. Rahmani, D (2024), " An In-depth Examination of Offsite Construction and Building Information Modelling Integration through a Maturity Assessment Framework" (Under Review).

## 8.1 Introduction

The construction industry has witnessed significant evolution in recent years yet continues to face with challenges such as cost overruns, project delays, and quality issues, which decrease its overall performance and productivity. In response, various methodologies and technological advancements have been introduced to improve industry construction practices (Shahzad et al., 2022). Among these,  offsite construction (OSC) (Abanda et al., 2017; Nawari, 2012; Yin et al., 2019) has emerged as a prominent approach, involving the prefabrication of components in a controlled factory environment, before transporting them to the construction site for final assembly. Over the years, this process has developed to the point that technology, such as Building Information Modelling (BIM), is becoming a significant tool in the delivery process (Olawumi, 2019). BIM is a tool that enables experts to collaborate in a virtual environment, improving communication and reducing clashes (Abanda et al., 2017).

BIM facilitates visualisation and information management throughout the project lifecycle, improving coordination and decision-making  (Rashidian et al., 2022). While both OSC and BIM have demonstrated their potential advantages individually, both can benefit more through integration (Ghalenoei et al., 2022; Kordestani Ghalenoei et al., 2022a). Due to the fragmented process, OSC requires efficient tools and technologies for communication to promote collaboration and communication. With its parametric modelling and integrated features, BIM can, on the one hand, help OSC with product design and process planning (Ramaji & Memari, 2016).

The OSC and BIM integration process could be complex because of the involvement of multiple stakeholders and the nature of the OSC projects (Kordestani Ghalenoei et al., 2022a; Rahman, 2014). Thus, effective collaboration and interaction are necessary among stakeholders, which could help better understanding of the integration process and assist them to deal with integration challenges (Sari et al., 2023).

Integration challenges could happen at different project lifecycles or occur because of the environment at the organisational level, including project, organisation, or industry (Kordestani et al., 2022; Nguyen et al., 2022). Each phase of project life cycle plays a significant role in the overall performance of OSC and have interconnection link to each other (Boafo et al., 2016). Challenges in the initial phase might vary with challenges happening in the execution phase, and in this case, different strategies are required to address the challenges. Planning, communication, and resource allocation become targeted and relevant when the challenges are associated with their representative life cycle (Boafo et al., 2016; Olawumi, 2019).

Another factor impacting the integration process is the presence of challenges due to different organisational levels. A challenge like practical design coordination between OSC and BIM may happen at the project level (Kluck & Choi, 2023; Waqar et al., 2023), while lack of skill and knowledge may exist at multiple levels. Therefore, implementing OSC and BIM requires investment in suitable technologies, training the workforce, and effectively managing the changes associated with integration and studies have emphasized the importance of organisational leadership support to overcome these challenges (Kordestani et al., 2022; Lopez et al., 2022).

Understanding the nature of the integration challenges enables stakeholders to focus on areas for improvement (Pluchinotta et al., 2022). However, a significant factor affecting the integration is the organisational capability that aids projects and organisations in identifying practical steps for adopting new technologies and processes, through the maturity level (Razkenari & Kibert, 2022). Existing research has examined OSC and BIM integration from various aspects including the combination of BIM and lean for prefabrication and OSC, maturity models and advanced technologies to improve OSC projects; however, in order to move towards higher level of integration relationship between the project lifecycle, challenges and maturity levels require to be investigated.

Therefore, this research addresses a critical gap in OSC and BIM integration by exploring challenges from a multi-level perspective (challenges at project life cycle and organisational level) and developing an integration maturity assessment framework. As integrating different methods and tools is a continuous process which relies on an organisation's current capacity and preparedness (Pluchinotta et al., 2022), businesses may need to redesign their workflows to integrate BIM and OSC techniques. However, without proper guidance, these adjustments could be costly and ineffective (Dumas & Beinecke, 2018). Thus, the objective of this study is to develop an integration maturity assessment framework for OSC and BIM within New Zealand construction projects that assists stakeholders in determining their integration levels and mitigate integration challenges by implementing low-risk modifications throughout their project lifecycle phases (Morris, 2013).

By identifying challenges comprehensively (through survey followed by case study), this research creates an enabling environment for widespread OSC and BIM utilisation. Furthermore, the multi-level approach emphasizes challenges specific to different project maturity levels, aiding in resource allocation and strategic planning throughout the project lifecycle. Ultimately, the integration maturity framework developed in this study can guide projects in effectively addressing challenges, enhancing teamwork, and advancing OSC and BIM integration within the construction industry.

## 8.2 Literature Review

The construction industry, like many others, is increasingly adopting new technologies such as OSC and BIM (Shahzad et al., 2022). The integration of BIM with OSC is vital for several reasons. Firstly, OSC projects often involve multiple stakeholders managing information in isolated systems, leading to inefficiencies and poor collaboration (Luo et al., 2020; Luo et al., 2019). Research has demonstrated that integrating BIM with technologies like sensing and tracking can enhance collaboration and efficiency in OSC by providing timely and structured information to stakeholders (Chen et al., 2015; Chi et al., 2015; Li et al., 2019).

### 8.2.1 Challenges in OSC and BIM Integration

However, OSC projects face significant challenges, including rework due to a lack of adjustments (Enshassi et al., 2019) and insufficient BIM integration in schedule management, which affects timely project delivery (Cho et al., 2021). Technologies like BIM play a crucial role in addressing these challenges by optimizing project delivery processes (Li et al., 2018a). BIM facilitates the creation of information-rich simulation models, helping reduce design errors and omissions. Therefore, integrating BIM with OSC addresses the root causes of inefficiency, fragmentation, and unpredictability, ultimately enhancing collaboration, efficiency, and project delivery in the construction industry (Bhattacharya & Mathur, 2022; Lee et al., 2015; Mao et al., 2015).

Despite these benefits, significant challenges remain. A comprehensive literature review identified three main groups of challenges: Implementation Costs, Integrated Knowledge Deficit, and Competency and Preparedness (Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022). Implementation Costs encompass expenses related to professional training, hardware and software acquisition, maintenance, redesign processes, and data management (An et al., 2020b; Kluck & Choi, 2023; Waqar et al., 2023). Additionally, hiring skilled professionals with expertise in OSC and BIM adds to the financial burden (Gbadamosi et al., 2020b).

The Integrated Knowledge Deficit highlights the need for transparency, knowledge sharing, and effective communication during BIM implementation in OSC. Effective communication is crucial for adherence to industry standards (Nguyen et al., 2022; Ribeiro et al., 2022). Challenges arise from coordinating OSM with onsite requirements, which can hinder integration efforts. Furthermore, insufficient training in OSC and BIM integration can lead to misunderstandings among stakeholders (Law et al., 2022; Nguyen et al., 2022; Yazıcıoğlu, 2021).

The final challenge, Competency and Preparedness, encompasses issues such as the lack of standards, limited understanding, insufficient practical experience, and knowledge gaps. The absence of standardised guidelines for integration can confuse businesses regarding project expectations and execution (Jiang et al., 2021; Wuni & Shen, 2020). This lack of clear direction and guidance impedes integration efforts, leaving businesses unprepared to implement best practices efficiently. Moreover, insufficient investment in technology and education exacerbates the industry's unpreparedness (Kordestani Ghalenoei et al., 2022a; Wuni & Shen, 2023).

### 8.2.2 OSC and BIM Integration Frameworks

Numerous studies have explored the benefits, challenges, and strategies related to OSC and BIM integration, providing valuable insights (Kordestani Ghalenoei et al., 2022a; PrefabNZ, 2018b; Shahzad et al., 2022; Wuni & Shen, 2023). However, a focused study is needed to examine integration challenges at the organisational level, including project, organisation, and industry perspectives, and to identify challenges throughout the project lifecycle. This identification will help projects adopt new technologies more effectively.

To navigate future integration, organisations require a structured approach to assess their current state and identify areas for improvement (Phang et al., 2020). A review of literature on BIM for OSC has explored workflows, frameworks, and guidelines for integration. For instance, Barkokebas et al. (2021) proposed a framework that applies digitalisation in OSC pre-manufacturing phases through a BIM Lean approach, minimising waste. Similarly, Moghadam (2014) developed an integrated BIM-Lean framework for offsite manufacturing operations, generating shop drawings and data for modular projects.

Efforts to establish standardised frameworks and best practices for integration are also underway. Bakhshi et al. (2022) combined customisation with a BIM-based Design for Manufacturing and Assembly (DFMA) method to improve client involvement in high-performance project outcomes. As shared information is crucial, various studies have developed BIM-based Management Systems for implementation in OSC projects (Hussein et al., 2021; Jang et al., 2022; Jiang et al., 2020; Wu et al., 2022).

### 8.2.3 Capability Maturity Model for OSC and BIM Integration

Maturity models are widely adopted frameworks used to evaluate and improve processes, technologies, and organisational capabilities (Paulk et al., 1993; Wendler, 2012). These models provide a structured pathway for organisations to identify their current level of maturity, benchmark against industry standards, and set targets for improvement (Kassem et al., 2013; Succar, 2010). In the context of OSC and BIM integration, maturity models serve as diagnostic tools to assess integration effectiveness, address key challenges, and offer strategic roadmaps for advancing maturity levels across projects (Li et al., 2019; Ortega et al., 2023a). They enable organisations to systematically evaluate their readiness, align workflows, and improve overall performance by identifying gaps in capabilities and processes.

The integration of OSC and BIM involves multiple stakeholders, advanced technologies, and dynamic workflows, all requiring systematic alignment to ensure seamless collaboration (Jung & Joo, 2011). The maturity model approach was chosen for its ability to provide a systematic evaluation of OSC and BIM integration maturity, identify critical gaps, align practices with industry benchmarks, and support continuous improvement (Wendler, 2012). While alternative approaches, such as performance metrics or Lean frameworks, offer valuable insights (Salem et al., 2006), they do not provide the same holistic evaluation across multiple dimensions of integration. Maturity models offer a structured lens through which integration processes can be assessed and improved over time, ensuring that both technical and managerial aspects of integration are addressed comprehensively (Paulk et al., 1993).

This study employs a staged maturity model to assess OSC and BIM integration, categorising the integration journey into sequential levels (Jung & Joo, 2011). These levels typically progress from an initial stage, where integration processes are ad-hoc and unstructured, to a managed stage, where processes become documented and repeatable. The next level, defined stage, standardises integration processes across projects, followed by the quantitatively managed stage, which focuses on measurable and data-driven improvements. Finally, the optimized stage represents a phase of continuous refinement and innovation through feedback loops and iterative learning (Kassem et al., 2013; Paulk et al., 1993; Succar, 2010). This staged approach enables organisations to identify their current level of integration maturity, develop targeted improvement plans, and benchmark against industry best practices. Assessment dimensions in this study include technology adoption, collaboration practices, information management, and integration across the project lifecycle (Brown et al., 2010; Kassem et al., 2013).

Despite the utility of maturity models, significant limitations persist in existing frameworks. Many current approaches lack comprehensive lifecycle coverage and fail to address the unique challenges posed by OSC. For example, while Costa et al. (2023) provides a holistic framework, it does not sufficiently address BIM integration or cover the entire project lifecycle. Similarly, Chen et al. (2014) highlights the role of digital technologies but lacks a structured maturity assessment framework. The limitations of existing models are further exemplified in Chen et al. (2023), which focuses solely on BIM without accounting for OSC. Additionally, frameworks such as the one proposed by Perera et al. (2023) are tailored to specific regional contexts, such as Australia, limiting their broader applicability in diverse construction environments.

Methodologically, existing studies have adopted varied approaches, including case studies, systematic reviews, and quantitative analyses. For instance, Jiang et al. (2020) employed an ontology-based approach for knowledge representation, while Razkenari (2022) provided strategic roadmaps through maturity modelling techniques. Despite these contributions, many existing studies remain heavily reliant on qualitative analysis, often lacking robust maturity scales. This reliance raises concerns about subjectivity and bias, limiting the generalisability of findings (Ortega et al., 2023b). Furthermore, most studies overlook the lifecycle perspective of OSC and BIM integration, failing to address the challenges that emerge at different stages of project execution.

To address these gaps, this study proposes a maturity assessment framework specifically designed to integrate OSC and BIM across the entire project lifecycle. By identifying integration challenges at the project level and offering a structured maturity assessment model, this research aims to deliver actionable guidelines for enhancing OSC and BIM integration. The staged maturity approach not only provides clarity on the current state of integration but also facilitates a roadmap for progressive improvement (Succar, 2010). This framework is positioned to address critical challenges, align with industry best practices, and ultimately improve project outcomes and overall construction industry performance.

## 8.3 Research Methods

The research employs a mixed-methods approach (explanatory sequential design) (Babaeian Jelodar & Shu, 2021; van Heerden et al., 2023), utilising survey and Linear Regression as the data analysis method for survey data. Additionally, it employs case studies using interviews and document reviews as data collection methods. Combining quantitative and qualitative methods through an online questionnaire and a case study allows for a more thorough exploration of the research questions by overcoming the limitations of using each method independently (Gutiérrez Braojos et al., 2020). The online questionnaire, representing the quantitative phase, was designed to collect numerical data on key variables related to the study. This approach enables data collection from a larger sample size, offering a broader view of the phenomena being studied. The quantitative findings help reveal trends, patterns, and correlations that might not be apparent through qualitative methods alone (Creswell et al., 2003; Ivankova et al., 2006).

Subsequently, the case study method was utilised as the qualitative phase, offering a detailed analysis of instances of OSC and BIM integration. This approach captures the depth of participants' experiences and perspectives, facilitating a contextual understanding of the complexities and subtleties associated with OSC and BIM practices (Gutiérrez Braojos et al., 2020; Tashakkori, 1998). The primary objective is to examine OSC and BIM integration challenges, first at the organisational level, second based on the project life cycle, and finally to develop a maturity framework for the construction sector. By using insights from both surveys and practical case studies, the research ensures there is triangulation (Jonsen & Jehn, 2009a). A two-step method comprising a survey (Step 1), and case studies (Step 2) was designed to meet research goals.

The results from both survey analysis and four case studies were considered to formulate the maturity framework—the survey aimed to gather construction data and enhance comprehension of OSC and BIM challenges. Meanwhile, the case study method was employed to acquire structured and practical insights into OSC and BIM implementation, particularly within the construction domain. To facilitate accurate comparison, the case study methodology focused on integration challenges and mitigation strategies, maturity specifications, and challenges linked with each maturity level across four distinct cases.

### 8.3.1 Survey

A questionnaire was developed as the method of data collection in this research to investigate three distinct, yet interrelated categories of challenges related to OSC and BIM integration (Appendix 5). After a careful review of the existing literature on integration challenges, significant groups of challenges were extracted as the main themes for developing the questionnaire. Multiple peer review sessions involving both industry professionals and academic experts were conducted to review the challenges, and finally, those with similar themes were excluded. The wording and structure of the identified challenges were then revised to enhance clarity and convey their meanings more effectively. Experts all had more than 5 years of experience in OSC and BIM, and the process helped authors to get the face validity of the data.

Three groups of challenges (Implementation Cost, Integrated knowledge Deficit, and Competency and Preparedness) with nine subgroups (as the questions with which challenges were measured) were considered for the survey. The questionnaire consists of two sections: Section A collected general demographic information. The second section was designed to assess whether there were differences in challenge levels across various organisational levels (project, organisation, industry) or if challenges differed at various stages of the project life cycle.

Participants were first asked to rate challenges using a 7-point Likert scale, ranging from 'Not at all important' to 'Extremely important'. Due to the greater variety of items, the 7-point Likert answer structure will perform better than other formats, increasing the likelihood that it will accurately reflect the participants' opinions (Alabi & Jelili, 2023). The Likert scale is utilised to convert qualitative data into quantitative for analysis and to gauge participants' attitudes towards challenges (Taherdoost, 2019). Construct validity for the challenges assessed with Confirmatory Factor Analysis (CFA). It aids in verifying if the selected indicators (items from the survey) accurately reflect the underlying constructs (Hair et al., 2014). A scale measurement was utilised to explore the organisational level of challenges and their project life cycle. The participant was requested to assess the likelihood of challenges occurring at various stages of the project life cycle.

Additionally, they were asked to express their opinion on whether the challenges they encountered were primarily influenced by the project's unique features, the organisation's circumstances, or the industry environment. The careful selection of scale items was intended to enhance the reliability of the survey construct (Dawes, 2008; Joshi et al., 2015). A slider scale of 100-point scale (from 0 to 100) adopted by Gershon et al. (1999) allowed them to determine the degree with precise numbers to which challenges could have happened at a project life cycle and could have been assigned to which organisational levels, where "100" denotes "highly belong to" and "0" denotes "not belong to at all", for project life cycle and organisational level.

Continued rating scales allow researchers to use not only non-parametric methods but also, if the data appears to be approximately normally distributed, apply parametric analysis, which is possible. Moreover, continuous scales are employed for various types of variables and statistical analyses. Ordinal data obtained from bipolar or unipolar Likert-type discrete rating scales are commonly subjected to non-parametric statistical procedures. Nonetheless, parametric statistical analyses may be appropriate for ordinal data showing an approximate normal distribution (Chyung et al., 2018). Linear regression was then applied to analyse the data collected at this stage.

A pilot study was conducted to demonstrate the validity of the survey. A sample of 30 individuals was randomly selected from the population to participate in the pilot study, and the results were used to refine the survey. The survey went through some adjustments in both phrasing and question structure, aiming mainly at reducing the length of some questions. The authors applied statistical analysis to the gathered data to ensure the appropriateness of survey logistics and the effectiveness of the questions (Gaur et al., 2020). Final data were collected from October 2022 to February 2023, and participants were asked to complete the online survey questionnaire through Qualtrics, a web-based survey tool. The selection of companies was based on reviewing their industry profile through their registration via BIMinNZ and OffsiteNZ as the leading industry bodies in New Zealand; this was to ensure their projects incorporated OSC and BIM.

Moreover, companies located only in New Zealand are included in the research scope. In total, 55 companies met the criteria for being in this study data collection process included in BIMinNZ (BIM Acceleration Committee, 2019) and 99 companies with OffsiteNZ (OffsiteNZ, 2023). Companies that were outside of the scope of the research were removed from the population size. As a result, 142 companies were chosen as the targeted population. 450 employees, including project managers, engineers, draftspersons, designers, and architects, work in the companies mentioned, and as a result, the survey link was sent to all of them. Based on the Cochran Formula and the study's modest population size, 113 was determined to be the proper sample size. At the 95% confidence level, the sample size was deemed adequate and reliable within an error range of +/- 8% (Cochran, 1977). Out of the 164 received responses, 116 valid responses were used for analysis.

IBM SPSS Statistics (version 28) was utilised for EFA, a commonly used software for statistical analysis that offers a range of data exploration tools (Morgan et al., 2004). EFA's purpose is to uncover latent constructs within the data by reducing a large number of observed variables into a smaller group of factors. After conducting EFA, IBM Amos (version 26) was used for CFA. Amos is tailored for structural equation modelling and offers a comprehensive framework to test hypotheses regarding the relationships between observed and latent variables (Kline, 1998). The CFA was applied to evaluate the factor structure identified during EFA, ensuring the validity of the factors derived.

### 8.3.2 Case Studies

A method involving exploratory and comparative case studies was employed to develop a maturity assessment framework and validate survey results concerning the use of BIM applications in OSC. Four diverse construction projects, ranging from small-scale buildings to large infrastructure projects, were chosen to understand the broader application of BIM in OSC (Snyder, 2012; Yin & Davis, 2007). These projects were selected based on accessibility to project data and documentation. They were deemed representative of the complex nature of construction and infrastructure projects in various sectors. All projects incorporated OSC elements and utilised BIM in their delivery process. The deep evaluation of the examples gives additional data and precise details on adopting BIM and OSC in construction processes that may be difficult to acquire using other data collection methods (Yin, 2012).

A comprehensive framework of case studies offers insights from different angles and can either support or challenge existing literature findings (Woodside, 2010). Figure 8.1 presents the comparative case study framework used in the current study. A comparative case study framework was established to ensure systematic documentation and meaningful comparison, drawing from Yin's perspective on case study methodology. According to this viewpoint, data must be triangulated through multiple data sources (Yin & Davis, 2007). Replicating logic and upholding the burden of proof are required for the framework, enabling consistent analysis across the four cases (Taylor et al., 2011).

Interviews were conducted both in person and via Microsoft Teams to accommodate geographical distances between some participants and the researcher. A total of five interviews were held, including two design managers (one from a contractor/manufacturer and one from a consultancy), a BIM manager (one from consultant and one from contractor/ manufacturer), and a draftsperson (consultant), all with over 10 years of industry experience. Their expertise provided valuable insights for the research. Interviews lasted approximately one hour each and were transcribed and reviewed carefully to ensure accuracy—indirect questioning during interviews aimed to prompt descriptions of the delivery process involving OSC and BIM (Appendix 6).

Furthermore, documents such as contracts, design files, and meeting notes have been reviewed for each case study. Thematic analysis for interview data and content analysis of collected data for meeting notes and documents were conducted using NVivo 20 software. While NVivo helped structure the data, the researcher conducted the analysis, employing content analysis and cross-referencing key findings with interview data for a thorough understanding of the case studies.

Triangulation was implemented throughout the data collection process to enhance the reliability and validity of the findings by integrating various sources—documents, meeting notes, and stakeholder interviews. This multiple case study design facilitated replication, reinforcing insights across different participants and contexts. The holistic approach was chosen, focusing on the overall OSC and BIM integration process, rather than specific sub-units, as these integration efforts are interdependent and involve multiple stakeholders across the project lifecycle. A comprehensive understanding of strategies and challenges was gained by examining the projects as a whole (Yin, 2009, 2018).

To minimise bias in assessing maturity levels across the case studies, a systematic and transparent evaluation approach was adopted. Data were collected from multiple sources, including interviews, project documentation, and software outputs, to ensure triangulation and validate findings. A standardised assessment framework was applied consistently across all cases, with predefined maturity criteria to guide the evaluation process. Additionally, researcher reflexivity was maintained throughout the analysis to acknowledge and mitigate potential subjective influences, and findings were cross-checked with industry experts where necessary.

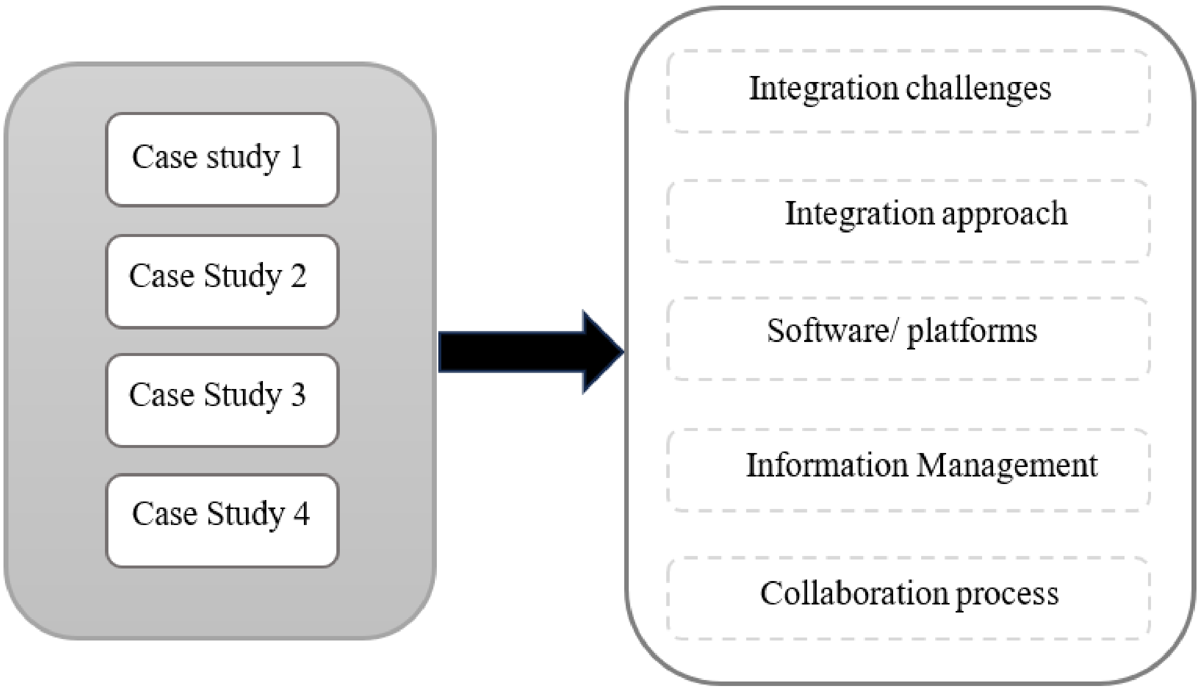


**Figure 8.1:** The case study framework used for comparative case study analysis

The framework dissects project details for each case, encompassing integration challenges, integration approach, software tools/ collaboration platforms, information management process, and collaboration process, which structured case study analysis. Given the highly contextual nature of project data, specific analytical components are necessary to categorise and assess each case accurately. Moreover, without standardised analytical components, comparing cases becomes extremely difficult.

The case selection aimed to pinpoint challenges in implementing OSC and BIM within construction. Additionally, details about the project itself, its contextual background, stakeholders, and the attributes of each maturity level, along with the corresponding challenges, are documented and categorised as typical, comparable data across cases. Document assessments and interviews were the primary data sources for the case studies. The challenges for OSC and BIM integration, as identified in the survey results, serve as the input for the case study. The objective is to validate these challenges and establish their correlation with each level of maturity. Essentially, the case study attempts to offer empirical evidence and insights into how challenges associated with OSC and BIM integration vary across different maturity levels within the construction sector.

## 8.4 Findings and Analysis

This section presents the findings and analysis for both methods applied in this research.

### 8.4.1 Survey

Table 8.1 presents the participant's demographic information. 48 out of 116 participants were engineers, and 36 project managers followed this. Quantity surveyors and drafters were included in the other categories, with 21 out of 116. As shown in the Table 8.1, many respondents have 1-5 years of experience in OSC and BIM. In considering the exclusion of participants with less than 5 years of experience, it's important to acknowledge the potential impact on both Data point and significance Test. Removing these participants would undoubtedly reduce the overall sample size. This reduction in sample size could significantly compromise the statistical power of the analysis.

With fewer data points, the ability of the statistical tests to detect significant differences or associations between variables would be diminished. In essence, the reliability of the significance Test would be compromised, as the statistical power to identify true effects within the data would be weakened. This is the limitation of population in these particular fields in NZ and for generalizability of the research, nonetheless, authors conducted two ANOVA tests to evaluate the significance of any differences between groups (Once for participant with experience and one for BIM experience). The results of the ANOVA test, including the Tukey HSD, Bonferroni, and Games-Howell post-hoc comparisons for variables which were significant are presented in Appendix 7.

**Table 8.1:** Demographic Information of Participants

| Profession/job roles of participants | Sample size | % Of respondents | Years of experience | Experience in Construction | Experience in OSC | Experience in BIM |
|---|---|---|---|---|---|---|
| Engineer | 48 | 41.4% | 0-5 | 33.3% | 22.9% | 37.5% |
| | | | 6-10 | 25% | 66.6% | 47.9% |
| | | | 11-15 | 29.1% | 6.2% | 10.4% |
| | | | 16-20 | 6.25% | 2.08% | 4.16% |
| | | | More than 20 | 6.2% | 2.08% | - |
| Architect | 8 | 6.9% | 0-5 | 12.5% | 37.5% | 62.5% |
| | | | 6-10 | 37.5% | 62.5% | 25% |
| | | | 11-15 | 25% | - | 12.5% |
| | | | 16-20 | 12.5% | - | - |
| | | | More than 20 | 12.5% | - | - |
| Planner | 3 | 2.6% | 0-5 | 33.3% | 66.6% | 63% |
| | | | 6-10 | - | 33.3% | 37% |
| | | | 11-15 | 66.6% | - | - |
| | | | 16-20 | - | - | - |
| | | | More than 20 | - | - | - |
| Project Management | 36 | 31.0% | 0-5 | 22.2% | 33.3% | 42.2% |
| | | | 6-10 | 19.4% | 52.7% | 50% |
| | | | 11-15 | 25% | 8.35% | 2.7% |
| | | | 16-20 | 22.2% | 5.55% | - |
| | | | More than 20 | 11.1% | - | - |
| Other | 21 | 18.1% | 0-5 | 19.05% | 33.3% | 33.3% |
| | | | 6-10 | 28.5% | 52.3% | 38.09% |
| | | | 11-15 | 9.52% | 9.5% | 19.0% |
| | | | 16-20 | 23.8% | 4.7% | 9.5% |
| | | | More than 20 | 19.05% | - | - |

The between-groups variation is significant ($F = 3.984$, $p = .010$) for CH1, suggesting that OSC experience has an impact on responses in CH1. However, post hoc tests (Tukey HSD, Bonferroni, Games-Howell) reveal no significant differences between specific groups, except for some marginal significance. No significant differences are found between groups based on OSC experience for CH2, as indicated by the non-significant F-statistic (F = .415, p = .743) and post hoc tests.

Similar to CH2, there are no significant differences between groups in terms of OSC experience for CH3 (F = 2.007, p = .117), although there is a trend toward significance in the post hoc tests. The between-groups variation is not significant (F = 1.998, p = .118), suggesting that BIM experience may not have a significant impact on responses in CH1. Similarly, there are no significant differences between groups based on BIM experience for CH2 (F = 1.703, p = .171). Once again, no significant differences are found between groups in terms of BIM experience for CH3 (F = .134, p = .940).

Moreover, a Randomized Control Trial (RCT) methodology has been applied to gather data, ensuring a rigorous approach to evaluating the intervention's impact. This ensures the selected sample is representative of the expert population (Chalmers et al., 1981; Spillane et al., 2010). By utilising this method, the researchers aimed to mitigate potential biases and establish a higher level of internal validity within their study design. Additionally, the utilisation of inferential statistics further strengthens the reliability and validity of the findings, allowing for the generalization of results beyond the sample population. Probability sampling techniques were implemented to enhance the generalizability of the research findings to the broader population, thus increasing the external validity of the study.

Overall, the combination of RCT methodology, inferential statistics, and probability sampling techniques contributes to a robust research framework that prove both the fairness of experiments and the generalizability of findings. Three factors for challenges were measured with different questions. Implementation Cost is measured by the high cost of training and the high cost of OSC and BIM implementation derived from the literature. Integrated Knowledge Deficit as the second factor was measured through lack of transparent practices during offsite manufacturing, lack of appropriate education and training, lack of planning (including resources and scheduling), and inadequate flow of information and periodical meetings. Moreover, the last factor was measured by the low level of understanding of OSC and BIM integration, industry preparation to deliver BIM, lack of standards and guidelines, lack of clear orientation or adequate practical studies, and lack of knowledge, limited skills, and experience.

The statistics from the CFA (Table 8.2) were analysed using recognised model fit thresholds. CMIN/DF values between 1 and 3, CFI > .95, SRMR< .08, RMSEA< .06, and PClose > .05 all indicate an excellent fit. Alternatively, a fit is considered satisfactory if it falls within the range of CMIN/DF between 3 and 5, CFI between .90 and .95, SRMR between .08 and .1, and RMSEA between .06 and .08, and PClose between .01 and .05 (Hu & Bentler, 1999). The latent variables' convergent validity was assessed using the Average Variance Extracted (AVE) measure, which exceeded .5 (Hair et al., 2010).

For validity, construct reliability (CR) values greater than .6 are preferred. A test of the HeteroTrait-MonoTrait (HTMT) ratio of correlations was performed using an AMOS plugin to measure discriminant validity (Gaskin & James, 2019). The results showed that none of the correlations surpassed the .85 threshold, indicating that discriminant validity was supported (Hair et al., 2010). The updated scale's reliability, as well as its convergent and discriminant validity, were also assessed. Confirmatory Factor Analysis (CFA) with IBM SPSS AMOS 28 demonstrated excellent fitness: $\chi2(24) = 17.124$, $p < .001$, CFI = .66, SRMR = .05, RMSEA = .000, PClose = .964) generated three factors with loadings ranging from .47 to .84. Maximum likelihood estimation allows authors to obtain meaningful results with relatively small sample sizes (Kline, 2013).

Linear regression is a widely used technique in predictive modelling and data analysis that helps examine the additive contribution of various independent variables in explaining or predicting an outcome variable. This method allows researchers to assess the impact of multiple predictors on a dependent variable in a systematic manner. In this study, regression analysis was used to explore the relationships between various challenges and their associations with different organisational levels, including project, organisation, and industry (Table 8.2).

Three separate regression models were applied, each focusing on a distinct dependent variable. The primary aim was to determine which challenges (CH1, CH2, and CH3) are most relevant to these contexts, with the goal of understanding how these challenges influence OSC and BIM integration at different organisational levels. The variables for the regression equations were selected based on statistical criteria, and tests were conducted to assess their significance and impact on the dependent variables (Keller, 2022; Pallant, 2020).

This approach was not used for prediction but rather for relationship analysis, as it aimed to understand the nature and strength of associations between challenges and their impact on integration at various levels. The method was particularly suitable for this research, as it allowed for the examination of complex interactions between multiple factors influencing integration in OSC and BIM at different organisational stages.

First, regression analyses were used to explore the relationship between various challenges and their associations with different organisational levels, including project, organisation, and industry (Table 8.2). Three separate models were used for each focusing on a distinct dependent variable. The primary aim was to determine which challenges, represented as predictors (CH1, CH2, and CH3), are most relevant to these contexts.

The regression analysis of "Project" reveals that the model is statistically significant, as indicated by an F-statistic of 3.994 with a p-value of .01. This model explains approximately 9.7% of the variance in the dependent variable. Among the individual predictors, CH2 appears to have a positive (coefficient of .301) and significant impact (P-value= .033) on "Project," suggesting that a one-unit increase in CH2 results in a .324-unit increase in the dependent variable. Conversely, CH1 has a negative (coefficient of -.268) and significant impact (P-value= .019), indicating that a one-unit increase in CH1 leads to a decrease of .269 units in "Project." Lastly, CH3, with a coefficient of .066, shows a positive but non-significant (P-value= .632) effect on "Project." These findings suggest that the predictors have varying influences on "Project," with CH2 and CH1 being the most prominent factors.

In the analysis of the "Organisation" variable, the regression model demonstrates statistical significance with an F-statistic of 3.62 and a p-value of .015. The model accounts for approximately 8.8% of the variability in the organisation variable, as reflected by the R-squared value (.064). Within the predictor variables, "CH3" emerges as a significant (P-value= .002) and positively influential factor, with a coefficient of .452. Conversely, "CH2" demonstrates a significant negative effect (P-value= .044) with a coefficient of -.288. "CH1" does not exhibit a statistically significant effect (P-value= .14). The regression analysis results for the "Industry" variable suggest that the model comprised of is not statistically significant, as indicated by an F-statistic of 2.046 and a p-value of .112, exceeding the standard significance level. The model accounts for only 5.2% of the variance in the industry variable, with an adjusted R-squared of .027. Among the individual predictors, "CH3" stands out with a statistically significant (P-value= .018) and positive influence. In contrast, "CH1" and "CH2" do not exhibit statistically significant effects on the industry variable, with P-values of .638 and .173, respectively.

The second regression analysis is related to the project life cycle phases, and the objective is to investigate which challenges happen at what project life cycle phase (Table 8.2). The results of the regression analysis for the "Initiation" phase reveal that the model, composed of predictors CH1, CH2, and CH3, is not statistically significant in explaining the variance within the dependent variable, as indicated by a non-significant F-statistic of 1.33 with a p-value of .268. The model accounts for a mere 3.4% of the variation with an adjusted R-squared of .009, reflecting the model's simplicity. None of the individual predictors, including "CH1," "CH2," and "CH3," demonstrate statistically significant effects. "CH2" appears to have a marginally significant negative impact (P-value= .049).

The results of the regression analysis for "Planning" are highly statistically significant in explaining the variation within the dependent variable, with a robust F-statistic of 9.428 and a p-value of <.001. Among the predictors, "CH1" demonstrates a significant (P-value= .000) negative impact, with a coefficient of -.416, implying that an increase in "CH1" results in a reduction of .411 units in the planning phase. Conversely, "CH2" demonstrates a significant positive influence (P-value= .005), with a coefficient of .384. However, "CH3" does not appear to show a statistically significant effect on the dependent variable.

The results of the regression analysis for the dependent variable "Execution" reveal a statistically significant model, as denoted by an F-statistic of 6.646 with a highly significant p-value of <.001. Among the individual predictors, "CH1" shows as a significant (P-value= .001) and positively influential factor, with a coefficient of .378. In contrast, "CH3" exhibits a significant negative effect (P-value= .043) with a coefficient of -.223. "CH2" does not demonstrate a significant effect (P-value= .738). The regression analysis results for the "Monitoring & Controlling" variable indicate that the model is not statistically significant, as evidenced by an F-statistic of 2.274 with a p-value of .084, greater than the common significance threshold of .05. Among the predictors, "CH3" stands out as a statistically significant (P-value= .015) and positively influential factor, with a coefficient of .297.

In contrast, "CH2" exhibits a marginally significant negative impact (.083) at $p < .05$ level, a coefficient of .267. "CH1" does not show a statistically significant effect (P-value= .219). The results of the regression analysis for the "Close Out" phase suggest that the model is not statistically significant in explaining the variance within the dependent variable, as indicated by an F-statistic of 2.211 with a p-value of .091. "CH1" and "CH3" do not show statistically significant effects. However, "CH2" demonstrates a statistically significant negative effect (P-value=.021).

**Table 8.2:** CFA structural factor loading matrix for variable study items

| Factors | Items | CFA | Construct Validity Measurements | | | | HTMT Measurements | | | Dependent Variable | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | α | CR | AVE | MSV | CH1 | CH2 | CH3 | P | O | I | In | Pl | Ex | MC | Cl |
| CH1 (Implementation Costs) | C7: High cost of training | .72 | .636 | .644 | .476 | .296 | | | | .019** | .14 | .638 | .564 | .000*** | <.001** | .219 | .154 |
| | C9: High cost of OSC and BIM implementation | .66 | | | | | | | | | | | | | | | |
| CH 2 (Integrated Knowledge Deficit) | C1: Lack of transparent practices during offsite manufacturing | .63 | .761 | .773 | .534 | .545 | .538 | | | .033* | .044* | .173 | .049* | .005** | .738 | .083* | .021* |
| | C4: Lack of appropriate education and training | .77 | | | | | | | | | | | | | | | |
| | C18: Inadequate flow of information and periodical meetings | .78 | | | | | | | | | | | | | | | |
| CH3 (Competency & Preparedness Deficit) | C13: The industry is not prepared to deliver BIM. | .47 | .804 | .826 | .554 | .545 | .526 | .735 | | .632 | .002** | .018* | .196 | .220 | .043** | .015* | .396 |
| | C14: Lack of standards and guidelines | .84 | | | | | | | | | | | | | | | |
| | C16: Lack of clear orientation or adequate practical studies | .79 | | | | | | | | | | | | | | | |
| | C17: Lack of knowledge, limited skills, and experience | .82 | | | | | | | | | | | | | | | |
| Intercept | | | | | | | | | | <.001** | <.001** | .000*** | <.001** | .000*** | <.001** | <.084 | <.001** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| F | 3.994 | 3.62 | 2.046 | 1.33 | 9.428 | 6.646 | 2.046 | 2.211 |
| ∆R | .097 | .088 | .052 | .034 | .202 | .151 | .052 | .056 |
| R2 | .097 | .088 | .052 | .034 | .202 | .151 | .052 | .056 |
| R2adj | .072 | .0064 | .027 | .009 | .180 | .128 | .027 | .031 |
| Sig | .01** | .015* | .112 | .268 | .001** | .001** | .112 | .091 |

Note: CR: Construct Reliability; AVE: Average Variance Extracted; HTMT: HeteroTrait-MonoTrait Ratio of Correlations; *: p < .05; P: Project, O; Organisation; I: Industry; In: Initiation; Pl: Planning; Ex: Execution, MC: Monitoring and Controlling, C: Closeout

### 8.4.2 Case Studies

In the current research, four projects have been chosen to investigate, ranging from small residential buildings to complex infrastructure projects. Each case study was reviewed first to verify the challenges resulting from survey analysis and second to help develop the OSC and BIM maturity model. Table 8.3 presents a brief description of the chosen projects, project type and their life cycle.

**Table 8.3:** Case studies description

| Project Description | Description | Project type | Project life cycle |
|---|---|---|---|
| Case 1 | Case 1 is a completed water project that runs through the Waikato and Auckland districts. Auckland's fast growth has put strain on the city's water supply network. Watercare, the organisation in charge of water supply management, has employed the Enterprise Model (EM) to handle this issue. The programme was launched to improve the treated water supply from the Waikato River to Auckland by 50 million litres daily. To assure the programme's success, many Workfront were involved, including Phase 1 in Tuakau and a Booster Pump Station in Papakura. | Large infrastructure | Completed |
| Case 2 | An in-progress commercial building in the South Island's west part. It is a single-story building located in Section 39 Block 1 Maori Reserve & Section 41 block, 1 Maori Reserve & Section 40 and Section 42 Block 1, Greymouth or Mawhera 21 Maori Reserve. | Medium size-commercial building | Under construction |
| Case 3 | The Ministry of Primary Industries - Interim Post Entry Quarantine (MPI-IPEQ) facility project seeks to build a dedicated facility for the quarantine of imported plants in accordance with New Zealand's biosecurity laws. Twelve connected greenhouses, a headhouse, a corridor between the headhouse and the greenhouses, a mechanical plant room space, and a parking area are among the many components that need to be designed and built for this project. The headhouse takes up around 240 square metres, while the greenhouses and the corridor take up about 500 square metres. Maintaining compliance with New Zealand's PC3 quarantine regulation is crucial for the institution. | Medium size-Quarantine facility | Closeout |
| Case 4 | A two-story residential building located in wellington has been planned to take advantage of and celebrate its elevated position, providing guidance for the subdivision and development of a new site. | Small size-residential building | Design and manufacture |

Based on preliminary observations, it was found that all the case studies used BIM technology during the OSC component design, manufacture, and installation processes. The case studies revealed distinct levels of integration maturity within the observed projects. Each level is characterised by specific attributes, demonstrating the extent to which OSC and BIM technologies are adopted and integrated. Table 8.4 provides the key findings derived from the case studies analysis. Findings indicate the existence of different levels of maturity, which tend to increase as collaboration and understanding of integration improve. Each level possesses distinct characteristics that determine the maturity level of each case, progressing from initial stages to optimization.

The development of the OSC-BIM integration maturity model was guided by insights drawn from the case studies, which served as a foundational empirical basis. The case studies provided a detailed examination of how OSC and BIM technologies were implemented across different projects, revealing varying degrees of integration maturity. Through these observations, patterns emerged that highlighted distinct attributes associated with different maturity levels, including technological adoption, process standardisation, and stakeholder collaboration.

The decision to adopt a five-level maturity model was based on both theoretical underpinnings and empirical observations. Existing literature on maturity models, such as those by Paulk et al. (1993) and Succar (2010), commonly employs five levels to represent incremental stages of growth and development. A five-level structure offers sufficient granularity to capture meaningful differences between integration stages while avoiding unnecessary complexity that could arise from additional levels. A three-level model would have oversimplified the nuanced variations observed across projects, while a seven-level model might have introduced excessive detail, making the model less practical for implementation.

The development of the level scales was an iterative process, informed by both literature and empirical data from the case studies. Initially, key themes and attributes observed in the case studies were categorised into preliminary stages, reflecting varying degrees of OSC-BIM integration. These stages were then aligned with established maturity model frameworks (Jung & Joo, 2011; Succar, 2010) to ensure conceptual consistency. Each level was carefully defined, with clear distinctions to avoid overlap and ensure logical progression from one stage to the next. Validation was achieved through cross-referencing with industry benchmarks and expert feedback to ensure that each level accurately represented an achievable and measurable state of maturity.

The content of Table 8.5 was developed through a synthesis of insights derived from the case studies and existing maturity model literature. Key integration attributes—such as technology adoption, stakeholder collaboration, process standardisation, and data management—were mapped across the five maturity levels. Case study findings were instrumental in defining specific characteristics for each level, while theoretical models provided additional guidance to refine and validate these attributes. The table was further reviewed and refined based on feedback from focus group discussions and expert validation sessions, ensuring coherence, clarity, and applicability to real-world OSC-BIM integration scenarios. This structured approach ensured that the maturity model is both empirically grounded and theoretically robust, providing a practical tool for assessing and improving OSC-BIM integration in construction projects.

**Table 8.4:** Case studies comparison results

| Criteria | Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|---|
| Integration challenges | Time constraint. Cultural challenges due to introducing new digital approach. Technical as a unique geospatial system needed to be created to support interoperability challenges between more than seven design authoring tools and coordination platforms. | Stakeholder's commitments. Misconceptions about BIM. Lack of centralised coordination. Client understanding and acceptance | Inadequate level of details, accuracy of 3D models. Lack of clash detection and inaccurate or missing material specifications. Cost implications in case of clash. | Financial considerations, managing cash flow. Upfront costs for overseas orders. Ensuring accurate measurements and coordination during on-site manufacturing. Compliance, and adherence to guidelines. |
| Integration approach | Recognising the need to coordinate multiple sources of information and disciplines, the team plans for integrating digital information from different organisations and disciplines into a collaborative environment. | Early contractor involvement to define scopes of work clearly, agreement among all parties involved in the project, following client agreement and contractual obligations, | Role-based communication channels, regular coordination meetings, standards such as the Post Entry Quarantine for Plants (PEQ.STD) are followed, and a BIM Execution Plan (BEP) is implemented for consistency and compliance. | Coordinating various components and stakeholders. Translating 2D drawings into 3D models and confirming alignment with consultants' components. Frequent engagement with stakeholders. |
| Software tools/ collaboration platforms | Procore, Aconex, or BIM 360, Revisto platform for visual collaboration, Revit | Word, Revit, Dropbox | Aconex, BIM 360, Revit | Revit |
| Information management process | ISO 19650 for information management. Creating a federated environment or that integrated environment which everyone had access, and it was updated overnight. Three simply colour-coding system used to show the status of the elements. | Using a shared system for file management internally. Sharing files with clients through cloud-based platforms. Having a database of information from previous projects, especially for mass timber. | Agreed change management process. Design files exchanged using BIM360. Construction files managed through Aconex. File formats include RVT for BIM data and PDF for other documents. BIM manager coordinates design modifications. Financial implications discussed with client representatives. | Having 3D models for client to give them understanding of the project. |
| Collaboration process | Adopted a digital integration strategy. Trial and error process to establish a robust hub. Real-time access to the latest information for on-site construction. | Collaborating closely with manufacturers, top drawers, and suppliers to understand needs and implement changes. | Having a virtual preview of how everything fits together before any actual work or manufacturing happens. | Collaboration occurs with internal and external stakeholders at project milestones. Client interaction happens typically on a weekly to monthly basis. Supplier engagement is frequent, especially with window and door manufacturers. Internal meetings occur regularly. |

Table 8.4 summarises the information based on the framework in Figure 8.1. A comparison is made using the five units of analysis that are part of the case study framework to show the

theoretical replication logic necessary for the case studies. The background of each case is divided into the units of analysis documented in each row of Table 8.4 to reach definitive results (Mohandes et al., 2023). A comparison of four distinct cases reveals challenges, integration approaches, software tools, and information management methodologies within the construction domain. Integration challenges varied from time constraints and cultural barriers to technical challenges like creating interoperable geospatial systems in Case Study 1.

In Case 2, stakeholder commitments and misconceptions about BIM posed obstacles to understanding and implementing digital approaches. At the same time, issues such as the lack of centralised coordination and inadequate 3D model details were also identified. In both Case 3 and Case 4, cost implications arose due to various factors, aligning with the challenges identified through surveys. The technical and cultural challenges such as lack of details, accuracy of models, lack of material specification and challenge of introducing a new digital approach to the team were some challenges mentioned during case study data collection as well.

Integration approaches across the cases demonstrated the effort to improve collaboration and information exchange. Approaches included coordinating multiple sources of information into collaborative environments, early contractor involvement, role-based communication channels, and translating 2D drawings into comprehensive 3D models. These approaches showed the importance of proactive coordination and alignment among stakeholders to mitigate integration challenges effectively. Additionally, software tools and collaboration platforms such as Procore, Aconex, BIM 360, Revit, and Dropbox were instrumental in facilitating seamless communication and data management across project teams.

Information management processes varied from employing ISO 19650 standards to creating federated environments and utilising cloud-based platforms for file management and sharing. A consistent theme emerged regarding the importance of real-time access to accurate project data and the adoption of standardised protocols for data exchange. Collaboration processes emphasized close engagement with stakeholders, virtual previews for design validation, and regular client and supplier interactions. These collaborative efforts fostered transparency, enhanced communication, and facilitated informed decision-making throughout the project lifecycle. In essence, effective integration, coupled with robust collaboration and information management practices, emerged as critical pillars for successful construction project execution in diverse contexts.

Based on the case study analysis, integration maturity levels were developed to illustrate the characteristics introduced at each level of integration. These levels assist stakeholders in understanding their current situation and determining the necessary steps to progress to higher levels. The maturity levels begin with the initial stage, characterised by a low level of understanding and awareness, which gradually increases as projects advance. Various activities, including the integration approach, information management process, and collaboration, play vital roles in shaping these levels and guiding progress.

The integration maturity levels provide a framework for assessing the evolution of integration practices within the organisation. They serve as a roadmap for identifying areas of improvement and implementing strategies to enhance integration capabilities. As projects move through the maturity levels, stakeholders gain deeper insights into the benefits of integration and the importance of cohesive collaboration and efficient information management processes. Ultimately, the integration maturity model serves as a tool for driving continuous improvement and achieving higher levels of integration effectiveness. Table 8.5 presents the characteristics of each maturity level.

**Table 8.5:** OSC and BIM Integration Maturity Model Characteristics

| Level | Characteristics |
|---|---|
| Initial | Ad-hoc adoption of OSC and BIM technologies.<br>Limited awareness and understanding of integration challenges.<br>Projects are reactive, with minimal planning for OSC and BIM.<br>Lack of optimized guidelines and clear orientation. |
| Managed | Basic understanding of OSC and BIM integration challenges.<br>Some project-specific planning for OSC and BIM.<br>Limited communication and collaboration among stakeholders.<br>Integration activities are managed on a project-by-project basis. |
| Defined | Clear project-level integration strategies and plans.<br>Improved communication and collaboration among stakeholders.<br>Proactive identification and mitigation of integration challenges.<br>Standardised guidelines for specific phases of the project life cycle. |
| Quantitatively Managed | Integration activities are measured and quantified.<br>Continuous improvement initiatives are in place.<br>Key performance indicators (KPIs) are used to assess integration success.<br>Lessons learned are systematically documented and shared. |
| Optimized | Integration activities are continuously optimized.<br>Innovation and advanced technologies are explored for improvement.<br>Industry best practices are consistently applied.<br>Integration strategies are adaptive and responsive to changing needs. |

## 8.5 Discussion

The first objective aimed to determine the organisational levels to which various challenges are attributed (project, organisation, industry). Furthermore, the second objective was to explore the challenges that could arise during different project life cycles.

### 8.5.1 Organisational Levels and Project Lifecycle Challenges

*Implementation Costs Challenge*

According to the linear regression results presented in Table 8.2, Implementation Costs, including the high costs of OSC and BIM implementation, along with the high cost associated with training, were found to be primarily linked to the project level and happen at planning and execution phases. Small market size and geographic distance from international markets can impact the implementation cost (Kordestani Ghalenoei et al., 2022a; Kordestani et al., 2022). This geographical circumstance affects the transportation of components and materials, often leading to project delays and an overall increase in costs and cost overrun (Halaszovich &

Kinra, 2020; Olaniran et al., 2015). Therefore, it is necessary to consider implementation costs during project planning, as these costs can significantly impact subsequent project phases. During the execution phase, projects demand specific skills and knowledge, requiring employee education, which needs both time and expenses. However, over time, the workforce may leave the company in pursuit of better opportunities elsewhere in other companies or even overseas, and all the knowledge will be taken with the person as they are reluctant to share the knowledge (Nauman et al., 2022). As a result, the training investments made by the company in its workforce must remain constant, which causes a challenge for projects involving OSC and BIM.

*Integrated Knowledge Deficit Challenge*

The integrated Knowledge Deficit group of challenges for OSC and BIM integration could be assigned to project and organisation levels and happen at different phases of the life cycle (Table 8.2). A lack of transparent practices during offsite manufacturing could happen due to a lack of communication and inadequate information sharing, reducing visibility, particularly during initiation and close-out phases. In the initiation phase, the feasibility study requires more detailed and accurate information on the available components and materials (Guo & Zhang, 2022). The challenge of inadequate education and training leads to a workforce deficiency, affecting the project's quality during the initiation and close-out phases. Inadequate planning, including resource allocation and scheduling mismanagement, further complicates project management. Lastly, the inadequate flow of information and infrequent meetings disrupt project communication and coordination during the initiation, planning, monitoring, controlling, and close-out phases (Kordestani Ghalenoei et al., 2022a; Nauman et al., 2022). These challenges contribute to the overall complexities of OSC and BIM integration across various project phases.

At the organisation level, firstly, the lack of transparent practices during offsite manufacturing can result in inefficiencies and miscommunication throughout the organisation, causing delays and added costs. These inefficiencies are combined by the temporary and one-off nature of many construction projects, making it challenging to establish standardised procedures (Guo & Zhang, 2022; Halaszovich & Kinra, 2020). Furthermore, the lack of appropriate education and training impedes the development of a skilled workforce, leading to knowledge gaps and potentially costly errors (Nauman et al., 2022). The lack of proper planning, including resource allocation and scheduling, often leads to the wrong allocation of resources, with adverse effects on project success. Additionally, the inadequate flow of information and infrequent meetings within organisations worsen these challenges, delaying effective communication and coordination at critical project phases. In sum, addressing these organisational-level challenges is essential to enhance the efficiency, cost-effectiveness, and overall success of OSC and BIM integration projects, where the integration of knowledge and best practices is important.

*Competency and Preparedness Challenge*

Competency and Preparedness are the last challenges for OSC and BIM integration based on the analysis of this study, which happens during the execution, monitoring, and controlling phases (Phase 3 and 4) of the project life cycle (Table 8.2). The lack of standardised guidelines creates misunderstanding and inefficiencies as organisations cope with inconsistent practices, resulting in inappropriate OSC and BIM adoption (Darlow et al., 2021). Simultaneously, the lack of clear orientation and limited practical studies leaves organisations unprepared to navigate the complexities of these methodologies, resulting in project delays and increased costs (Kordestani Ghalenoei et al., 2022a). Furthermore, the lack of knowledge, skills, and experience at the organisational level mixes these issues, as organisations often want the necessary expertise to implement OSC and BIM effectively. This collection of challenges, including low understanding, industry readiness, lack of standards, insufficient orientation, and limited knowledge and skills, decreases the Competency and Preparedness of organisations and the construction industry for the integration of OSC and BIM.

Another level to which this challenge belongs is the industry level. The low level of understanding of OSC and BIM integration within the industry often results from the absence of standardised guidelines and clear orientations. This lack of a comprehensive framework contributes to a broken environment where industry professionals struggle to understand the full potential of these technologies. The consequence is a limited ability to control the advantages of OSC and BIM effectively. In addition, industry readiness to deliver BIM is impeded by a lack of standardisation and guidelines, further reducing successful integration (Kordestani Ghalenoei et al., 2022a).

Insufficient practical studies and examples will multiply the issue, as professionals find themselves with limited practical guidance and real-world cases to look at, which increases the challenges in the execution and monitoring phases. Lastly, a deficiency in knowledge, limited skills, and experience within the industry, particularly in the execution, monitoring, and controlling phases, is a critical challenge, resulting in project delays and higher costs (Olaniran et al., 2015). These challenges show the need for a more structured and knowledge-improved system to enhance Competency and Preparedness within the OSC and BIM integration.

The result of the research structured framework presented in Figure 8.2. The framework depicts the organisational level, including project, organisation, and industry, on the left side. The horizontal view demonstrates the project life cycle, starting from initiation and finishing with the close-out phase. Planning, execution, monitoring, and controlling happen between orders. Challenge number one belongs to the project level only and happens in the planning and execution phases. While challenge number two belongs to both project and organisation levels and occurs across the project life cycle, expect execution. The last group of challenges related to Competency and Preparedness happen at two phases of the project life cycle: execution and monitoring and controlling. The challenge is associated with organisation and industry levels.

Figure 8.2 shows that two out of three groups of challenges belong to more than two organisational levels, stating the interrelations between the levels and challenges. The presented framework offers project managers a structured approach to understanding and addressing the critical challenges associated with OSC and BIM integration across different phases of the project life cycle and organisational levels. This framework enables project managers to identify critical control points, allocate resources effectively, develop risk mitigation and contingency plans, foster communication and collaboration among stakeholders, which the project team need to succeed (Ninan et al., 2019), establish project success metrics, and promote a culture of continuous improvement. By using this framework, project managers can enhance their ability to proactively manage the challenges, ultimately leading to more successful OSC and BIM integration projects and benefiting all project stakeholders.

| | Initiation | Planning | Execution | Monitoring & Controlling | Close Out |
|---|---|---|---|---|---|
| **Project** | Integrated Knowledge Deficit | Implementation Costs<br>Integrated Knowledge Deficit | Implementation Costs | Integrated Knowledge Deficit | Integrated Knowledge Deficit |
| **Organisation** | Integrated Knowledge Deficit | Integrated Knowledge Deficit | Competency & Preparedness Deficit | Integrated Knowledge Deficit<br>Competency & Preparedness Deficit | Integrated Knowledge Deficit |
| **Industry** | | | Competency & Preparedness Deficit | Competency & Preparedness Deficit | |

**Figure 8.2:** OSC & BIM integration challenges across project life cycle and organisational level

### 8.5.2 OSC and BIM Maturity Assessment Framework

The refined model presented in Figure 8.3 offers an in-depth perspective on the maturity of OSC and BIM integration, establishing a holistic understanding by linking characteristics and challenges to case studies. As projects progress towards maturity, strategies are required to address challenges and foster enhanced collaboration in integrating OSC and BIM within the construction sector. The model outlines explicitly the maturity levels of integration in OSC projects employing BIM, each exhibiting distinct characteristics. Notably, as the maturity level increases, so does the degree of integration. The subsequent section of the model provides information on integration challenges derived from surveys and validated through case studies. This section examines each challenge explicitly within the context of case studies, elaborating on associated challenges at each maturity level. This comprehensive approach not only explains how integration is evolving but also provides a detailed understanding of the challenges, helping create practical strategies and enhancements for better integration of OSC and BIM in the construction industry.

Moreover, it demonstrates the position of each case study on the maturity assessment framework based on their approach and processes during the project life cycle, considering both the present state and the move towards their maturity level (Liang et al., 2016). Based on the data, Case 4 exhibits a low level of integration for OSC and BIM due to the small size of the project. BIM was primarily used for interacting with manufacturers and developing 3D models for client presentations rather than for clash detection or information management. A low level of understanding among stakeholders is a distinct factor at this stage, with limited data exchange and no planning for BIM use in the OSC delivery process (Kreider & Messner, 2013).

Considering the defined characteristics and processes, this integration of OSC and BIM is at the initial level. At this stage, fundamental needs must be addressed, and transitioning to another level may entail significant changes in organisational operations and require more resources (Razkenari & Kibert, 2022). In Case 2, stakeholders demonstrate a better understanding of integration, with the necessity of a centralised person highlighted as a critical factor for achieving integration in their project. They adhere to internal standards, sharing details within their organisation, which defines stage 2 of "Cross-disciplinary model coordination" (Seng, 2012). Based on the case study analysis, this project is at the early stage of maturity level 2 (Managed).

Case 3 is transitioning from Managed (Level 2) to Defined (Level 3). At this stage, operational technology systems show improving connectivity and interoperability, although full integration across layers has not yet been achieved. Standardisation enhances vertical communication in operations and control systems, supported by cloud services facilitating remote device connectivity (Razkenari & Kibert, 2022). While various platforms have been used for sharing and exchanging design and construction data among stakeholders, challenges such as inaccurate levels of details and cost implications in clashes between contractors persist.

However, using BIM for clash detection has reduced many clashes in their project thus far (Suliman & Rankin, 2021).

Among the four cases, only Case 1 demonstrates a higher level of integration of OSC and BIM. The project, scheduled for completion within one year, required collaboration with over ten different sources of data from various platforms and design authoring tools. Accessing the latest information through the "Digital Engineering" platform ensured that gaps were eliminated, enabling construction teams to begin on-site work as soon as the design phase commenced. However, digitally sharing information posed a significant risk if the verification process was not completed accurately. The team ensured that the design was fully coordinated and constructible to ensure successful prefabrication. The actions taken by stakeholders during the project transitioned it from Defined to Quantitatively Managed at the maturity level (Razkenari & Kibert, 2022).

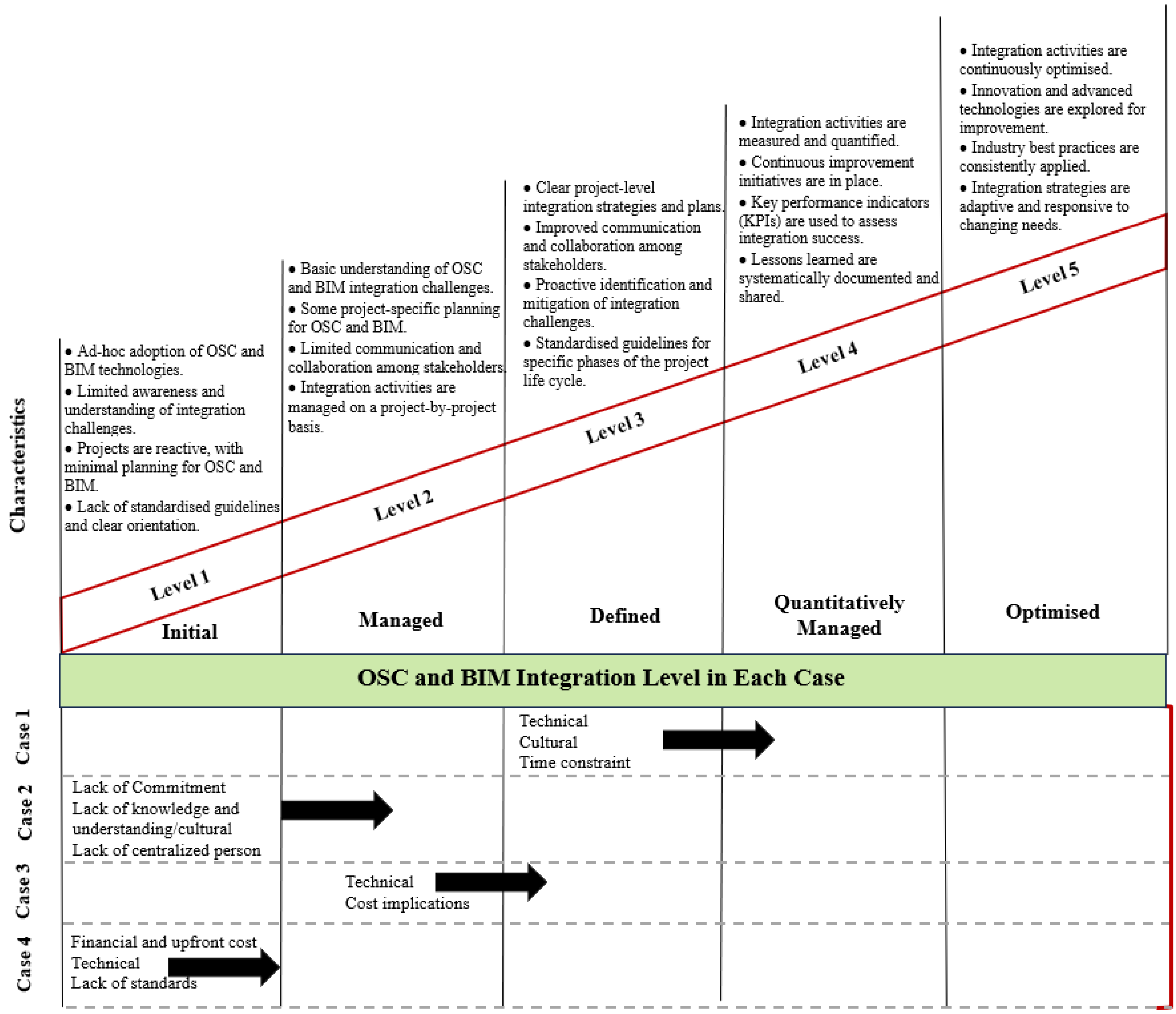


**Figure 8.3:** OSC and BIM Maturity Assessment Framework in the Construction Industry

### 8.5.3 Assessment Framework Generic Recommendation

Effective collaboration is paramount for successful integration between OSC and BIM technologies, with proactive coordination among stakeholders crucial for addressing integration challenges. Establishing role-based communication channels and conducting regular meetings are essential for ensuring clarity in project scopes. Maximising the use of modern software tools and collaboration platforms, such as Procore and Revit, enhances communication and data management, empowering stakeholders to make informed decisions. Efficient information management, including real-time standardised protocols, facilitates transparency and informed decision-making and informed decision-making. Strong collaboration processes, such as virtual previews and regular interactions with clients and suppliers, foster trust, and cooperation, driving project success. By implementing these recommendations, project teams can enhance OSC and BIM integration maturity, delivering value to stakeholders.

### 8.5.4 Case by Case Recommendation

In examining integration requirements across various project scales, each context presents its own set of unique challenges and complexities showing that using BIM in OSC delivery process could be more applicable for larger projects based on their capability and resources. Through the analysis of four distinct cases, insights into integration dynamics prevalent in small, medium, large, and infrastructure projects have been gleaned. In small-scale projects (Case 4), challenges often stem from financial constraints and the introduction of new digital methodologies. Overcoming them involves tasks such as converting 2D designs into 3D models and utilising tools like Revit for streamlined communication and data management. This two-story residential building project reflects a small-scale construction project with a low OSC level.

Medium-scale projects (Cases 2 and 3) introduce different integration concerns, including technical challenges during the design phase. Effective coordination among stakeholders is pivotal, supported by the implementation of role-specific communication channels and BIM Execution Plans (BEP). Collaborative endeavours with clients and suppliers, facilitated by platforms like Aconex and BIM 360, ensure transparency and regulatory adherence. Case 2, is currently under construction, represents a medium-sized with an OSC level ranging from low to moderate. Integration challenges include stakeholder commitments and centrelised coordination, addressed through early contractor involvement and clear definition of scopes of work. The project's collaboration process involves a trial-and-error approach to establish effective digital integration, supported by software tools like Word, Revit, and Dropbox.

Case 3, with an OSC level ranging from low to moderate includes challenges like ensuring compliance with New Zealand's quarantine regulations and maintaining coordination among various components. The project's integration approach embassies role-based communication channels and adherence to standards like the BEP. Collaboration occurs with internal and external stakeholders, including frequent engagement with manufacturers and suppliers.

Large-scale projects (Case 1) face with a variety of challenges, such as time constraints and stakeholder commitments. Key strategies here include the implementation of interoperable geospatial systems and early contractor involvement. Software tools like Revit and Dropbox aid in communication and file management, vital components of successful collaboration. This project, focused on enhancing Auckland's water supply, represents a large-scale infrastructure initiative with an OSC level ranging from moderate to high. Integration challenges were significant, including the need to develop a unique geospatial system to support interoperability among multiple design authoring tools. The project's integration approach involved coordinating digital information from various sources into a collaborative environment, facilitated by software tools like Procore, Aconex, and Revit. The project's completion signifies successful management of time constraints and technical complexities.

## 8.6 Conclusion

To achieve the study objectives, challenges derived from the literature were analysed to investigate their organisational level and project life cycle using linear regression analysis. CFA was conducted to assess the construct validity of the data. Four case studies have been reviewed to develop the maturity assessment framework. Five levels of integration maturity were identified, and based on their approach, each case level was recognised as well. It is concluded that Implementation Cost could happen at early stages, while Integrated Knowledge Deficit could happen almost at all phases. Results showed that Competency and Preparedness are mostly related to the execution and monitoring phases. OSC and BIM integration challenges could spread across the whole life cycle; however, depending on the nature of the challenges and sub-challenges, they could have been different and require specific strategies, too. Research results showed that the lack of knowledge is consistent; regardless of whether the project is in the early stages or near completion, specific skills and knowledge are always necessary to succeed in the integration.

On the other hand, it is crucial to consider at what organisational level stakeholders could play a critical role and based on their resources, they must act. At the industry level, broader collaboration and longer action plan predecessors are required. At the project and organisation levels, data and resources are more accessible, making it probably easier for stakeholders to handle the challenges (Figure 8.2). The maturity framework shows (Figure 8.3) how the features of each level affect how well OSC and BIM are integrated and what challenges are linked to each level. Some challenges are specific to each level, as illustrated by case studies. For instance, if Case 2 is at level 2, it indicates that the project has already progressed beyond the previous level. Consequently, the approach to handling challenges varies based on the characteristics of each level. Understanding the maturity level of integration necessitates a thorough investigation into appropriate strategies.

This research is related to academic areas by exploring the specific challenges related to various project life cycles and organisational levels. It will help academics focus on the specific areas that need deeper investigation to mitigate the challenge of OSC and BIM integration and present related strategies. The study can influence the development of the guidelines and best practices regarding the usage of BIM in the OSC delivery process. The study provided a deeper understanding of the integration challenges, which helped expand the academic exploration.

Moreover, the maturity framework provides a systematic approach to understanding and improving integration practices. The industry would benefit from this study by understanding the challenges and Integration In-depth, and stakeholders can target their investments and efforts where they are most needed, potentially saving costs and improving project efficiency. It can aid in identifying where the most training, investments and actions are required to help set the priorities and the goals to improve the integration of OSC and BIM. The maturity framework serves as a valuable tool both for projects and organisations within the industry, aiding in the identification of essential requirements for progressing towards full integration within their respective projects.

This study has certain limitations that should be considered for next steps. Firstly, the measurements may not be applicable in other countries because the data were taken from a sample of New Zealand construction projects. Nonetheless, a similar approach may be taken to investigate integration practices in other nations. Furthermore, the 116-participant sample size satisfies the requirements for doing factor analysis in general; however, having a larger sample size for more accurate output could be beneficial. Moreover, 40 percent of survey respondents had less than 5 years of BIM experience, and over 30 percent had less than 5 years of OSC experience. While this distribution may seem unbalanced, it reflects the current demographic landscape of professionals entering the construction industry, particularly in the context of emerging technologies such as BIM and OSC in New Zealand. Finally, more investigation is required to explore the strategies which could mitigate the specific challenges at various project lifecycles.

# Chapter 9: Strategic Integration Framework for OSC and BIM

***The current chapter is based on the following article:***

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. Sutrisna, M. Rahmani, D (2024), "OSC and BIM Integration Strategic Integration Framework Across Project Life Cycle" (Under Review).

## 9. 1 Introduction

The construction industry is predominantly characterised by conventional construction methods, with low levels of innovation and technological advancements (Shahzad et al., 2023). This includes the offsite construction (OSC) market, despite the relatively high demand for efficient OSC solutions to address the shortfall in affordable housing (Zou et al., 2022). In the construction industry, conventional methods are still widely used due to their familiarity, ease of use and resistance of industry to change. Additionally, the industry's challenges and lack of demand for technological advancements also hinder the implementation of new innovations in many countries including New Zealand's construction industry.

In recent years, Building Information Modelling (BIM) has emerged as a significant technological development for OSC projects. BIM refers to the collaborative process of creating, sharing, and utilising building lifecycle information (Eastman et al., 2011). The integration of BIM and OSC offers numerous benefits, such as improving information exchange and modelling (Nawari, 2012), addressing schedule delays (Li et al., 2017), and managing production flows (Arashpour et al., 2016b).

However, these benefits are limited by challenges including high implementation costs, lack of knowledge, and insufficient skills and experience (Kordestani Ghalenoei et al., 2022a). These challenges occur at various project lifecycle stages and can significantly impact subsequent phases if not addressed early. Additionally, integration varies in maturity, requiring distinct actions to enhance its effectiveness and progress towards higher levels (Razkenari & Kibert, 2022). Even though BIM in OSC is growing in other countries, research in this area is still in early stages in New Zealand.

Zou et al. (2022) revealed that New Zealand's OSC professionals have varying levels of understanding of BIM during the design process, with 36% reporting its integration into their workflows. The study highlighted BIM's potential to improve productivity and accelerate project delivery yet noted significant challenges in implementing BIM for OSC due to its unique workflows. Despite its potential, no standardised workflows or comprehensive solutions for integrating BIM into OSC have been presented in the literature (Kordestani et al., 2022; Likita et al., 2023; Porwal et al., 2023; Zou et al., 2022).

This study addresses these gaps by proposing the Strategic Integration Framework for OSC and BIM. The framework is designed to manage risks by identifying challenges early and providing solutions to minimise delays and costs. It promotes resource optimization by focusing on critical areas and fosters continuous improvement in BIM integration practices. By enhancing collaboration, communication, and stakeholder knowledge, the framework aims to establish best practices and improve project outcomes (Ocheoha & Moselhi, 2018). By enhancing collaboration, communication, and stakeholder knowledge, the framework aims to establish best practices and improve project outcomes.

## 9. 2 Literature Review

The background section provides an overview of the integration of OSC and BIM, highlighting the potential benefits, key challenges, and existing frameworks that inform the development of effective integration strategies across various stages of construction projects.

### 9.2.1 OSC and BIM Integration

The integration of OSC and BIM offers significant opportunities to optimize the entire construction lifecycle. OSC allows for the offsite prefabrication of components, while BIM provides a comprehensive digital model that captures the physical and functional aspects of a building (Gbadamosi et al., 2019). When combined, these approaches minimize on-site disruptions, reduce waste, accelerate project timelines, and enhance collaboration among project stakeholders (Abanda et al., 2017; Harris & . 2021; Yin et al., 2019). BIM, in particular, facilitates the creation of a virtual construction environment where stakeholders can collaborate, simulate, and analyse various aspects of a project before construction even begins (Alazmeh et al., 2018; Ghaffarianhoseini et al., 2017).

### 9.2.2 OSC and BIM Integration Challenges

To fully realise the potential of OSC and BIM integration, several challenges must be addressed. These challenges can be better understood through System Integration Theory and Strategy Development Theory, which provide essential frameworks for explaining how technological alignment and strategic planning are crucial for successful integration. System Integration Theory focuses on the coordination and alignment of various technological and organisational components within a system (Kossiakoff et al., 2011).

This theory emphasizes the need for seamless communication and coordination between various elements, such as stakeholders, tools, and data systems. In the context of OSC and BIM, this theory helps explain why collaboration and information sharing are critical. For example, Jiang et al. (Jiang et al., 2021) highlight the need for greater collaboration among stakeholders, as successful integration requires smooth information flow across diverse technologies and platforms. This is crucial for reducing friction between conventional construction methods and modern BIM-driven processes.

Strategy Development Theory, on the other hand, looks at how organisations plan and execute strategies to achieve long-term goals while addressing challenges. It emphasizes the importance of aligning internal capabilities with external opportunities (Porter, 1991). This theory helps explain how organisations can align internal capabilities with external opportunities, particularly in the face of integration challenges. For example, Razkenari et al. (Razkenari et al., 2020) discuss how high initial investment costs for BIM adoption can deter companies from making the shift, while Kordestani et al. (Kordestani Ghalenoei et al., 2022a) emphasize the importance of overcoming resistance to conventional construction practices. By applying strategic planning, organisations can effectively allocate resources, mitigate the financial risks associated with technological shifts, and facilitate the adoption of new methods like BIM. This theory highlights that strategic planning is crucial for managing integration challenges, guiding organisations through the adoption process, and ensuring that technological and organisational capabilities are aligned with the goals of integration.

Lastly, Organisational Structure Theory is also relevant in this context, as it examines how a company's internal structure must evolve to support new technologies and workflows. As highlighted by Razkenari & Kibert (2022) and Barkokebas et al. (2021), successful OSC and BIM integration requires not just adopting new technologies, but also restructuring workflows, training staff, and standardising processes. This organisational shift is essential for overcoming internal resistance and ensuring that all stakeholders are on board with the integration process. Addressing these challenges requires strategic planning, industry collaboration, and the development of protocols that foster continuous improvement (Razkenari & Kibert, 2022). Moreover, ensuring the ongoing upskilling of stakeholders and the standardisation of processes are critical to overcoming organisational and cultural barriers (Ayalp & Ay, 2020; Barkokebas et al., 2021; Li et al., 2019).

### 9.2.3 Integration at Project Life Cycle

The challenges of integrating OSC and BIM evolve across the project lifecycle, requiring modified strategies at each phase. In the early design and planning stages, effective coordination and information exchange between stakeholders are critical, especially when incorporating offsite prefabricated components into BIM models (Luo et al., 2019). System Integration Theory emphasizes the importance of efficient information flow to align stakeholders' technologies and processes, ensuring the BIM model accurately represents offsite elements (Kossiakoff et al., 2011). In the construction phase, integration challenges focus on ensuring offsite components fit onsite conditions, requiring real-time data sharing and coordination among teams. Poor integration at this stage can lead to delays and costly rework (Nguyen & Kim, 2011). The theory highlights the need for consistent communication across all stakeholders to manage risks and update BIM models as conditions change (Galbraith, 1974).

Later stages, such as compliance and handover, present challenges like costly design changes or safety risks. Zou et al. (2022) highlight the importance of proactive stakeholder collaboration to address these complexities, achieving efficiency and sustainability in OSC and BIM integration. Addressing these issues requires firms to adapt their processes as projects progress, a capability supported by Maturity Models, which assess readiness and guide improvements (Crawford, 2021; PMBOK, 2021). By integrating theories like System Integration and Organisational Maturity, the industry can address integration challenges across project phases, improving efficiency, cost-effectiveness, and resilience in construction projects.

### 9.2.4 Existing Frameworks and Guidelines

The integration of OSC and BIM has been extensively studied, with various frameworks and guidelines proposed to improve efficiency, reduce waste, and enhance project delivery. For example, integrating Lean principles with BIM has been explored as a way to streamline workflows and minimize waste, with BIM acting as the primary source of project-related information (Barkokebas et al., 2021; Likita et al., 2023). Similarly, combining Design for Manufacturing and Assembly (DfMA) with BIM has proven effective in optimizing design for offsite manufacturing, thereby reducing rework and improving overall efficiency (Bakhshi et al., 2022). However, while these frameworks provide technical solutions to specific challenges, they often overlook broader organisational and stakeholder coordination issues that are essential for seamless integration(Jang & Lee, 2018). Theories such as System Integration and Stakeholder Management emphasize the need for aligning systems, roles, and communication across complex workflows to address these limitations (Freeman, 2010; Kossiakoff et al., 2011).

To further support integration, several studies have focused on developing "BIM-based management systems" to enhance information management and collaboration across stakeholders. These systems standardize processes and ensure relevant data flows efficiently through different project phases (Hussein et al., 2021; Jang et al., 2021; Jiang et al., 2021; Wu et al., 2022). The Capability Maturity Model (CMM) has also been employed to assess organisational readiness for integration, guiding improvements through low-risk operational adjustments (Antoniades, 2014; Liang et al., 2016; Razkenari & Kibert, 2022; Schumacher et al., 2016). Despite these advancements, many frameworks remain limited in scope, failing to adequately address multi-trade coordination or the alignment of organisational and project-level objectives (Cano et al., 2020; Suliman & Rankin, 2021). These gaps further underscore the relevance of Organisational Structure Theory, which can provide insights into role clarity and hierarchical dynamics necessary for effective integration (Mintzberg, 1980).

Technological advancements, such as IoT, Augmented Reality (AR), Virtual Reality (VR), and Artificial Intelligence (AI), have also been proposed to enhance OSC and BIM integration (Tang et al., 2019a). These technologies can improve workflows, reduce costs, and minimize errors through real-time data sharing and advanced visualization techniques (Tang et al., 2019a; Xu et al., 2018). However, the implementation of such technologies introduces additional challenges, including high costs and the need for specialized training (Dumas & Beinecke, 2018). Strategic Development Theory becomes particularly relevant here, as it emphasizes aligning internal capabilities with external opportunities (Porter, 1991), ensuring that organisations can effectively adopt emerging technologies while overcoming challenges such as resistance to change and financial constraints (Razkenari et al., 2020).

A significant body of research has explored integration challenges at both the project and organisational levels. For instance, high implementation costs and integrated knowledge deficits are often cited as key barriers during the planning and execution phases of projects (Jiang et al., 2021; Kordestani et al., 2024). Knowledge deficits, such as inadequate training and a lack of transparency in offsite manufacturing practices, further hinder integration efforts (Kordestani et al., 2024). These findings align with the principles of System Integration Theory, which emphasizes seamless communication and coordination to overcome fragmentation and ensure alignment across processes (Kossiakoff et al., 2011).

Maturity models have been used to evaluate integration levels, offering structured pathways for organisations to progress from initial stages to optimized integration states (Cano et al., 2020; Suliman & Rankin, 2021). For example, Kordestani et al. (2024b) developed a maturity assessment framework that categorizes integration levels from "initial" to "optimized" and provides targeted strategies for addressing challenges at each level. While maturity models offer valuable insights, they often fail to address dynamic, project-specific challenges that arise across different phases of the project lifecycle, such as compliance errors during construction or rework costs due to design changes (Nguyen & Kim, 2011)

Despite these contributions, existing frameworks lack a holistic approach that encompasses technical, organisational, and stakeholder-centric challenges. This highlights the need for a comprehensive framework that integrates theoretical insights from System Integration, Strategy Development, and Stakeholder Management to address these gaps. Such a framework would not only guide the integration of OSC and BIM throughout the project lifecycle but also provide actionable strategies for overcoming challenges, ensuring alignment across organisational levels, and fostering sustainable construction practices. By addressing these gaps, this study aims to develop a robust framework tailored to the unique needs of the New Zealand construction industry.

## 9. 3 Research Methods

A sequential mixed-methods approach applied to achieve the research objectives in current study (Babaeian Jelodar & Shu, 2021; van Heerden et al., 2023), ensuring that each method built upon the findings of the previous stage. This included a survey, case study, and a focus group. A mixed method approach is particulary beneficial when employing qualitative and quantitative methodologies (Gough, 2015), as it provides both breadth and depth by combining statical analysis with rich contextual insights (Tashakkori et al., 2020).

The study followed a three-phase structure. First, a survey was conducted to explore integration challenges and strategies, forming the quantitative foundation of the research. Second, case studies were developed to provide qualitative depth and illustrate practical applications of strategies and stakeholder roles identified in the survey. Finally, a focus group was conducted to validate and refine the developed integration framework, combining insights from earlier phases. Case studies reviewed integration strategies and responsible stakeholders, while expert views on developed framework were assessed in in the focus group (Babaeian Jelodar et al., 2016). Because quantitative approaches were used in the data analysis, the study is likewise quantitative (Bakhtiarizadeh et al., 2022).

Survey data was extracted form a comprehensive study done by Kordestani et al., (2022a) which explored OSC and BIM integration challenges and strategies and proposed a conceptual framework. The survey results were analysed to identify patterns, which were then explored in greater detail through case studies. Case studies provided rich, contextual data to examine the nuances of stakeholder responsibilities and strategies in real-life projects. These findings informed the development of a draft integration framework, which was subsequently evaluated and refined through the focus group. This sequential and iterative process ensured that each phase informed and strengthened the next, resulting in a cohesive analysis.

The first study's objective was to identify applied strategies to mitigate OSC and BIM integration challenges and determine which stakeholders are responsible for implementing these strategies. Second objective was to develop an integration framework using surveys, case studies, and focus groups on a cumulative manner. To achieve second objective, the integration framework was developed by adopting the maturity level scale of Kordestani et al. (2024b), combined with inputs from the survey and case studies.

The maturity level scales offer a structured progression from ad-hoc adoption to continuous improvement, focusing on mitigating integration challenges. This structured approach provided a logical progression from identifying challenges and strategies (survey) to understanding their practical application (case studies), culminating in a validated framework (focus group). By applying insights from the survey, case studies, and focus group, the research ensured triangulation (Jonsen & Jehn, 2009b), enhancing the validity and reliability of the findings. The transition between these methods is illustrated in Figure 9.1.

### 9.3.1 Survey

The survey was designed based on previous work by Kordestani et al. (2022a) to investigate strategies for mitigating OSC and BIM integration challenges. The survey results formed the quantitative baseline for identifying key challenges and strategies. These findings informed the case study design, ensuring alignment between quantitative and qualitative phases. The data collected between October 2022 and February 2023 yielded 164 responses. However, 48 of these responses were excluded due to incompleteness, and consequently, 116 valid responses were used for analysis. The exclusion process was applied uniformly, without consideration of specific respondent characteristics, to minimise the likelihood of bias (Dewitt et al., 2019).

The study focused on New Zealand offsite manufacturing (OSC/OSM) companies implementing BIM in their delivery process. Information from two principal sources of registered companies in New Zealand was reviewed to gather companies' data (BIM Acceleration Committee, 2019; OffsiteNZ, 2023). Companies outside the study's scope were excluded and in total, 450 emails were sent to potential respondents.

There are two components to the questionnaire: A general demographic was gathered in Section A. The purpose of the second section was to evaluate appropriate strategies for reducing integration challenges (Appendix 5). Two factors for strategies and three for integration measured by different questions. A 7-point Likert scale used to ask participant to rate from "Never used" to "Every time". When feasible, experts recommend adopting tools like 7-point Likert to make use of a wide range of alternatives on the scale. Consequently, during analysis, the replies can be extracted into more focused categories (Dawes, 2008; Joshi et al., 2015).

The reliability and validity of the questions, testing the survey design and improving response rates happened through the pilot study involving the random selection of thirty participants from the population (Van Teijlingen & Hundley, 2002). Pilot resulted in few wording and question structure changes, with the primary goal being to shorten the questions. To make sure that the logistics of the survey were adequate and that the questions were effective, the authors performed statistical analysis on the collected data as well (Gaur et al., 2020). Questions and survey structure modified based on the pilot study and then distributed through Qualtrics an online platform. Data were analysed using AMOS24.

### 9.3.2 Case Studies

An exploratory and comparative case study approach was used to investigate how projects addressed challenges in integrating OSC and BIM. The findings from the survey informed the selection of case study projects, focusing on those that represented diverse contexts and strategies. By examining survey-identified challenges and strategies in real-world settings, the case studies provided practical insights that enriched the research's qualitative dimension. The selection of the four case studies was carefully guided by specific criteria to ensure a comprehensive and meaningful exploration of OSC and BIM integration challenges. The chosen projects represented a diverse range of contexts, from small structures to large infrastructure projects, ensuring a broad understanding of integration strategies (Snyder, 2012; Yin & Davis, 2007).

Importantly, each project actively utilised OSC and BIM throughout the entire project lifecycle, making them relevant to the study's focus. The projects were also selected based on accessibility to detailed data, including design documents, contracts, and meeting notes, which allowed for a thorough investigation of the integration process. Another critical consideration was the willingness of key stakeholders to participate in interviews, providing valuable insights that enriched the data collection process. Examining these examples provides detailed insights into the adoption of BIM and OSC, which are often difficult to obtain through other methods (Yin, 2012). This diverse selection of projects not only enhanced the study's depth but also ensured that the findings were not limited to a single type of project, thereby improving their broader applicability. The holistic case study approach, as outlined by Yin (2009), was particularly suited to this research, allowing for an in-depth examination of the interconnected nature of OSC and BIM integration across different stages of the project lifecycle.

The study employed a framework for conducting comparative case studies, facilitating systematic documentation and meaningful comparisons, drawing upon Yin's methodology. Data triangulation, involving multiple data sources, was essential (Figure 9.1). Consistency in analysis across the four cases was ensured by replicating the logic and maintaining the burden of proof (Taylor et al., 2011).

Interviews were conducted with a range of professionals, including digital managers, project managers, design managers, draftspersons, and architects. Each session lasted approximately one hour and was meticulously transcribed for accuracy. Indirect questioning techniques were employed to encourage detailed insights into the delivery process and the integration of OSC and BIM. In the case study analysis, NVivo 20 software was used to extract specific strategies employed to mitigate OSC and BIM integration challenges. The qualitative data collected from interviews was analysed using NVivo software to extract strategies related to OSC and BIM integration. Transcripts were imported into NVivo and reviewed for accuracy.

Strategies were identified and grouped into thematic categories, including stakeholder engagement and education, planning and strategy development, technical integration and coordination, and engagement and collaboration. This thematic grouping was informed by recurring patterns in the data and cross-referenced with relevant literature. NVivo's matrix coding tools facilitated a cross-case comparison, highlighting commonalities and differences across projects (Yin, 2018), which contributed to the development of the integration framework.


**Figure 9.1:** Case study framework

The framework evaluates project specifics for each case, focusing on methods to mitigate integration challenges, case requirements, and the roles of key stakeholders involved in the investigation. Accurate classification and evaluation are essential due to the highly contextual nature of project data. Without standard analytical components, meaningful case comparisons become difficult. The case selection process aimed to identify strategies and methods for addressing challenges in implementing BIM and OSC within the New Zealand construction sector.

Information on stakeholders, project contexts, and other relevant factors was collected and categorised into common, comparable data across all cases. Interviews and document reviews served as the primary data sources. The objective was to explore the strategies employed in the case studies and to understand the roles of stakeholders at different levels of maturity and stages in the project life cycle. The case study provides valuable insights into how OSC and BIM integration strategies vary based on these factors, supporting a deeper understanding of the integration process.

### 9.3.3 Focus Group

The next step of the research method in this study was a focus group to collect subjective data from individual and understand divers perspectives on OSC and BIM integration challenges (Sandelowski, 2008; Saunders et al., 2009). Building on the findings from the survey and case studies, the focus group validated and refined the integration framework. Participants were encouraged to critically evaluate the framework's components and suggest modifications, ensuring its practical applicability. As Stewart and Shamdasani (2014) noted: ‘The most common purpose of a focus group interview is for an in-depth exploration of a topic about which little is known’.

One focus group session was held to validate the developed framework (Figure 9.4). The integration framework was presented in its preliminary form, developed using survey data and insights from case studies. Discussions centred on its practical relevance and applicability within the New Zealand construction domain, enabling the researchers to make refinements based on expert feedback. The participant selection process for the focus groups aimed to encompass representatives from three key stakeholder groups: clients, consultants, and contractors/manufacturers. Specific criteria were established to ensure that participants possessed the requisite expertise for the study's objectives. This included being senior-level practitioners within the construction industry, demonstrating extensive experience in project delivery methods, proficiency with relevant software, exposure to diverse contract forms, and knowledge of BIM and OSC.

Additionally, accessibility was considered, given the logistical challenge of gathering individuals in one location simultaneously (Breen, 2006). Initially, ten experts were contacted to attend the session, however due to their availability, focus group was held with 7 experts. The meeting lasted for four hours and started with an introduction to the topic (Appendix 8). A handout with the brief description of the project, aim of the meeting, main questions and developed framework was distributed to participants prior to the meeting. The participants were encouraged to discuss the challenges they had, what strategies they used and who was responsible for actions based on their experience in the integration of OSC and BIM. Then they asked to discuss the different sections of the framework to validate weather the components are applicable or needs modification. To improve the validity of the suggested methodological approach and the reliability of the collected data, this study made sure that data sources were triangulated by using two primary methods: audio recording and note-taking and then transcripts it to text (Johnson, 2017).

## 9. 4 Findings

This section presents the findings from three main research methods used in this study: survey, case study, and focus group. First, an overview of the survey results is provided, based on input from a previous study. Then, the detailed findings from the case studies and focus group discussions are presented, offering comprehensive insights into the research objectives.

### 9.4.1 Survey Findings

Two factors for strategies and three for integration were measured with different questions (Kordestani et al., 2024). The primary themes for creating the questionnaire were identified by carefully going over the literature on integration factors and mitigation strategies. Following several peer review meetings with specialists from academia and industry, the criteria were examined, and those with recurring themes were eventually eliminated. The discovered strategies and integration variables were then reworded and reorganised to improve clarity and more effectively communicate their meanings. “Integration Facilitators” is measured by early engagement of stakeholders, providing clarity of outcomes and benefits, and creating action plans and roadmaps for OSC and BIM integration. “External Support & Policy Regulation” is measured by graduate and internship programmes, financial support from the government, mandating the use of BIM in OSC, use of contractual provisions, and use of government guidelines derived from the literature.

First integration factor (BIM-Driven OSC Readiness) is measured through projects have a high readiness level for facilitating OSC through BIM, and there is a high level of understanding of BIM functions for OSC implementation. Using BIM software facilitated OSC compliance to design, collaboration on a cloud-based BIM platform facilitated the design process, and collaboration on a cloud-based BIM platform facilitated transportation used to measure the second integration factor (BIM-Enabled Collaboration & Facilitation). And BIM-Enabled OSC Enhancement as the last factor for integration is measure by applying BIM facilitated the identification of OSC requirements, applying BIM facilitated collaboration between manufacturing and installation, applying BIM facilitated the management of OSC constraints.

Model fit thresholds that are widely accepted were used to analyse the CFA statistics. An excellent model fit is indicated by CMIN/DF values between 1 and 3, CFI >.95, SRMR<.08, RMSEA<.06, and PClose >.05. Alternatively, according to Hu and Bentler (1999), a fit is deemed adequate if it falls between the following ranges: CMIN/DF between 3 and 5, CFI between .90 and .95, SRMR between .08 and .1, RMSEA between .06 and .08, and PClose between .01 and .05. The convergent validity of the latent variables was evaluated by means of the Average Variance Extracted (AVE) measure, which was found to be more than .5 (Hair et al., 2010). Construct reliability (CR) values larger than .6 are favoured for validity. An AMOS plugin was utilised to assess the HeteroTrait-MonoTrait (HTMT) ratio of correlations to determine the discriminant validity (Gaskin & James, 2019).

In line with Hair et al. (2010), the findings demonstrated that no correlation was more than 85, proving the discriminant validity of the findings. It is also evaluated the convergent and discriminant validity of the modified scale, in addition to its reliability. Reasonable fitness was proven by Confirmatory Factor Analysis (CFA) with IBM SPSS AMOS 26: five factors with loadings ranging from .63 to .94 were produced ($\chi 2(67) = 1.592$, $p = .001$, CFI =.940, SRMR

=.06, RMSEA =.072, PClose =.087). With comparatively small sample sizes, authors can obtain relevant results by maximum likelihood estimation (Kline, 2013). About 9% of respondents worked for clients, 35% were contractors, and most respondents (56%) were employed by consulting firms. In terms of experience, 24% of respondents had less than five years' worth, 25% had six to ten years' worth, and the remaining 50% had more than eleven years' worth, with about 25% having fifteen years or more. Remarkably, most participants had only 0–5 years of experience working on BIM and OSC projects, demonstrating the current population of expert in New Zealand. The biographic data reflects the composition of experts who are working in New Zealand offsite as it has a small industry (Zou et al., 2022). Just 2.5% and 5% of participants, respectively, said they had worked on OSC and BIM projects for more than 16 years.

**Table 9.2:** CFA Structural factor loading matrix for variable study items

| Factors | Construct Validity Measurements | | | | HTMT Measurements | | | | | `Items | CFA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | α | CR | AVE | MSV | ST1 | ST2 | INT1 | INT2 | INT3 | | |
| ST1 (Integration Facilitators) | .728 | .733 | .579 | .359 | .692 | | | | | S4: Early engagement of stakeholders | .64 |
| | | | | | | | | | | S3: Providing clarity of outcomes and benefits | .71 |
| | | | | | | | | | | S5: Creating action plans and roadmaps for OSC and BIM integration | .72 |
| ST2 (External support and policy regulation) | .806 | .809 | .514 | .359 | 600*** | .717 | | | | S2: Graduate and internship programmes | .68 |
| | | | | | | | | | | S12: Financial support from the government (e.g., tax subsidies) | .71 |
| | | | | | | | | | | S13: Mandating the use of BIM in OSC | .77 |
| | | | | | | | | | | S16: Use of contractual provisions | .71 |
| INT1(BIM-Driven OSC Readiness) | .818 | .820 | .696 | .306 | .226† | .544*** | .834 | | | IN1: Projects have a high readiness level for facilitating OSC through BIM | .83 |
| | | | | | | | | | | IN2: There is a high level of understanding of BIM functions for OSC implementation. | .83 |
| INT2 (BIM-Enabled Collaboration & Facilitation) | .836 | .760 | .615 | .497 | .569*** | .446*** | .553** | .784 | | IN3: Using BIM software facilitated OSC compliance to design. | .78 |
| | | | | | | | | | | IN5: Collaboration on a cloud-based BIM platform facilitated the design process | R |
| | | | | | | | | | | IN8: Collaboration on a cloud-based BIM platform facilitated transportation. | .69 |
| INT3 (BIM-Enabled OSC Enhancement) | .845 | .848 | .651 | .497 | .552** | 333*** | 432*** | 705*** | .807 | IN12: Applying BIM facilitated the identification of OSC requirements | .84 |
| | | | | | | | | | | IN13: Applying BIM facilitated collaboration between manufacturing and installation. | .80 |
| | | | | | | | | | | IN14: Applying BIM facilitated the management of OSC constraints. | .78 |

Note: CFI: Comparative Fit Index; SRMR: Standard Root Mean Square Residual; RMSEA: Root Mean Square Error of Approximation; PClose: Probability of Close fit; α: Cronbach's Alpha; CR: Construct Reliability; AVE: Average Variance Extracted; MSV: Maximum Shared Variance; HTMT: HeteroTrait-MonoTrait Ratio of Correlations; *: p < .05. R: Removed`
†: p <.1, *: p < .05; **: p <.01; ***: p < .001

### 9.4.2 Case Studies Findings

Four projects have been selected for investigation in the current study; they range in complexity from simple residential building to complex infrastructure projects. Every case study is examined twice: once to confirm the strategies arising from the survey analysis (Kordestani et al., 2024) and strategies which project used in their integration process, and again to assist in exploring who is the responsible stakeholders to apply strategies. Table 9.1 provides an overview of the selected projects. Based on preliminary observations, all the projects used BIM technology throughout the OSC delivery process, from design to manufacture and installation. At some point, consultants or manufacturers handed over their shop drawings and models to the construction team. However, if proper collaboration was lacking during this handover, issues arose during the construction and installation phases. The case studies used distinct strategies to mitigate integration challenges at different project lifecycle. Some of the strategies were similar with output of previous study and some were unique. Figure 9.2 provides the key findings derived from the case studies analysis.

Figure 9.2 illustrates the information derived from the case study framework (Figure 9.1). It demonstrates the theoretical replication logic essential for the case studies by comparing the two units of analysis within the case study framework. To ensure conclusive findings, the result of each case is divided into the documented units of analysis shown in Figure 9.2 (Mohandes et al., 2023). The integration maturity levels depicted in the figure are drawn from a previous study, which defines specific characteristics for each level. As integration progresses, the level becomes more mature.

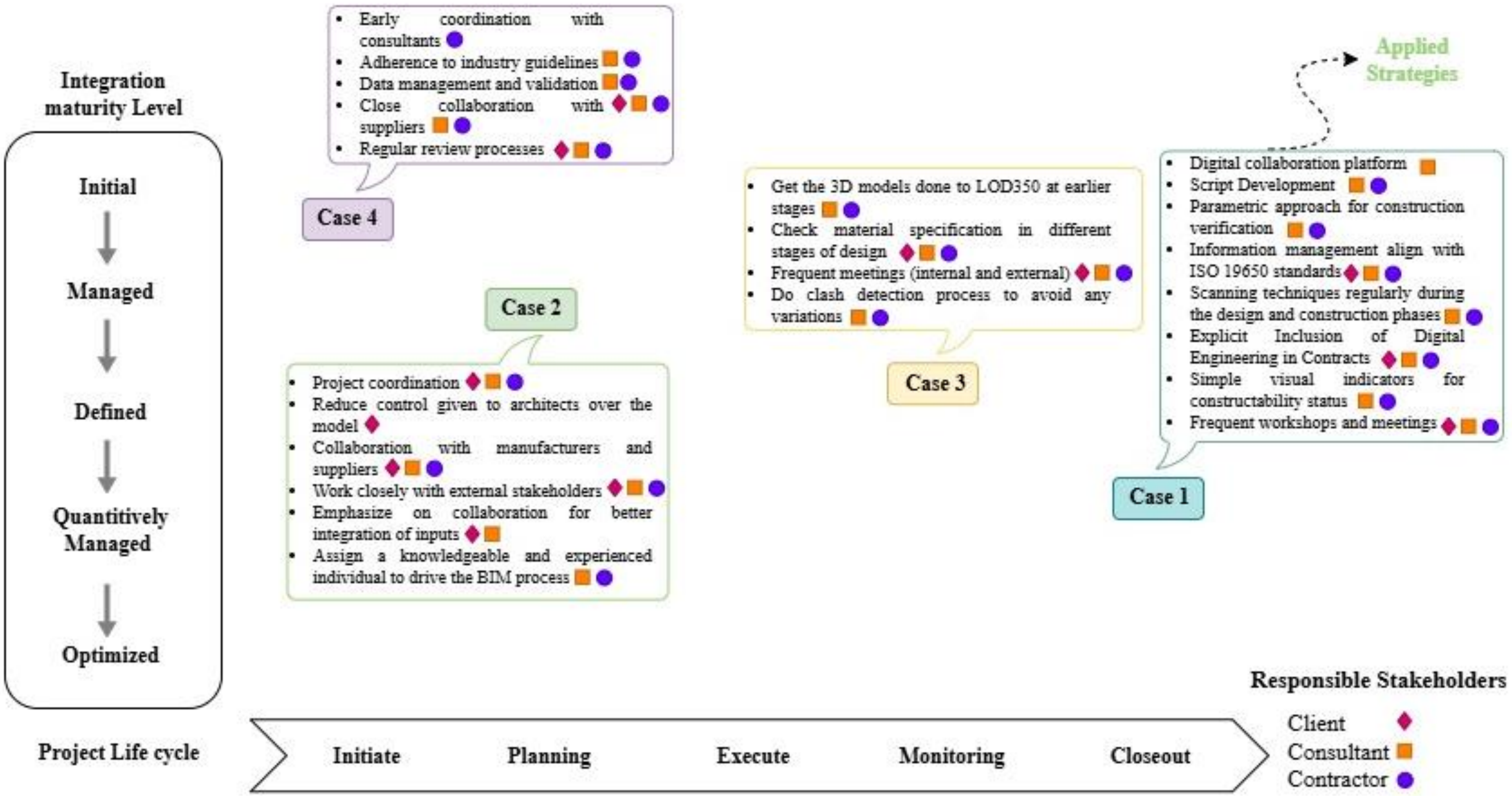


**Figure 9.2:** Case studies comparison results

At initial stage, there is a low understanding of integration challenges, and projects lack a proper integration plan. However, as they advance through the levels, they begin to utilise standards and guidelines, develop a basic understanding, and at optimized level, their processes achieve the highest level of integration in OSC and BIM. This optimization includes continuous improvement in integration activities. Each case was at different phase of project life cycle which is presented in the Figure 8.2 (Kordestani et al., 2024a).

**Table 8.1:** Case studies specification

| Project Description | Project Size | Project Life cycle | Project type & Location | Imported/Local |
|---|---|---|---|---|
| Case 1: This is a completed water project which spread through Waikato and Auckland regions. The project was implemented to increase the treated water supply by 50 million litres daily from the Waikato River to Auckland. The programme involved several Workfront, including Phase 1 in Tuakau and a Booster Pump Station in Papakura, to ensure the programme's success. | 16 kilometres, large | Completed | Water project-Waikato | Local and imported |
| Case 2: The second case study is an in-progress commercial building in the South Island's west part. It is a single-story building located in Section 39 Block 1 Maori Reserve & Section 41 block, 1 Maori Reserve & Section 40 and Section 42 Block 1, Greymouth or Mawhera 21 Maori Reserve. | 21875 square metres, large | Design phase | Commercial-Greymouth | Local and imported |
| Case 3: The MPI-IPEQ Facility project, which stands for Ministry of Primary Industries - aims to establish a specialised facility for the quarantine of imported plants following the bio-security regulations of New Zealand. The project involves designing and constructing of 12 interconnected greenhouses, a headhouse, a corridor connecting the headhouse and the greenhouses, a mechanical plant room area, and a parking area. | 500 square metres, medium size | Under construction | Greenhouse-Auckland | Local and imported |
| Case 4: A two-story residential building located in wellington has been planned to take advantage of and celebrate its elevated position, providing guidance for the subdivision and development of a new site. | 250 square metres, Small sized | Design and manufacture | Residential-Wellington | Local |

Case study review objective was to identify the mitigation strategies and their responsible stakeholders who applied them at each project. In Case 1, the consultant took the lead in establishing a digital collaboration platform, enhancing communication and coordination among project stakeholders. Both the consultant and contractor adopted a parametric approach for construction verification, ensuring accuracy and precision in project implementation, similarly they collaborated on script development, streamlining processes and enhancing efficiency in project execution. All project stakeholders aligned information management practices with ISO (International Organisation for Standardisation) 19650 standards, ensuring consistency and compatibility across the project lifecycle. This document outlines principles and guidelines for managing information in BIM, applicable across the entire life cycle of built assets and adaptable to projects of different sizes and complexities (ISO, 2018).

While consultant and contractor employed scanning techniques regularly during design and construction phases, facilitating accurate documentation and progress tracking. Case 2 is at planning and design phase at the time of the case review and so, project stakeholders prioritised project coordination and close collaboration with manufacturers and suppliers, which based on their experience will help them to minimise the risk delay and disruption during construction phase. Another applied strategy in this project is that client reduce the control given to architects over the model and emphasized more on a collaborative approach among all project participants.

In Case 3, the consultant and contractor focused on the development of 3D models to Level of Development 350 (LOD) at earlier stages, which enhanced the accuracy and completeness of project documentation. LOD determines the detail with which components are represented in a model, specifying what information items are included and defining the model's usability and limitations for specific tasks (Latiffi et al., 2015; Leite et al., 2011). Additionally, all project stakeholders checked material specifications at different stages of design to ensure compliance with project requirements and standards. Frequent internal and external meetings facilitated communication and collaboration among project teams. Furthermore, the consultant and contractor conducted clash detection processes to identify and resolve conflicts, which minimised variations and delays in project execution. While, in Case 4, the contractor initiated early coordination with consultants, establishing the groundwork for continuous collaboration.

Both the consultant and contractor strictly adhered to industry guidelines, ensuring compliance and quality standards. They prioritised data management and validation, thereby enhanced the reliability and integrity of project information. Additionally, all project stakeholders emphasized close collaboration with suppliers, which fostered efficient supply chain management. Regular review processes, implemented by the client, consultant, and contractor, ensured continuous improvement and alignment with project objectives.

In general, while both Case 1 and Case 4 prioritise digital collaboration and information management (Figure 9.3), Case 1 emphasizes technological tools and standards alignment, whereas Case 4 focuses on early coordination and collaboration with suppliers. Moreover, Case 1 emphasizes on digital platforms and contract provisions (Figure 9.4), whereas Case 3 highlights the significance of early 3D modelling and frequent meetings for effective integration. And finally, Case 1 used technological solutions and contract provisions as a strategy, while Case 2 prioritises project coordination and stakeholder engagement.

Across the cases, common themes such as early coordination, stakeholder collaboration, and adherence to industry standards emerge as foundational principles for successful integration of OSC and BIM. However, the specific strategies employed vary based on the unique challenges and project requirements encountered in each case. While some cases prioritise digital tools and standards alignment, others emphasize proactive communication and stakeholder engagement. By understanding these diverse strategies, practitioners can shape their approach to OSC and BIM integration to suit the specific needs of their projects, ultimately moving toward higher level of integration.

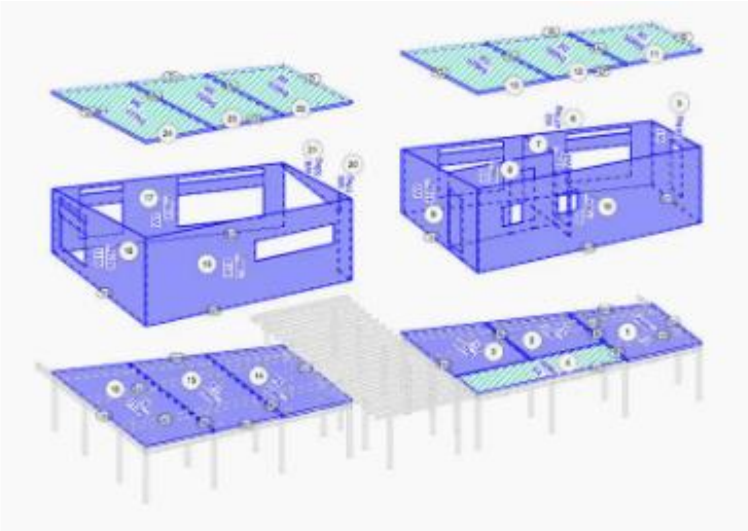

**Figure 9.3:** Using BIM to Improve Digital Collaboration and Information Management - Case 4

**Figure 9.4:** Application of digital engineering and 3D modelling- case 1 (Harlos et al., 2022)

### 9.4.3 Developed Integration Framework

The framework developed in this study (Figure 9.5) aims to advance the integration of OSC and BIM at the project level by developing a framework that guides stakeholders through different phases of the project lifecycle, enhancing integration maturity and overall project performance. Various inputs were gathered to construct the framework, which covers the project lifecycle from initiate to closeout at the project level. The framework comprises four sections: a diagnostic checklist, integration pathway, strategic interventions, and a stakeholders' engagement plan.

*Diagnostic Checklist:* The first step involves using a maturity checklist containing integration characteristics to assess the projects' maturity levels. Each level, as mentioned previously, is associated with specific attributes. By examining their Offsite Construction (OSC) delivery processes, project stakeholders can determine their integration maturity level.

*Integration Pathway:* This step assists projects in identifying challenges based on their maturity level and project phase. After identifying the maturity level, this step involves a continuous review of challenges. This proactive identification helps project teams prepare and prevent challenges from arising. Since challenges in earlier stages can impact subsequent phases of the project lifecycle, mitigating them early on is preferable.

*Strategic Intervention:* Following challenge identification, it is crucial to deploy strategies to mitigate integration challenges. Strategies may be continuous throughout several project lifecycle stages, such as training or maturity level enhancements, or they may occur once, such as early stakeholder engagement, which should occur in the project's early phases.

*Stakeholders Engagement Plan:* In the final stage of the framework, it is essential to appoint the responsible stakeholders to execute the strategies. Some strategies require collaboration among all stakeholders, while others necessitate specific stakeholder actions. Therefore, based on their required roles, stakeholders can prepare and formulate plans throughout the project lifecycle.

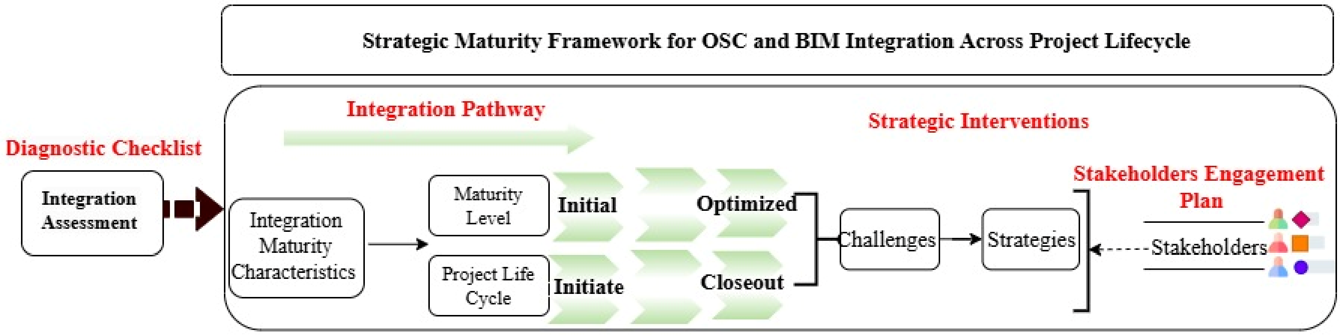


**Figure 9.5:** OSC and BIM integration framework components

A comprehensive framework, including integration maturity characteristics, challenges at different levels and project life cycle, targeted strategies, and responsible stakeholders, is illustrated in Figure 9.6. This framework draws upon inputs from various research and data collection methods. Detailed explanations for each component of the framework are provided below. The case study review offers detailed analysis and insights from real-world examples, while the focus group allows for gathering diverse perspectives directly related to the research topic. This combination ensures a comprehensive understanding and content validity of the study's findings through mixed method (Teddlie & Tashakkori, 2009).

*Integration Maturity Level Characteristics*

Kordestani et al. (2024a) developed a maturity assessment framework for OSC and BIM integration based on case studies. The framework consists of five levels: initial, managed, defined, quantitatively managed, and optimized. Each level reflects distinct characteristics derived from case study analysis which helps stakeholder to identify their level of maturity. At the initial level, projects adopt OSC and BIM technologies reactively, lacking strategic planning and standardised guidelines, leading to limited understanding and fragmented implementation. In the managed level, projects begin to understand integration challenges but still lack cohesion and standardised approaches. Moving to the defined level, projects establish clear integration strategies, enhancing communication and collaboration among stakeholders, and promoting consistency in project delivery. Transitioning to the quantitatively managed level, projects adopt a data-driven approach, measuring integration activities and implementing continuous improvement initiatives. Finally, at the optimized level, projects prioritise innovation and refinement, exploring advanced technologies and industry best practices to enhance integration efforts on a project-by-project basis (Figure 9.6).

*Integration Challenges*

The second part of the framework outlines the challenges identified through two methods: a survey and case studies, providing insight into what projects can anticipate at each stage (Kordestani et al., 2022; Likita et al., 2023; McDermott et al., 2023; Zou et al., 2022). Initially, two groups of challenges were identified from the survey, which were then confirmed during the case study review. Additional challenges were incorporated into the list based on the collected data. Each phase of the project life cycle and integration maturity level is associated with specific challenges.

Some challenges recur across different stages, while others are unique to a particular stage. These challenges are assigned to each stage based on the reviews of cases and the challenges faces during the integration of OSC and BIM in projects. During the initial stage of maturity and project, challenges related to training demand and lack of knowledge are emphasized, while for stages such as optimized, financial aspects of integration take priority. Three stages of the integration section are currently blank as no specific challenges were identified during the data collection process. These challenges will be further reviewed, verified, and modified through focus group sessions with industry experts.

*Mitigation Strategies*

Mitigation strategies were derived from two sources: the first group of strategies was measured with two factors with different questions through survey, and additional strategies were identified through the case study review, aligning with one of the current study's objectives. After exploring strategies from two methods, they were then compared, similar ones combined, and new groups of strategies developed based on the themes. Projects utilised various methods to address integration challenges, with approaches differing based on their level of integration.

For instance, Case 1, which demonstrated a higher level of integration among the cases, developed a digital platform to reduce the number of requests for information (RFIs) issued during the design process. Additionally, they implemented real-time data collaboration, updating information after each modification and informing the construction team about the status of different design components. On the other hand, another project (Case 3) emphasized on frequent internal and external meetings to prevent misunderstandings and facilitate early clash detection. By employing these strategies, projects at different levels could effectively tackle challenges and progress towards improved integration. Table 9.2 presents the final list of the strategies from both survey and case study.

*Responsible Stakeholders*

Three main stakeholders including client, consultant, and contractor (and manufacturer)—each have their own goals and may see integration challenges differently, leading to different approaches (Kordestani et al., 2023). In the framework, stakeholders are visually distinguished by specific colours and shapes to enhance clarity and minimise confusion. Furthermore, related stakeholders are connected to strategies, indicating the specific challenges they are responsible for addressing. The information for the framework was gathered through case study reviews, which involved semi-structured interviews with involved parties and document reviews throughout the project's various life cycles. Document reviews encompassed meeting notes containing information on attended stakeholders, project information sheets, and scope details.

**Table 9.2:** Mitigation strategies for OSC and BIM integration

| Themes | Strategies | Survey | Case Study |
|---|---|---|---|
| Stakeholder Engagement and Education | Early engagement of stakeholders | ✓ | ✓ |
| | Educating and upscaling stakeholders on OSC and BIM integration benefits | ✓ | ✓ |
| | Providing clarity of outcomes and benefits | ✓ | |
| | Government support | ✓ | |
| Planning and Strategy Development | Creating action plans and roadmaps for OSC and BIM integration | ✓ | |
| | Mandating the use of BIM in OSC through contractual provisions | ✓ | ✓ |
| | Clear definition of scope and work levels | | ✓ |
| | Developing a collaborative approach among stakeholders | ✓ | ✓ |
| | Establishing a BIM Execution Plan (BEP) for project alignment | | ✓ |
| Technical Integration and Coordination | Centralised and detailed Modelling | | ✓ |
| | Coordination of Offsite Components | | ✓ |
| | Implementing Guidelines and Standards for consistency | | ✓ |
| | Utilising Coordination Platforms for efficient communication | ✓ | ✓ |
| | Early clash detection to prevent issues | | ✓ |
| | Internal design coordination | | ✓ |
| Engagement and Collaboration | Utilising client engagement tools to involve them in the process | | ✓ |
| | Facilitating stakeholder interaction | ✓ | ✓ |
| | Implementing control modifications and change management procedures | | ✓ |
| | Promoting Information Sharing through effective channels | ✓ | ✓ |
| | Conducting frequent meetings to ensure progress and alignment | | ✓ |
| | Collaborating with suppliers for streamlined processes and innovation | | ✓ |

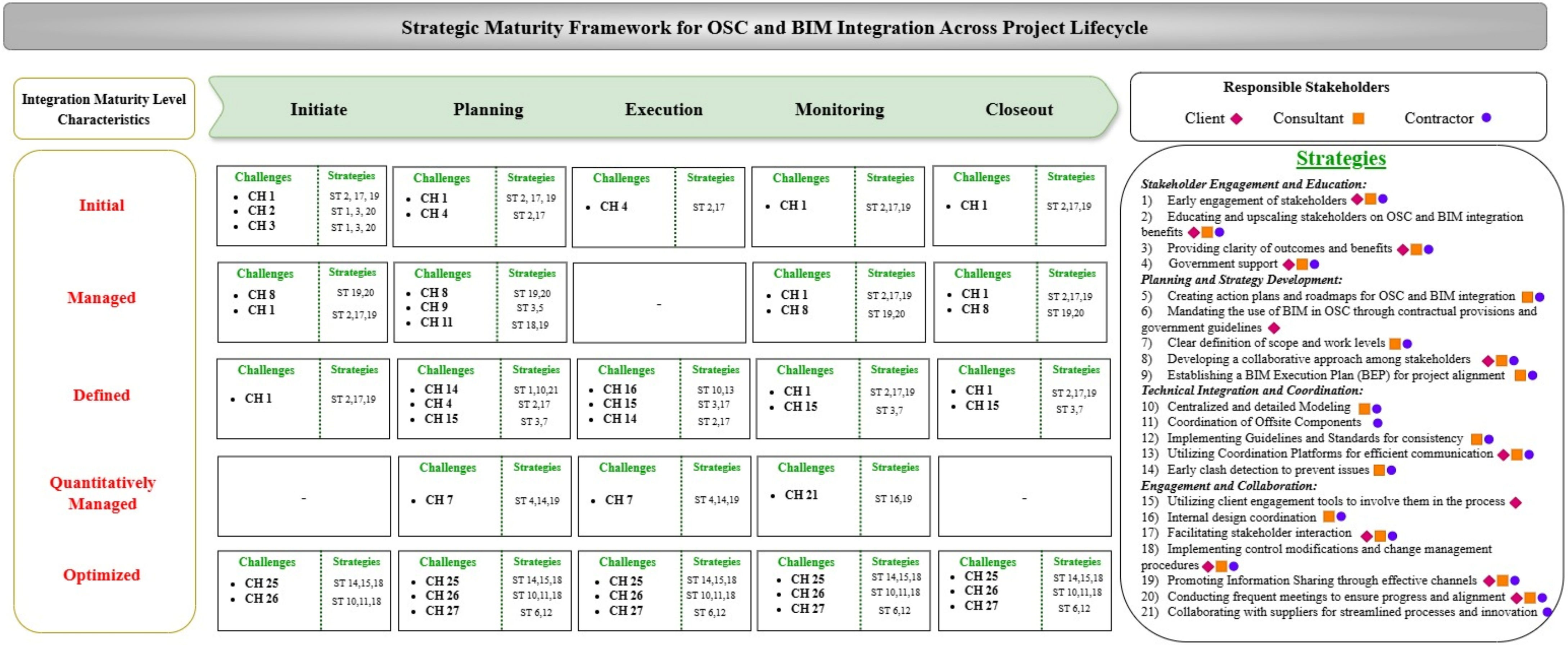


**Figure 9.6:** Strategies Maturity Framework for OSC and BIM Integration Across Project Life Cycle

### 9.4.4 Focus Group Findings

A focus group session was organised to validate and enhance the developed framework (Figure 9.6). The focus group comprised experts including principal and digital engineering managers, BIM specialists, prefab manufacturer engineers, and project manager. Each participant had more than 15 years of experience working with BIM in OSC projects, providing a deep understanding of the integration of BIM in OSC workflows. Table 9.2 presents the background information of the focus group participants. Experts participated in discussions revolving around semi-structured questions, exploring various aspects such as the clarity and comprehensibility of the framework, alignment of challenges with specified stages, identification of any overlooked challenges, and the applicability of strategies to the identified challenges.

**Table 9.3:** Focus group participants' background information

| Expert | Current position | Stakeholder's group | Experience (years) |
|---|---|---|---|
| E1 | Digital Assets & Engineering Lead | Consultant | 15+ |
| E2 | Digital Engineering Leader | Consultant | 21+ |
| E3 | Digital Engineer | Consultant | 16+ |
| E4 | Head of Product Design | Contractors/manufacturers | 17+ |
| E5 | Head of Design | Client | 20+ |
| E6 | Manager Offsite Manufacturing | Client | 35+ |
| E7 | Manager Offsite Manufacturing | Contractors/manufacturers | 18+ |

Additionally, correct assignment of responsible stakeholders and the need for additional strategies or the removal of irrelevant ones have been discussed. The recording of the session ensured that every valuable insight and suggestion put forth by the participants was accurately captured. This sound recording served as a reliable reference point for subsequent analysis and refinement of the framework. By transcribing the discussions, a detailed comparison could be made with the notes taken during the session, enabling a thorough examination of the points raised and facilitating further improvements to the framework.

During the discussions, participants reached an agreement on the integration maturity levels, indicating a shared understanding and agreement on this aspect of the framework. However, there was a collective recognition of the need to enhance the clarity of the framework by demonstrating the "Time" and "Maturity Level" by using arrows. This suggestion aimed to ensure that the framework remained accessible and easily comprehensible to all stakeholders involved. In the review of challenges, each phase of the project was systematically examined to identify any gaps or inconsistencies in the alignment of challenges with their corresponding maturity levels. Through this methodical process, new challenges like lack of practical process, and lack of consistency between different stakeholders monitoring approach emerged, reflecting the diverse complexities encountered throughout the project lifecycle. Furthermore, existing challenges were refined in terms of their structure and wording to accurately reflect the correct context related to the integration stage. For example, "Cost of training" challenges, renamed to include other aspects which affect the cost like software and hiring people which is the technical resource at initiate stage of the integration.

Similarly, each strategy outlined in the framework reviewed thorough to assess its relevance and alignment with the identified challenges. Strategies that were considered unrelated or redundant were discarded, while necessary modifications were made to ensure a coherent and effective integration approach. One more strategy (added as the result of the expert's discussion and proposed challenges), Internal design coordination moved to the "Technical Integration and Coordination", strategy number 21 modified to "Commitment to long-term collaboration" for better clarification. First group changed from "Stakeholder Engagement and Education" to "Stakeholder Engagement and Improvement."

According to the focus group findings currently there is no support from New Zealand government in terms of implementing OSC and BIM and "Government support" strategy renamed to "Seek for government support" as a potential strategy. Finally, the assignment of responsible stakeholders to the identified challenges was carefully evaluated to ensure clarity and accountability. Adjustments were made as needed to accurately reflect the roles and responsibilities of each stakeholder in addressing the integration challenges. Detailed refinements are provided in the Figure 9.7. This review process aimed to refine the framework's components strategic direction, ensuring that it provided actionable guidance for addressing integration challenges effectively and helps projects to move step by step towards better integration.

## 9. 5 Discussion

The primarily aim of this research is to facilitate the integration of OSC and BIM across various maturity levels and project life cycle phases by developing a strategic framework. The framework is designed to simplifies processes, optimize resource utilization, and ultimately elevate project outcomes by systematically addressing integration challenges and aligning strategies with responsible stakeholders. It emphasizes that successful integration requires a combined effort across different stakeholders and project stages.

### 9.5.1 Multidimensional Nature of OSC and BIM Integration

Each framework stage plays a crucial role in navigating the complexities of integration across different maturity levels and project life cycle phases in a simple way. For transition from one level to another, projects need to prioritise various factors based on their current level and the targeted one (Razkenari & Kibert, 2022). At lower levels, these actions include building foundational knowledge and awareness of integration challenges by investing in training and education initiatives to equip stakeholders with the necessary skills and understanding which is a significant challenge in integration (Razkenari & Kibert, 2022; Zou et al., 2022). While moving to another level, projects must focus on enhancing communication and collaboration among stakeholders (Wang et al., 2022), continues improvement, establishing clear channels for information. These examples show how identifying improvements area will help projects to move to higher levels of integration in a simple way by meeting the criteria of previous level.

### 9.5.2 Integration Challenges Across Project Lifecycle and Maturity Levels

The integration challenges of OSC and BIM evolve through the project lifecycle, with each phase presenting unique challenges. In the initiation phase, challenges focus on defining clear objectives and addressing knowledge gaps, aligning with System Integration Theory, which emphasizes the need for technological coordination (Kossiakoff et al., 2011). This research contributes by emphasizing the importance of early stakeholder engagement to overcome these gaps. In the planning phase, aligning integration goals with project objectives and ensuring adequate resources reflect Strategy Development Theory, which stresses aligning internal capabilities with external opportunities (Porter, 1991). This study highlights how strategic planning aids integration at this stage.

During the execution phase, technical resource management and communication between offsite and onsite teams become crucial. Issues such as the misalignment of software platforms used by different teams or insufficient training in data handling can exacerbate coordination difficulties. This aligns with Organisational Structure Theory, emphasizing the need for organisational adaptation to support new technologies (Mintzberg, 1980). This research fills a gap by illustrating how these challenges can be managed through structural and technological alignment. In the monitoring phase, tracking performance and addressing deviations require consistent monitoring across stakeholders, in line with System Integration Theory which highlights the importance of a standardised approach to monitoring.

Finally, in the closeout phase, transitioning project data and capturing lessons learned align with Strategy Development Theory and Organisational Structure Theory (Freeman, 2010; Kossiakoff et al., 2011; Mintzberg, 1980), emphasizing clear processes for knowledge transfer.

This study contributes by proposing a structured closeout phase to ensure continuous improvement which is mentioned throughout the cases studies as well.

Looking at vertical side of the framework, at initial level, challenges stem from ad-hoc adoption of technologies and limited awareness of challenges. Stakeholders often lack the necessary skills and understanding of OSC and BIM technologies which spreads through the whole project life cycle at this level (Innella et al., 2019). Early engagement of the stakeholders and educating them can help foster alignment and commitment. Moreover, as design need to be freeze before consent application, early collaboration will help to avoid any further changes (Razkenari et al., 2020). Developing short-term action plans and mandating BIM usage through contractual provisions can provide clarity and direction for integration efforts. Strategies suggested at this level, aims to develop the fundamental knowledge where BIM and OSC can thrive. Contractors and consultant handle technical coordination, and guidelines implementation, while clients ensure sustained collaboration and commitment to integration goals.

Projects understand integration challenges at the managed level but face limited communication and collaboration among stakeholders. Throughout the project life cycle, challenges vary but often involve communication, coordination, and education. In the planning phase, poor information flow and client understanding hinder integration. During execution, inadequate information exchange and training, along with the need for centralized coordination, pose challenges. The monitoring and closeout phases require ongoing education, coordination, and clear deliverables to ensure sustainable integration. Mitigation strategies, based on stakeholder management and system integration theories, focus on enhancing communication, collaboration, and stakeholder engagement. These strategies help align stakeholders and improve project outcomes.

According to stakeholder management theory (Atkin & Skitmore, 2008; Freeman, 2010), early engagement and collaboration reduce conflicts and improve project performance. In Case 1, the consultant initiated a digital collaboration platform during the closeout phase, improving communication and aligning with integration standards. Similarly, Case 2 highlights the importance of early coordination with manufacturers to minimise delays during construction. These examples demonstrate how continuous collaboration across all project phases is essential for effective OSC and BIM integration, as supported by system integration theory (Kossiakoff et al., 2011). Regular stakeholder engagement, as seen in the case studies, facilitates seamless integration and drives project success.

At the defined level, stakeholders face technical and cultural challenges, coupled with issues of stakeholder commitment, which can hinder the smooth execution of integration activities. Specifically, poor data management systems or unclear data ownership structures often exacerbate these challenges. To address these issues, creating short-term action plans, mandating BIM usage through contractual provisions, and adopting data-sharing protocols are essential strategies.

Moving to the next level, quantitatively managed includes continuous improvement initiatives and measured integration activities. Significant challenges emerge across project phases, notably including the lack of clarity in client objectives during initiation, the need for early contractor involvement in planning, and challenges in information exchange and quality control during execution. Mitigation strategies centre around proactive stakeholder engagement, clear communication of outcomes and benefits, and the establishment of collaborative approaches. KPIs (key performance indicator) can be established to assess integration success based on various metrics, including stakeholder engagement levels, adherence to action plans, BIM usage rates, and the effectiveness of collaboration efforts. Implementing structured documentation and promoting information sharing are key aspects of quantitatively managed. Lessons learned from each phase can be systematically documented and shared among stakeholders, enabling continuous learning and improvement throughout the project lifecycle.

In the Optimized stage of integration, challenges persist throughout the project's progression, particularly in financial matters and cash flow management, recurring across various phases from initiation to closeout. Stakeholders hold pivotal roles in addressing these challenges through early involvement, education, and the implementation of control measures. It's crucial at this stage to bring others up to speed and enhance integration methods, although securing adequate technical resources presents a significant hurdle. Strategies such as early stakeholder engagement, education, and transparent communication of objectives facilitate effective collaboration and expectation management.

Utilising coordination platforms aids in efficient communication, while control adjustments and change management processes proactively tackle issues. Proactive financial management and resource allocation remain crucial, highlighting the importance of adaptability and adherence to industry standards for achieving optimization. The persistent challenges identified, highlight the ongoing importance of proactive stakeholder engagement and transparent communication throughout the project journey. Furthermore, the adaptable nature of integration strategies demonstrates the need for continuous evolution in response to stakeholder capabilities, project dynamics, and improving cohesive and collaborative environment.

While this study focuses on the New Zealand construction sector, it is important to note that the survey design and conceptual framework were grounded in an extensive literature review encompassing studies conducted globally (Likita et al., 2023; Liu et al., 2021b; Moshtaghian & Noorzai, 2023; Ocheoha & Moselhi, 2018; Sooriyamudalige et al., 2020; Tang et al., 2019a). These studies provided insights into challenges, strategies, and integration factors from diverse contexts, including regions with advanced OSC and BIM. For example, the strategy of early stakeholder engagement, a critical theme in this study, aligns with findings in UK-based research highlighting its importance for OSC adoption. Similarly, the emphasis on policy regulation echoes studies from China and Singapore, where governmental mandates have significantly accelerated OSC and BIM integration (BCA, 2016; Jiang et al., 2021). Although the findings reflect New Zealand's unique industry characteristics, such as its relatively small market size and emerging expertise in OSC and BIM, the study incorporates globally recognised practices, enhancing its applicability to other contexts.

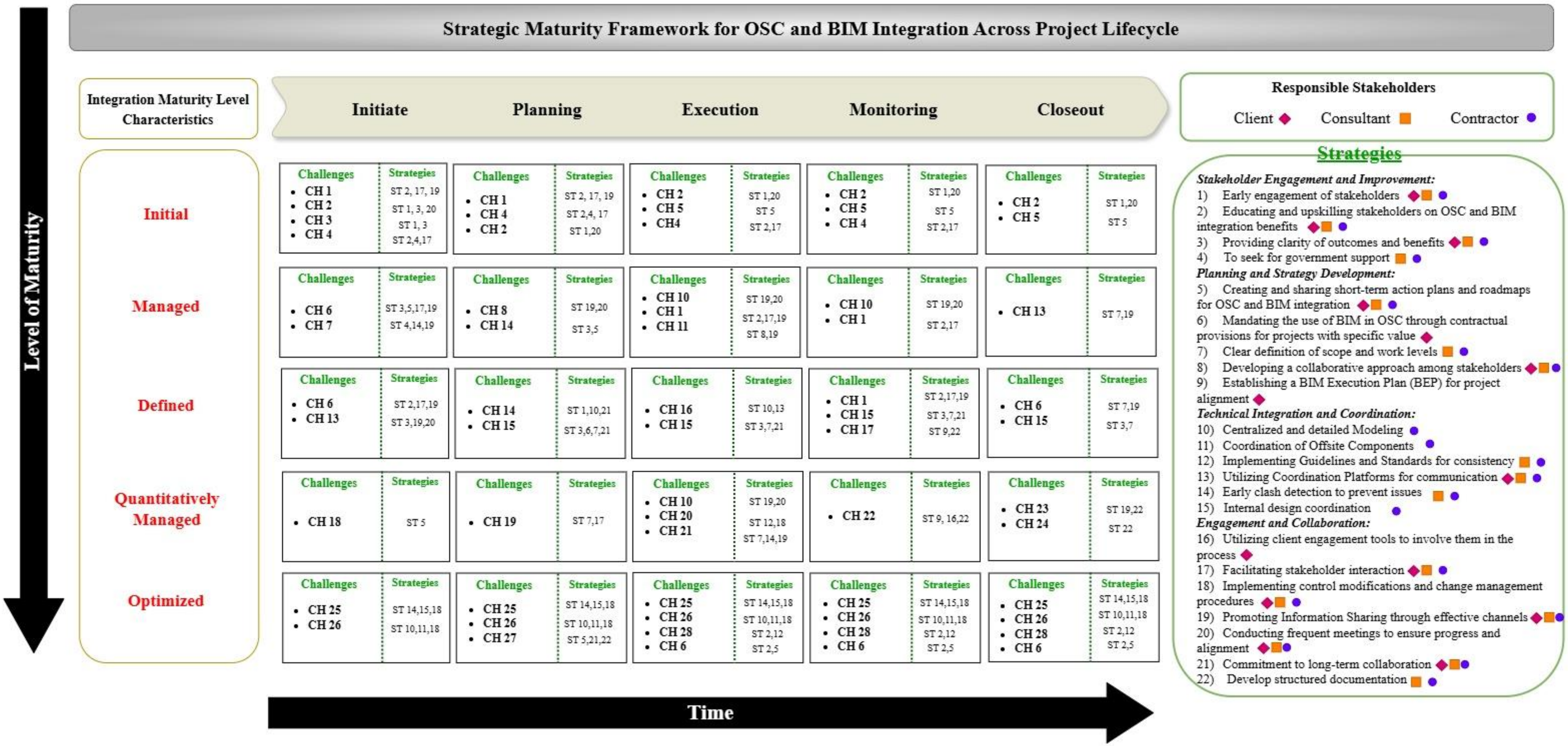


**Figure 9.7:** Refined Strategies Maturity Framework for OSC and BIM Integration Across Project Life Cycle

## 9. 6 Conclusion

This study developed a structured integration framework for OSC and BIM to achieve higher levels of integration. It identified key challenges, such as limited stakeholder awareness, financial constraints, and inadequate communication, and proposed strategies like early engagement, clear planning, and technical collaboration to address them. Stakeholders play distinct roles: clients focus on engagement and mandating BIM, contractors handle technical integration, and consultants ensure effective interaction. The framework highlights a progression from addressing foundational issues to exploring advanced technologies, emphasizing continuous innovation and adaptation across project life cycle stages.

***Academic Implications***

This study contributes to the academic understanding of OSC and BIM integration by addressing several key theoretical concepts. By developing a comprehensive integration framework, the study provides valuable insights into system integration within the construction sector, illustrating how BIM and OSC can be aligned to enhance overall project performance. The framework also emphasizes the importance of strategy development in guiding stakeholders to overcome integration challenges, particularly through structured approaches to planning and execution.

Additionally, the research underscores the significance of stakeholder management, showcasing how clients, contractors, and consultants each play distinct roles in driving successful integration. The study highlights the need for tailored approaches to managing these stakeholders' involvement in early engagement, technical integration, and ongoing collaboration. Furthermore, the study explores the role of organisational structure in facilitating OSC and BIM integration. By aligning integration strategies with organisational practices and processes, the research provides a deeper understanding of how structural factors influence the success of integration efforts.

The research also introduces a maturity model, which tracks the progression of integration across different project life cycle stages and maturity levels. This model emphasizes continuous improvement, suggesting that successful integration requires an evolving approach that adapts to emerging challenges and opportunities throughout the project lifecycle. Through these contributions, the study enriches the theoretical discourse by systematically addressing integration challenges at different stages and maturity levels. It lays a foundation for future research into the application of these concepts and offers a comprehensive framework for researchers and practitioners to further explore integration in the context of OSC and BIM.

***Practical Implications***

From an industry perspective, the study provided a practical framework that stakeholders can use to enhance OSC and BIM integration. The framework, which involves four stages—Diagnostic Checklist, Integration Pathway, Strategies Interventions, and Stakeholders Management—offers a strategic approach to managing risks and optimizing resources. Integrating BIM into OSC workflows can enhanced productivity and project delivery, despite the challenges posed by OSC. Practical recommendations include early stakeholder engagement, clear planning, technical integration, and enhanced collaboration. Different stakeholders have distinct roles: clients should prioritise early engagement and mandate BIM usage in contracts, contractors should focus on technical integration and coordination, and consultants should facilitate interaction and provide expertise. This structured approach assists stakeholders in effective financial planning, overcoming financial challenges, and ensuring successful implementation of integration initiatives.

Furthermore, the findings highlight the importance of ongoing education and training initiatives to enhance stakeholder awareness of OSC and BIM integration. By addressing the gap in industry practice, the study promotes a more collaborative and efficient approach to OSC and BIM integration, setting industry standards and improving project outcomes.

Moreover, the framework offers a practical tool for industry practitioners to implement BIM across different project life cycle stages and maturity levels, providing structured guidance for enhancing integration efforts. Emphasizing stakeholder engagement, financial planning, and resource management addresses common industry challenges, promoting a more efficient approach to OSC and BIM integration.

This study has some limitations. The applicability of the measurements may be limited to New Zealand construction projects, as the data were derived from a sample specific to this region. However, a similar approach could be adapted for studying integration practices in other countries. Although the sample size of 116 participants meets the general requirements for conducting regression, a larger sample size could enhance the accuracy of the findings. Additionally, the survey revealed that 40 percent of respondents had less than 5 years of BIM experience, and over 30 percent had less than 5 years of OSC experience. This distribution reflects the current demographic profile of professionals in New Zealand construction, particularly in relation to emerging technologies like BIM and OSC. Finally, case studies were selected based on data accessibility and their relevance to OSC and BIM integration. Further investigation into additional case studies from similar sectors would be beneficial.

While the findings are rooted in the New Zealand context, the framework incorporates globally recognized practices from an extensive literature review, enhancing its potential for broader applications. Regional differences, such as market maturity and policy environments, may influence its direct applicability in other contexts. Future research could compare its implementation across diverse regions to further validate and refine the framework. Additionally, future studies should quantitatively assess the framework's effectiveness, perhaps through comparative analysis between projects that use the framework and those that do not. Testing the framework through performance metrics (e.g., cost, time, and quality indicators) will help demonstrate its measurable benefits and contribute to refining its application in various project settings.

# Chapter 10: Conclusion and Recommendation

## 10. 1 Research Overview

The research study has successfully achieved its objectives, which were centred around improving the integration of OSC and BIM in the New Zealand construction industry. The integration of these two concepts is considered essential for enhancing the efficiency, sustainability, and overall performance of construction projects. Current research continuously emphasizes the significance of integrating OSC and BIM and seeks to improve this integration by addressing the associated challenges. While previous studies have shown a growing interest in this area, focusing on lean principles, advanced technology, and the cost and time benefits of integration, there is a gap in research specifically identifying the challenges faced by stakeholders and the strategies to mitigate them.

In this research, the focus on the project level reflects the contextual contingencies encountered during the study, particularly the accessibility of project-level data and the greater flexibility for implementing changes at the project level compared to the organisational or industry levels. Thus, contingency theory supports the choice of narrowing the research scope to projects, as this approach best suited the constraints and opportunities presented by the research environment in the construction industry.

These challenges can occur at different stages of the project lifecycle and may vary based on the current level of integration within a project. Therefore, identifying these challenges can provide valuable insights into how projects can progress towards higher integration maturity levels. This study aims to advance the integration of OSC and BIM at the project level by developing a framework that guides stakeholders through different phases of the project lifecycle, enhancing integration maturity and overall project performance. Moreover, it intends to offer a new perspective and classification of challenges, contributing valuable knowledge to the field of construction management.

This chapter is dedicated to disseminating and classifying the significant findings of this study. Initially, the achievement of the research objectives listed below was discussed using the logic presented by the thesis. The research aimed for:

1) Assess the current state of OSC and BIM integration research and identify factors influencing integration globally and in New Zealand.
2) Develop a conceptual integration framework for OSC and BIM in the New Zealand construction industry at the organisational and project levels.
3) Explore underlying factors and investigate the relationships and effects of factors affecting integration in the New Zealand construction industry.
4) Analyses challenges from a multi-level perspective (stakeholders, project lifecycle and organisational level) in the New Zealand construction industry.
5) Develop an integration maturity assessment framework for OSC and BIM within New Zealand construction projects.
6) Identify effective strategies for OSC and BIM integration and clarify the roles and responsibilities of stakeholders in implementing these strategies across project lifecycle stages.
7) Create a framework to integrate OSC and BIM in the New Zealand construction industry, addressing lifecycle challenges towards integration maturity.

The discussions begin by outlining the connections between the findings and how they contribute to achieving the research objectives (Section 10.2). Following this, two dedicated sections delve into the research contributions to both construction management theory (Section 10.3) and practice (Section 10.4), thoroughly highlighting the key conclusions and findings. These sections emphasize how the study advances theoretical understanding and offers practical insights for industry application. Finally, the discussion addresses the limitations of the research (section 10.5), providing a critical evaluation of the study's scope and potential areas for future investigation.

## 10. 2 Objective Development

The primary focus of this study is to create a strategic framework aimed at improving the integration of OSC and BIM in the New Zealand construction industry by implementing strategies to mitigate challenges across the project lifecycle. To achieve this goal, the study developed seven research objectives, and a summary of how each objective was achieved is outlined in the following subsections.

### 10.2.1 Objective 1- Assess the current state of OSC and BIM integration research and identify factors influencing integration globally and in New Zealand

Objective One was achieved in Chapters Two and Three of this thesis. In Chapter Two, the study reviewed previous research first to assess the current state of OSC and BIM adoption and integration and second to identify the factors affecting OSC and BIM integration. The findings of scientometric analysis indicated that New Zealand lags behind OECD (Organisation for Economic Co-operation and Development) countries in integrating OSC and BIM. Based on the selected keywords-related themes tracked since 2005, the peak number of research on OSC and BIM occurred during 2017-2018, with the United States, Canada, China, the United Kingdom, and Hong Kong leading the way (Figure 3.3). Notably, no previous studies on OSC and BIM integration have been conducted in New Zealand.

From 2000 to 2021, there has been a clear upward trend in the progression of themes in academic publications, showing a clear upward trend of research in OSC, prefabrication, and new technologies (Figures 3.4 and 3.5). Research themes have evolved to include OSM, modular construction, sustainable building, productivity, and the potential of BIM for these areas. Studies have also explored Design for Manufacturing and Assembly (DFMA), Lean principles, and digital technology adoption. This analysis indicates that while many aspects of OSC and BIM have been investigated recently, there is an evident lack of studies specifically addressing the integration of OSC and BIM.

The next stage focused on identifying challenges and strategies for OSC and BIM integration globally and in New Zealand to achieve Objective One fully. Since no comprehensive study had previously reviewed integration challenges, each concept was separately reviewed, and interviews were used to develop and confirm the OSC and BIM integration challenges. Six clusters of challenges were identified for OSC: transportation, training and experiences, planning and designing, financial, collaboration and commitment, and industry innovation and process (Table 3.1).

For BIM implementation, challenges such as lack of knowledge, human resources, financial constraints, legal issues, interoperability and collaboration, and lack of standardisation were identified (Table 3.2). Initially, six integration strategy clusters were identified through the systematic literature review (SLR) (Table 3.3). Then, semi-structured interviews confirmed and complemented the findings of the SLR stage, categorising significant OSC and BIM implementation challenges (Tables 3.5 and 3.6) and identifying additional integration strategy clusters, including policy documentation and technology management (Table 3.7).

The literature review revealed that both OSC and BIM face significant implementation challenges, reflecting common underlying issues in the construction industry. A major shared challenge for both OSC and BIM is the lack of skilled operatives and insufficient training programmes. This indicates a critical need for better educational frameworks and continuous professional development to support the adoption of these technologies. Additionally, both OSC and BIM suffer from low standardisation and insufficient industry standards, underscoring the importance of developing comprehensive guidelines and demonstrating clear business value. Financial constraints also pose a significant challenge for both OSC and BIM, with high initial costs and other financial barriers impeding widespread adoption. Addressing these financial challenges requires strategic investments and financial incentives to mitigate the initial economic burden and foster long-term benefits.

Collaboration and human factors present another common challenge. OSC faces issues of poor coordination and stakeholder collaboration, while BIM struggles with cultural resistance and reluctance to share data. Enhancing communication strategies and fostering a collaborative industry culture are vital steps toward overcoming these barriers. However, OSC and BIM also face unique challenges. OSC deals with transportation issues, such as module transport difficulties and design limitations due to transportation restrictions. In contrast, BIM encounters legal constraints, including intellectual property concerns and the absence of mature BIM contracts. Therefore, projects aiming to integrate these two concepts need to consider the unique challenges associated with each.

Interviews with New Zealand experts supported the findings and highlighted unique local challenges. New Zealand's small and remote construction environment limits OSC viability, and conservative industry attitudes hinder technological adoption. Additionally, limited digital documentation practices and resistance to change further impede progress. While New Zealand faces common challenges in OSC and BIM integration similar to other countries, the local context presents additional, unique challenges. Addressing these requires adapted strategies that consider New Zealand's specific industry characteristics and support needs. Therefore, a comprehensive list of factors affecting OSC and BIM integration was explored.

### 10.2.2 Objective 2. Develop a conceptual integration framework for OSC and BIM in the New Zealand construction industry at the organisational and project levels

Chapter 3 of the thesis contributed to achieving Objective Two of this research by presenting a conceptual framework for OSC and BIM integration challenges and strategies as the preliminary study findings (Figure 3.6). Findings from Objective One were used to develop the conceptual framework. The developed framework consisted of three components: the challenges, the identified strategies, and the application level. Six groups of challenges and strategies derived from the literature were refined through the interview process, with some being excluded, some modified, and additional factors added.

The framework provides a tool for identifying strategies to address challenges. For example, lack of periodic meetings, insufficient collaboration, and poor integration can be mitigated by early planning and engagement, which reduces rework. This strategy falls within the communication cluster identified in the interviews. Early involvement requires new forms of contracts, which is another strategy cluster in the framework (Figure 3.6). This approach shows that challenges and strategies are interrelated, meaning one strategy can help solve multiple challenges. The framework (Figure 3.6) helps stakeholders identify and address challenges in applying OSC and BIM.

### 10.2.3 Objective 3- Explore underlying factors and investigate the relationships and effects of factors affecting integration in the New Zealand construction industry

To achieve Objective Three, the study examined the challenges and strategies of integrating OSC and BIM among industry professionals. Additionally, integration itself was assessed using different questions as a third group to investigate the relationship among different factors (Chapters 5 and 6). Consequently, three underlying factors for challenges were proposed

(Tables 5.4 and 6.3). The first one is named "Implementation Cost", as it includes items related to the expenses of implementing OSC and BIM, including associated training costs. This name reflects the financial burdens associated with adopting these technologies. The second factor is "Integrated Knowledge Deficit", as it involves items representing the lack of knowledge necessary for effective OSC and BIM integration. This name indicates a gap in the integrated knowledge required for the integration process. The third factor for challenges is the "Competency and Preparedness Deficit," including items related to the lack of skills and readiness among stakeholders for integrating OSC and BIM. The name signifies a shortfall in the necessary competency and preparedness.

Mitigation strategies include two underlying factors: "Integration Facilitators" and "External Support and Policy Regulation." (Tables 5.4 and 6.3). The former highlights tools and methods that ease the integration of OSC and BIM, emphasizing factors aiding the integration process. The latter relates to external strategies such as governmental support, financial incentives, and policy regulations, reflecting external influences that can either promote or hinder integration. Finally, integration is presented with three underlying factors (Tables 5.4 and 6.3): "BIM-Driven OSC Readiness," "BIM-Enabled Collaboration and Facilitation," and "BIM-Enabled OSC Enhancement." The first factor indicates the overall understanding and preparedness for integrating OSC and BIM, driven by BIM capabilities. The second factor relates to the collaborative and facilitative aspects of using BIM in OSC processes, signifying the collaborative enhancements enabled by BIM. The last factor includes items related to the improvements in OSC facilitated by BIM, highlighting the enhancement of OSC through BIM integration.

To investigate the relationship and effects of each challenge and strategy on different integration factors, the study employed Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM). The findings revealed that Implementation Costs and Competency and Preparedness Deficits significantly affect BIM-Driven OSC Readiness, while External Support and Policy Regulation positively influence integration. The study also showed that challenges and strategies have varied effects on BIM-Enabled Collaboration and Facilitation, as well as BIM-Enabled OSC Enhancement. Additionally, experience in construction and OSC significantly impacts integration readiness. By using a quantitative methodology, the study classified challenges, strategies, and integration factors into eight fundamental groups, establishing a robust framework and revealing the critical role of underlying factors in achieving improved integration.

### 10.2.4 Objective 4- Analyses challenges from a multi-level perspective (stakeholders, project lifecycle and organisational level) in the New Zealand construction industry

Objective Four was achieved in Chapters 6 and 7 in three stages. In the integration process, various stakeholders are involved, and different resources need to be provided by various stakeholders working collaboratively; therefore, stakeholders' (client, consultant, and contractor) influence over the various challenges was investigated. One significant challenge revolves around ensuring transparency in the OSC manufacturing process. Contractors emphasize clear communication from manufacturers to manage resources efficiently and meet project deadlines. Conversely, consultants prioritise accurate information for integrating OSC components into BIM models to meet design specifications and regulatory requirements. Another challenge arises from the temporary nature of construction projects. Contractors focus on efficient task completion within project timelines, while consultants consider long-term implications, aiming for alignment with sustainable design principles.

Transportation and logistics pose additional challenges for both contractors and consultants. Contractors manage logistics to avoid delays and disruptions in onsite installation, while consultants optimize transportation routes for cost and environmental sustainability. Effective communication is essential to address these challenges collaboratively. Clients prioritise clear communication channels to ensure project requirements are understood and met, while contractors rely on communication to coordinate work activities and manage challenges onsite. Understanding these differences helps the stakeholders to prioritise their resources, develop targeted strategies and enhance stakeholder engagement (Chapter 7).

Following this, integration challenges encountered across the project life cycle were explored (Chapter 8). In the initiation phase, issues concerning implementation costs and integrated knowledge deficit surfaced, although lacking statistical significance. The high costs and lack of information symmetry during this phase may complicate decision-making and resource allocation processes. Transitioning to the planning phase, challenges become more pronounced, with both implementation costs and integrated knowledge deficit significantly affecting outcomes. The burden of high training and implementation expenses, coupled with insufficient transparency and knowledge gaps, presents an impressive challenge to effective planning (Figure 8.2).

As projects progress to the execution phase, challenges pertaining to both implementation costs and competency and preparedness deficits become prominent. Cost constraints might hinder timely task execution, while a deficiency in industry standards and expertise could compromise quality and efficiency. In the monitoring and controlling phase, competency and preparedness deficits play a pivotal role in project oversight, underscoring the significance of industry standards and skilled personnel for ensuring project success. Although challenges related to implementation costs and integrated knowledge deficit may not be statistically significant during the close-out phase, they could still exert indirect effects on final project delivery and handover processes.

To comprehensively address Objective Four, challenges at different organisational levels were analysed (Chapter 8). At the project level, challenges stem from an integrated knowledge deficit and competency and preparedness deficit, impacting project team dynamics and performance. Inadequate training and expertise may impede collaboration and innovation within project teams. Zooming out to the organisational level, challenges related to both implementation costs and integrated knowledge deficit appear significant, affecting organisational effectiveness and strategic decision-making. High costs and knowledge gaps may impede progress and hinder the adoption of innovative practices.

At the industry level, competency and preparedness deficits emerge as significant challenges, highlighting systemic issues such as a lack of industry standards and skills shortages. These challenges hinder industry-wide progress and innovation, limiting the realisation of OSC and BIM integration's full potential. The prevalence of implementation costs and integrated knowledge deficit across different project phases and organisational levels underscores their pervasive nature within the industry. These challenges often intersect, exacerbating project complexities and organisational inefficiencies. Conversely, competency and preparedness deficit challenges exhibit varying degrees of influence across different project phases and organisational levels. While significant at certain stages, their impact may be mitigated by factors such as project management practices and organisational capabilities (Figure 8.2).

### 10.2.5 Objective 5- Develop an integration maturity assessment framework for OSC and BIM within New Zealand construction projects

Objective five was achieved in Chapter Seven. The developed framework (Figure 8.3) based on integration maturity levels effectively illustrates the characteristics introduced at each stage of integration, providing stakeholders with a clear understanding of their current integration status and the necessary steps to move forward. Notably, as the maturity level increases, the degree of integration will increase as well. The subsequent section of the model provides information on integration challenges derived from the survey and validated through case studies. This section examines each challenge explicitly within the context of case studies, elaborating on associated challenges at each maturity level. This comprehensive approach not only explains how integration is evolving but also provides a detailed understanding of the challenges, helping create practical strategies and enhancements for better integration of OSC and BIM in the construction industry.

The maturity levels include Initial, Managed, Defined, Quantitatively Managed, and Optimized. At the Initial level, projects adopt OSC and BIM reactively without strategic planning or using standardised guidelines, which results in fragmented implementation. Progressing to the Managed level, projects begin to identify integration challenges but still lack unified approaches. At the Defined level, projects establish clear integration strategies that enhance communication and collaboration among stakeholders. Moving toward Quantitatively Managed, projects adopt a data-driven approach to measure integration activities and implement continuous improvement initiatives. Finally, at the optimized level, projects prioritise innovation and refinement, exploring advanced technologies and industry best practices to enhance integration efforts systematically across individual projects.

The case study reviews explored the challenges faced by each project, irrespective of its scale or scope. These challenges notably included time constraints, stakeholder commitments, and technical complexities. Such challenges underscored the significance of effective project management, change management strategies, and specialised technical know-how. However, variations existed among the projects, with some dealing with cultural resistance to digital transformation and the necessity for centralised coordination. In contrast, others encountered issues related to regulatory compliance, detail in 3D models, and cost management.

These disparities demonstrate the diverse group of challenges inherent in OSC and BIM integration, necessitating tailored strategies for each project. Nevertheless, amongst these differences, common themes emerged, including the importance of effective communication, stakeholder engagement, and precise planning.

By positioning each case study within this maturity framework, stakeholders can evaluate their current state and progress towards higher maturity levels. This approach not only tracks the evolution of OSC and BIM integration but also provides a detailed understanding of associated challenges, fostering the development of practical strategies for better integration. Ultimately, the framework highlights the importance of effective collaboration, strategic planning, and continuous improvement in enhancing the maturity and success of OSC and BIM integration in construction projects.

### 10.2.6 Objective 6- Identify effective strategies for OSC and BIM integration and clarify the roles and responsibilities of stakeholders in implementing these strategies across project lifecycle stages

Strategies to mitigate challenges and identify responsible stakeholders were explored to achieve Objective Six (Chapter 9). Results from surveys and case studies were used to compile a comprehensive list of effective strategies (Table 9.2). “Integration Facilitators” and “External Support and Policy Regulation” were explored through surveys and then confirmed by reviewing the case studies. Additionally, key strategies for integrating OSC and BIM emerged from the examined cases.

For example, in Case 1, the project led the establishment of a digital collaboration platform, employing parametric approaches and adhering to ISO 19650 standards for information management. Case 2 prioritised early engagement with manufacturers and suppliers to mitigate construction phase risks, promoting a collaborative project approach. In Case 3, stakeholders focused on early 3D modelling and frequent meetings to ensure accuracy and compliance with project requirements alongside robust clash detection processes. Case 4 emphasized early coordination with consultants, employing industry standards, and enhanced data management practices (Figure 9.2).

Following this, the responsible stakeholders for implementing strategies were explored through case study reviews. Throughout these cases, stakeholders, including consultants, contractors, and clients, played critical roles in implementing strategies to address specific project challenges, fostering successful OSC and BIM integration. In Case 1, the contractor adopted a parametric approach and collaborated on script development, while in Case 2, the client reduced control over the model to foster collaboration among all project participants.

In Case 3, both consultant and contractor focused on 3D model development and clash detection, with all project stakeholders checking material specifications and participating in frequent meetings. In Case 4, the contractor initiated early coordination and managed data validation, the consultant ensured adherence to industry guidelines and standards, and the client implemented regular review processes and collaborated closely with suppliers. These examples illustrate how various stakeholders in each case study took responsibility for implementing specific strategies to enhance OSC and BIM integration. The findings highlight the critical importance of targeted strategies in overcoming integration challenges, ultimately enhancing OSC and BIM integration in construction.

### 10.2.7 Objective 7- Create a framework to integrate OSC and BIM in the New Zealand construction industry, addressing lifecycle challenges towards integration maturity

Objective Seven achieved through a four-stage integration framework presented in Chapter Eight. The framework (Figure 9.5) begins with a Diagnostic Checklist that outlines the characteristics of each maturity level. This checklist allows project stakeholders to assess their status and identify specific areas that need improvement. The next stage, the Integration Pathway, helps stakeholders understand their current and future challenges as they progress through different levels of the project life cycle and maturity. This pathway provides a roadmap for projects to navigate through various stages of integration, anticipating and addressing potential challenges.

The third stage is Strategic Intervention, which follows challenge identification and is a crucial stage in the framework. Strategies may be continuous throughout several project lifecycle stages, such as training or maturity level enhancements, or they may occur once, such as early stakeholder engagement, which should occur in the project's early phases. The last stage of the framework, the Stakeholder Management Plan, identifies who is responsible for dealing with these challenges. It clarifies whether all stakeholders, specific groups or individual members are responsible for addressing specific issues. This clarity ensures that stakeholders are prepared and can use strategic interventions effectively. It emphasizes the importance of collaboration and coordinated efforts among stakeholders to achieve successful integration.

A focus group session involving experienced BIM and OSC experts was organised to validate and enhance the developed framework (Figure 9.6). The experts discussed the clarity, comprehensibility, and applicability of the framework, focusing on the alignment of challenges with specified stages and the assignment of responsible stakeholders. Key suggestions included demonstrating “Time” and “Maturity Level” with arrows for better clarity. The discussion identified new challenges, such as the lack of practical processes and consistency in monitoring approaches, while refining existing challenges for accuracy. Strategies were also reviewed, with irrelevant ones discarded and modifications made for coherence, such as renaming “Government support” to “Seek for government support.” The assignment of responsible stakeholders was evaluated to ensure clarity and accountability, ultimately refining the framework to provide actionable guidance for effective OSC and BIM integration.

The framework emphasizes continuous improvement and adaptation. As projects move through the integration pathway, they can refine their strategies based on feedback and lessons learned. This iterative approach ensures that integration practices evolve and improve over time. Overall, this finding contributes to simplifying the integration of OSC and BIM through a structured framework and understanding of integration in New Zealand. It demonstrates that specific strategies and approaches can enhance the integration of OSC and BIM by addressing specific challenges.

## 10. 3 Theoretical Contribution and Recommendation

Certain aspects of this PhD thesis have encouraged contributions of theoretical, technological, and practical significance. Several methods used in this thesis, such as a literature review, interviews, surveys, case studies, and focus group, resulted in theoretical triangulation and more evidence-based findings. The study takes an interdisciplinary approach, combining theoretical data from various sources to establish a foundation for importing new concepts and understanding new knowledge areas. Throughout this research, many categories of theories and concepts were developed. These categories have the potential to generate new perspectives in the domains of integration and collaborative approaches that are relatively unstructured for OSC projects. The study's contributions address a wide range of challenges, including financial, human, and technical issues.

The main theoretical contribution of this study lies in the development of a strategic framework for OSC and BIM integration, which is a novel finding. Such a framework, with the level of detail of strategies, challenges, and actions, was not previously available. The findings go beyond the existing literature and offer a holistic framework for improving integration in the OSC delivery process while implementing BIM. Unlike previous studies that focus primarily on technological improvements, this structured framework considers challenges, the role of stakeholders and maturity integration levels. It offers insights into the factors influencing integration during the project life cycle, helping stakeholders make informed decisions that prioritise their resources.

The integration of dynamic capabilities theory (Teece et al., 1997) and strategy as practice (SAP) (Whittington, 2006) represents an important step forward in understanding how construction firms can adapt to changing market conditions. By emphasizing flexibility, organisational learning, and the ability to reconfigure resources, this study advances the application of strategy development in the context of OSC and BIM integration. However, a limitation of dynamic capabilities theory is its lack of prescriptive clarity on how firms can practically build and develop these adaptive capabilities, especially in industries like construction, where rigid project timelines and budgets often conflict with the need for adaptability. The strategies proposed in this study offer valuable insights, but further research is needed to explore how these capabilities can be cultivated in environments with high financial and operational constraints, such as the construction industry in smaller markets like New Zealand.

The application of General Systems Theory (Bertalanffy, 1969) and cybernetics (Ashby, 1956b) provides a strong foundation for understanding the integration of OSC and BIM as a dynamic system composed of interdependent parts. These theories offer valuable insights into managing interdependencies and feedback loops, which are essential in construction projects involving complex digital and physical processes. However, a limitation of systems theory is that it offers limited guidance on managing practical, real-time communication challenges between disparate digital platforms and organisational subsystems. This study addresses this gap by proposing strategies to enhance communication and collaboration, but future research could further refine these theories in the context of digital transformation and increasingly automated construction processes.

In addition, while cybernetics offers a useful framework for maintaining system stability, the assumption that systems can always adapt to achieve stability may not hold in rapidly evolving technological landscapes like OSC and BIM. The construction industry is frequently disrupted by new technologies, making stability less of a norm. Future research should explore more dynamic systems approaches that reflect the unpredictable and disruptive nature of digital transformation in the construction sector.

The current body of knowledge is expanded, especially regarding the effective implementation of OSC-based projects, through the identification of BIM and OSC integration challenges and strategies. The framework found practical gains from OSC, and BIM could be used as a model for processes and activities at the project and organisational levels (Chapter 3). The database created by these research results will be used in subsequent studies to determine OSC and BIM integration strategies in New Zealand (Chapter 4).

On the other hand, by employing a quantitative technique to validate the challenges and strategies for OSC and BIM integration in construction projects, the research advances the understanding of the subject. The main conclusions drawn from the literature demonstrate a clear relationship between strategies, challenges, and integration, emphasizing the role that challenges play in the constant influence on integration. The study grouped challenges, strategies, and integration factors into eight fundamental variables to enhance comprehension of OSC and BIM integration. Earlier research examined issues such as inadequate information, a competent labour force, and transportation-related constraints. The study's findings offer mitigation strategies. The results are applicable for refining a preliminary guideline for better OSC and BIM integration, as the questionnaire survey evaluated OSC and BIM integration in construction. While the results are not applicable to other types of projects, the methodology used can be replicated for initiatives in other nations worldwide (Chapter 5).

Moreover, the study indicates that underlying characteristics that are not immediately apparent may be crucial in achieving better integration and should be carefully considered. The inherent connections between these notions can be clarified by discussing relationship challenges and strategies. By providing the knowledge for OSC projects and highlighting challenges and strategies that affect integration, the study advances academic research. This strengthens the study's findings' robustness and offers a solid academic foundation, especially when combined with the application of rigorous procedures like EFA, CFA, and SEM. Chapter 6 offers a more systematic understanding of the complexity inherent in OSC and BIM integration by classifying challenges, strategies, and integration elements into eight key types.

According to Chapter 7, the study is anticipated to have a significant impact on improving knowledge of the current situation and determining the best strategies for strengthening OSC and BIM integration in New Zealand. This research contributes to stakeholder theory by exploring the unique challenges faced by different stakeholders in OSC and BIM integration, and whether variations exist. Building on Shenhar and Holzmann (2017) work, it highlights the dynamic nature of stakeholder roles and priorities, which evolve throughout the project lifecycle. By identifying how stakeholder concerns shift over time, this study provides valuable insights for future research, guiding the development of targeted strategies to mitigate integration challenges. It advances the understanding of stakeholder management in complex, multi-stakeholder environments, particularly in the context of construction and digital integration.

Furthermore, the development of a maturity assessment framework (Chapter 8) for OSC and BIM integration is a valuable theoretical contribution that builds on the principles of Capability Maturity Models (CMM). This framework offers practical guidance by linking maturity levels with specific challenges and strategies, enabling stakeholders to assess and improve integration practices systematically. However, a common critique of maturity models, including the one proposed here, is their assumption of linear progression through maturity stages. In practice, organisations may need to jump between levels or even regress due to external market disruptions or technological setbacks.

Additionally, while the maturity model offers a structured roadmap for improvement, it may focus too heavily on process optimization and standardisation, potentially overlooking the need for innovation and creative problem-solving in dynamic and rapidly changing markets like OSC and BIM. Higher maturity levels do not always guarantee better outcomes, as experimentation and adaptability are often crucial to achieving successful integration. Future research could explore how maturity models can account for non-linear progression and how they can balance the need for structure with the flexibility required for innovation and creativity in integration processes.

Lastly, this research proposes a straightforward methodology to close the knowledge gap currently present in the integration of OSC and BIM. The results provide insightful information for future study and development and aid in understanding the strategies and challenges associated with this integration. Adopted integration approaches are crucial, as the dynamic link between project life cycle issues and maturity levels highlights this. Achieving integration excellence requires constant adaptation and improvement. It is recommended by the study to adopt this framework at the project level, using maturity characteristics to assess maturity levels, followed by an integration pathway to understand current and future challenges. The stakeholder management plan then clarifies responsibilities, ensuring that all parties are prepared to address specific issues effectively (Chapter 9).

The findings of this study can inform the development of guidelines and best practices for OSC and BIM integration. These guidelines should focus on mitigating identified challenges and leveraging the strategies outlined in the framework. Academics should focus on specific challenges related to various project life cycles and organisational levels. Future research should aim to deepen the understanding of these challenges and develop related strategies for OSC and BIM integration.

By implementing the results of this study, the construction industry in New Zealand can enhance its OSC and BIM integration practices, leading to more efficient and successful project outcomes. This study not only addresses the existing gap in knowledge regarding OSC and BIM integration but also provides valuable insights for future research and development, emphasizing the need for continuous improvement and tailored integration approaches.

## 10. 4 Practical Contribution and Recommendation

The use of construction expert opinions has provided a measure of validity and significantly contributed to the practicality of this research. By combining theory and practice, the study offers a robust foundation for managerial recommendations. The study has combined different strategies and practices, disseminating classified outcomes that make the knowledge area more accessible to construction professionals and raise awareness of the discussed issues. Research findings can be directly implemented by industry as they have been developed and tested with actual case studies.

The industry would benefit from this study by gaining an in-depth understanding of the challenges and integration processes. Stakeholders can target their investments and efforts where they are most needed, potentially saving costs and improving project efficiency. The study aids in identifying areas where the most training, investments, and actions are required, helping to set priorities and goals to improve the integration of OSC and BIM.

The maturity framework serves as a valuable tool for both projects and organisations within the industry. It aids in identifying essential requirements for progressing towards full integration and guides industry practitioners in implementing BIM across different project life cycle stages and maturity levels. Emphasizing a collaborative approach among stakeholders at various organisational levels is crucial for advancing integration efforts. Ongoing education and training initiatives are essential to enhance stakeholder awareness and understanding of OSC and BIM integration. These initiatives ensure that all parties are well-equipped to handle integration challenges and can effectively collaborate to achieve project goals.

Additionally, the framework assists stakeholders in effective financial planning and resource management, overcoming financial challenges, and ensuring the successful implementation of integration initiatives. This can lead to more efficient allocation of resources and better overall project outcomes. As a structured tool, the framework helps practitioners identify and understand OSC and BIM development and training integration in New Zealand.

These findings are beneficial at a governance level for formulating policies and prioritising research in the implementation of OSC and BIM. Policymakers can apply this study to identify critical topics in OSC for future research and policymaking to enhance productivity. Despite some limitations, the study's findings can be used to enable and improve BIM and OSC integration in any construction industry. The study suggests that future research may focus on examining the correlations between factors affecting integration issues and methods. Further quantitative and qualitative analysis is needed to examine the framework and assess the validity of the findings.

During the initial phases of projects, construction practitioners can benefit from the findings by addressing three identified challenges and factors related to low-level integration. Professionals can thus focus on strategic options like training and developing action plans instead of having to identify challenges. Presenting the primary factors of OSC and BIM integration challenges and strategies to improve relevant guidelines is another main practical implication of this study. The study provides a clear relationship between challenges, strategies, and integration, helping stakeholders understand the connection between factors and use targeted strategies to improve integration. The findings show how the construction industry can use BIM in OSC delivery to make automation quicker and better, helping companies save money, work safely, and stay competitive. The insights gained from understanding these challenges and strategies can help create standardised guidelines for integrating different aspects of construction, making processes more organised and efficient benefiting everyone involved.

Moreover, while the research provides clear practical applications for OSC and BIM integration strategies at the project level, it is important to consider how these findings can evolve in response to market dynamics. A valuable addition to future integration efforts would be the introduction of a feedback loop and lessons learned process. Given the rapidly changing nature of construction markets—driven by new technologies, supply chain fluctuations, and evolving client expectations—feedback collected at key stages of the project can help organisations assess and adapt their integration strategies. This approach ensures that the framework remains responsive to shifts in market demands and can be refined to improve its relevance and effectiveness in future projects.

In dynamic markets, documenting lessons learned from each project is equally important. By capturing insights into both the successes and challenges encountered during OSC and BIM integration, organisations can build a knowledge base that informs better decision-making in future projects. Although the current framework does not explicitly include a feedback loop, incorporating these mechanisms would enable the framework to adapt to market shifts and technological advancements. This forward-looking approach ensures that integration strategies remain flexible, allowing organisations to respond proactively to evolving industry trends and market conditions. Moreover, while the research provides clear practical applications for OSC and BIM integration strategies at the project level, it is essential to outline who will benefit from the framework, when and how it can be applied, and why it holds value in addressing current challenges.

The framework is particularly valuable for project managers, organisational leaders, and policymakers who are directly involved in planning, managing, and overseeing OSC and BIM integration processes. It can be applied during the planning, execution, and evaluation stages of construction projects to improve coordination, address integration challenges, and ensure alignment with project objectives. In practice, the framework offers a structured approach for managing the complexities of OSC and BIM integration, providing clarity on key challenges, recommended strategies, and expected outcomes. It helps organisations streamline workflows, optimise resource allocation, and reduce risks associated with integration failures.

Furthermore, given the rapidly changing construction markets—driven by technological advancements, supply chain disruptions, and evolving client expectations—the framework equips organisations with a proactive tool to adapt to these shifts. While it does not explicitly include a feedback loop or lessons-learned mechanism, future integration efforts could benefit from incorporating these elements to ensure continuous improvement. By adopting this framework, organisations can enhance decision-making, improve project delivery outcomes, and create a foundation for sustained success in OSC and BIM integration efforts.

## 10. 5 Research Limitations

A discussion of possible limitations of this research is as follows:

Firstly, semi-structured interviews with New Zealand experts were conducted to test and confirm the conceptual framework presented in Chapter 2 in September and October 2021. The countrywide lockdowns due to the COVID-19 pandemic in New Zealand affected data collection, as all interviews were conducted online. This situation might have led to less open and honest responses, impacting the depth and richness of the data.

Secondly, the survey sample consisted of participants from various disciplines, ranging from residential to infrastructure sectors. Due to the small size of New Zealand, it was not possible to separate participants to see if there were differences in the results. Although the sample size is satisfactory for most data analyses, the analysis may be limited due to the lack of data. Over 40 percent of survey participants have less than five years of BIM experience, and over 30 percent have less than five years of OSC experience. While this distribution may seem unbalanced, it reflects the current demographic landscape of professionals entering the construction industry, particularly in the context of emerging technologies such as BIM and OSC. Removing these participants would undoubtedly reduce the overall sample size, significantly compromising the statistical power of the analysis. With fewer data points, the ability of the statistical tests to detect significant differences or associations between variables would be diminished. Consequently, the reliability of the significance tests would be compromised, as the statistical power to identify actual effects within the data would be weakened.

Thirdly, the maturity model and results might differ depending on the sector (e.g., building vs. commercial vs. infrastructure) and the type of OSC (e.g., prefab with low levels of OSC vs. volumetric with a high extent of modular/OSC). However, due to the small size of New Zealand and the relatively recent popularity of OSC and BIM, there were insufficient participants for detailed data collection. Moreover, the presented framework only focused on the project level, as organisation and industry levels were not considered due to data accessibility issues.

Finally, a significant limitation is the scope of the research. The study was based in New Zealand, which has a relatively small industry within a specific geographical location separate from the international market. Although the minimum sample and response rate requirements were met in all statistical tests, the small size of the New Zealand construction industry restricts the number of respondents for different analyses. Due to the exploratory nature and complexity of the research, the attributes of challenges and strategies were directly evaluated.

Given the specific context of the New Zealand construction industry, the findings of this study may not be directly generalisable to other countries or larger construction markets. The relatively small sample size and the demographic distribution of participants, particularly in terms of their experience with BIM and OSC, reflect the emerging state of these technologies in New Zealand. Moreover, the challenges of BIM adoption have not been explored, as they fall outside the scope of this research. This study specifically focuses on the challenges and strategies for integrating OSC and BIM. The primary objective is not to address the initial reluctance of practitioners to adopt BIM but rather to develop a framework for effective OSC and BIM integration.

Despite these limitations, the study provides a foundation for future research aimed at extending and generalising the outcomes to other contexts. Future studies could apply the proposed framework in regions with more mature OSC and BIM practices or in larger markets where these technologies are more widely adopted. Additionally, exploring sector-specific variations, such as differences between residential and infrastructure sectors, or varying levels of OSC, could provide further insights. Larger, international studies with more diverse samples could help validate the findings and assess the applicability of the framework beyond the New Zealand context. This would enhance the generalisability of the study's outcomes and contribute to the global discourse on OSC and BIM integration.

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# Appendices

Appendix 1: Ethics Approval

Appendix 2: Literature and Citation Analysis for Chapter 2

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# Appendix 1

## Ethics Approval

MASSEY
UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Dear:

Thank you for the above application that was considered by the Massey University Human Ethics Committee:

at their meeting held on

On behalf of the Committee I am pleased to advise you that the ethics of your application are approved.

Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

Yours sincerely

Dr Brian Finch Chair, Human Ethics Chairs' Committee and Director (Research Ethics)

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Dear:

Thank you for your notification which you have assessed as Low Risk.

Your project has been recorded in our database for inclusion in the Annual Report of the Massey University Human Ethics Committee.

The low risk notification for this project is valid for a maximum of three years.

If situations subsequently occur which cause you to reconsider your ethical analysis, please contact a Research Ethics Administrator.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

**A reminder to include the following statement on all public documents:**

*"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are responsible for the ethical conduct of this research.*

*If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact Dr Brian Finch, Director - Ethics, telephone 06 3569099 ext 86015, email humanethics@massey.ac.nz. "*

Please note, if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to complete the application form again, answering "yes" to the publication question to provide more information for one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

Dr Brian Finch Chair, Human Ethics Chairs' Committee and Director (Research Ethics)

Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand T 06 951 6841; 06 95106840
E humanethics@massey.ac.nz; animalethics@massey.ac.nz; gtc@massey.ac.nz

# Appendix 2

## Literature and Citation Analysis for Chapter 3- OSC Challenges

| Cluster | Grouped challenges and Keywords | References | Citation | Unique citations |
|---|---|---|---|---|
| Transportation | The transportation of modules, Issues of logistics and transport, long-distance transport, Ineffective Logistics, Transportation and logistics considerations, Improper transportation methods, Limitations to design due to transportation restriction | (Aburas, 2011; Arashpour et al., 2016a; Assaad et al., 2020; Bell & Southcombe, 2012; Bertram et al., 2019; Boafo et al., 2016; Boyd et al., 2013; Chauhan et al., 2019; Chi et al., 2015; Gbadamosi et al., 2019; Generalova et al., 2016; Goulding et al., 2015; Hong et al., 2018; Hu et al., 2019; Hwang et al., 2018a, b; Jin et al., 2018; Kolo et al., 2014; Lou & Kamar, 2012; Mao et al., 2015; Mirus et al., 2018a; Phillips et al., 2016; Rahman, 2014; Smith & Quale, 2017; Steinhardt & Manley, 2016; Tam et al., 2015; Zhai et al., 2014; Zhong et al., 2017) | 28 | 28 |
| Training and experiences | Training, Unavailability of training, Lack of trained and skilled operatives, Lack of educational programme. | (Aburas, 2011; Arashpour et al., 2016a; Arashpour et al., 2016b; Ayalp & Ay, 2020; Boafo et al., 2016; Gan et al., 2018a; Gan et al., 2018b; Gao et al., 2020; Generalova et al., 2016; Goulding et al., 2015; Ho et al., 2018; Hong et al., 2018; Hwang et al., 2018a; Jang et al., 2021; Kamali & Hewage, 2016; Lou & Kamar, 2012; Mao et al., 2015; Mirus et al., 2018a; Rahman, 2014; Razkenari et al., 2020; Smith & Quale, 2017; Tam et al., 2015; Zhai et al., 2014; Zhang et al., 2018) | 24 | 16 |
| | Project management knowledge, Lacking knowledge and expertise, Lack of a knowledge portal, lack of contractor experience, Poor understanding | | | 27 |
| | Lack of experience, Absence of technically skilled trained labour, Lack of skilled labour, limited skilled on-site labour available, lack of manufacturer or suppliers' skills, Lack of technical experience, Lack of experienced technicians | | | 18 |
| Planning and designing | Inflexible for late design changes, lack of standard designs, low standardisation, lack of repetition possibility and increase of risk, lack of codes and standards available, lack of appropriate scale and repetition possibilities | (Aburas, 2011; Boyd et al., 2013; Gan et al., 2018a; Gan et al., 2018b; Gbadamosi et al., 2020b; Jang et al., 2021; Kamali & Hewage, 2016; Lou & Kamar, 2012; MacAskill et al., 2021; Rahman, 2014; Razkenari et al., 2020; Sooriyamudalige et al., 2020; Tong, 2021; Wasim et al., 2020; Wuni & Shen, 2020; Zhang et al., 2018) | 15 | 20 |
| | Poor aesthetic performance, impaired aesthetics, and monotonous architecture | | | 10 |
| | Need for additional project planning and design efforts, need for more pre-project planning, failure to adhere to the schedule. | | | 15 |
| Cost | Insufficient industry investment, Higher initial cost, High cost, cost and time aspects, large initial investment, High capital investment | (Boyd et al., 2013; Gan et al., 2018a; Gan et al., 2018b; Gbadamosi et al., 2019; Gbadamosi et al., 2020b; Hwang et al., 2018a, b; Rahman, 2014; Razkenari et al., 2020; Sooriyamudalige et al., 2020; Xu et al., 2020; Yuan et al., 2018; Zhang et al., 2018) | 13 | 18 |

| | | | | |
|---|---|---|---|---|
| **Collaboration and commitment** | Stakeholder collaboration, extensive coordination, detailed coordination, lack of periodical meetings, inadequate flow of information, incapability of clients in providing good communication | (Boyd et al., 2013; Chen et al., 2021; Gan et al., 2018a; Gan et al., 2018b; Gao et al., 2020; Gbadamosi et al., 2019; Gbadamosi et al., 2020b; Harris & . 2021; Ho et al., 2018; Hong et al., 2018; Hwang et al., 2018a, b; Mirus et al., 2018a; Rahman, 2014; Razkenari et al., 2020; Sooriyamudalige et al., 2020; Wasim et al., 2020; Wuni & Shen, 2019; Xu et al., 2020; Xue et al., 2018; Yuan et al., 2018; Zhang et al., 2018) | 22 | 15 |
| | Early commitment, upfront commitment | | | 3 |
| **Strategies and actions** | Loos of control on site, difficulties in inventory control, constraints caused by site conditions | (Ayalp & Ay, 2020; Gan et al., 2018a; Gan et al., 2018b; Gao et al., 2018; Gbadamosi et al., 2019; Rahman, 2014; Razkenari et al., 2020; Wuni & Shen, 2019, 2020; Xu et al., 2018; Zhang et al., 2018) | 12 | 6 |
| | the limited capacity of suppliers, lack of manufacturers and suppliers | | | 8 |
| | Project procurement methods | | | 7 |
| | Low-quality imports, quality issues, inadequate quality, and dimensions of the aggregate | | | 13 |
| | Practices of government, lack of legislation | | | 5 |
| | Lack of contractor incentives, the reluctance of manufacturers, lacking social climate acceptance, Negative perception, Conservative industry culture, inter-manufacturer rivalry and protection | | | 14 |
| | The dominance of conventional project process, historically powerful tendering framework | | | 12 |
| | Limited market demand | | | 8 |
| | Management problems, inappropriate business model | | | 7 |

# Literature and Citation Analysis for Chapter 3- BIM Challenges

| Cluster | Grouped challenges and Keywords | References | Citation | Uniqu citations |
|---|---|---|---|---|
| Lack of Knowledge | Inadequate project experience, practitioners' Knowledge, lack of training. | (Abanda et al., 2017; An et al., 2020b; Aram et al., 2013; Barkokebas et al., 2021; Chen et al., 2015; Ezcan et al., 2013; Hosseini, 2016; Ji et al., 2020; Jin et al., 2017; Lee & Kim, 2017; Lee et al., 2015; Makabate et al., 2021; Nawari, 2012; Tan et al., 2019; Ullah et al., 2019) | 15 | 16 |
| Human resources | Cultural resistance, lack of motivation, and issues related to the willingness to share data. | (Alazmeh et al., 2018; Annex & Rules, 2015; Ji et al., 2020; Lee et al., 2015; Nawari, 2012; Tan et al., 2019) | 6 | 13 |
| Financial | Higher initial cost, BIM adoption cost, cost barriers. | (Alazmeh et al., 2018; Annex & Rules, 2015; He et al., 2021; Ji et al., 2020; Lee et al., 2015; Tan et al., 2019) | 5 | 11 |
| Legal Constraints | Legal issues, legal barriers, intellectual property rights concerns, and lack of a mature BIM contract. | (Abanda et al., 2017; Alazmeh et al., 2018; Annex & Rules, 2015; He et al., 2021; Ji et al., 2020; Lee et al., 2015; Makabate et al., 2021; Tan et al., 2019) | 7 | 8 |
| Interoperability and collaboration | Low interoperability, insufficient interoperability and collaboration among different disciplines, interoperability problem among various BIM software tools, difficulties in applying BIM, different ' 'stakeholder's needs, and difficulties in implementing BIM. | (Abanda et al., 2017; Alazmeh et al., 2018; An et al., 2020b; Annex & Rules, 2015; BCA, 2016; Ezcan et al., 2013; He et al., 2021; Hosseini, 2016; Ji et al., 2020; Lee et al., 2015; Makabate et al., 2021; Nawari, 2012; Ocheoha & Moselhi, 2018; Tan et al., 2019; Ullah et al., 2019; Zhai et al., 2019) | 16 | 16 |
| Lack of Standardisat ion | Lack of clear guidance, no clear orientation or adequate practical studies, lack of industry standards, unclear business value, system complexity, and poor integration with existing systems. | (Abanda et al., 2017; Ezcan et al., 2013; Ji et al., 2020; Jin et al., 2017; Lee & Kim, 2017; Lee et al., 2020; Lee et al., 2015; Ocheoha & Moselhi, 2018; Rahimian et al., 2019; Tan et al., 2019; Tang et al., 2019a; Ullah et al., 2019) | 12 | 14 |

# Appendix 3

## The Criticality Index for Chapter 3

| Criticality index (score scheme) | Ample of express Language used for the presence of challenges | Ample of express Language used for lack of challenges |
|---|---|---|
| **1** | It cannot be significantly associated; it is not empirically evidential; it has little impact; it may not be sufficient. | ----- |
| **2** | If it occurs or Causes problems, A minimum level must exist. It is perceived that it will have a negative Potential impact. | It might positively affect an enthusiastic mindset; it will lead to enhancements. |
| **3** | Common elements were Influence; Lack of the knowledge will affect; Would involve having; Is developed; Affect components; Showing and demonstrating the delay; Leads to delay; Will generate; Are based upon; Requires levels of; Contribute to; Conciliate, Correspond to; Represented by; More effective; hamper; Important challenges; Imped; Important in facilitating; In order to invoke; Will change the attitude. | Positively affects; Is Positively Associated to; Positive determinant; Lead to positive effects; Will develop; Courage; Will facilitate |
| **4** | Is needed to reduced; Characteristics of success in achievement; Is important; If happened leads to formation of; Important success factor; Underpins; Achieve outstanding results; Typically defined by; Important element of success; It is defined by, A powerful force that maintains; Characterized by; Built on a foundation; Can contribute significantly; High levels; Are prerequisites; Critical in initiating; Sound basis for achieving; Essentially provides; There is a need; Depends on. | It leads to success and will potentially improve; it is minimally problematic; it facilitates development and is encouraging. |
| **5** | Critical; Essential; Exclusive to the outcome; Highly important; Vital; Significantly correlated, Key elements of success; Key indicators; Requires as key indicators; Can only be achieved through; The most important elements; Core element, Established principles, defined by; The fundamental principles; Absolute reliance; Ultimately needed. | Will significantly improve, Will form, Is possible; No effects; Highly positive. |

# Appendix 4

## Interview Questions

**School of Built Environment**
**Massey University, Auckland**
**Private Bag 102904**
**North Shore**
**Auckland 0745**
**New Zealand**

**Participant Information Sheet**

**Title of Project:** Offsite Construction and BIM Integration Challenges and Strategies in New Zealand Construction Industry

**Name of Researcher:** Nazanin Kordestani

**Degree:** PhD candidate

**Department:** School of Built Environment Research

**Supervisors:** Dr Mostafa Babaiean Jelodar, Dr Daniel Paes, and Professor Monty Sutrisna

**About Research Project**

You are invited to participate in the above-mentioned research title regarding research currently undertaken for a PhD study at Massey University. The current research addresses the implementation of Building Information Modelling (BIM) as a tool in Offsite construction to improve integration in the New Zealand construction industry. The research endeavours to identify the challenges and strategies- for BIM integration into offsite construction in New Zealand within the construction industry.

**Data Collection**

The interviews will be conducted in two different sections:

- The general interview questions (10 to 15 minutes)
- The specific interview questions (20 to 30 minutes)

The interview information is anonymous, and individual data will not be identifiable. The Massey University data repository will securely keep all the information gathered through this interview, and only the researchers involved in this project will have access to it.

**Ethics Notification (No: 4000024955)**

Peer review evaluation determined this project to be low risk. The ethical conduct of this research is the responsibility of the researchers listed above. Please contact Prof. Craig Johnson, Director of Research Ethics, if you have any issues with how this study was conducted that you want to discuss with someone other than the researchers. Telephone (06) 356 9099 x 85271, email humanethics@massey.ac.nz

**Funding**

The researcher has been awarded the Massey University Doctoral Scholarship for three years.

***Statement of Consent***

I agree to voluntary take part in this research study undertaken by Nazanin Kordestani. I have read the participant information sheet (PIS). I understand the nature of the research and the basis on which I have been selected. I have had the opportunity to ask questions and have them answer to all my satisfaction.

- I understand that any participation in the research is voluntary and where my employer's consent for my participation is required, my employer has provided an assurance that my participation or non-participation will not affect my employment status and relationship in any way.

- I understand that the raw data gathered during the data collection procedures will be kept confidential and stored securely without access of any other party except the research team members for three years and subsequently be destroyed by appropriate means.
- I understand estimated time duration of the interview/survey questionnaire stated in the PIS.
- I agree/ do not agree for the interview to be audio- recorded.
- I understand that I may choose to have the recorder turned off anytime during the interview.
- I understand that any audio recording or data collection done under my permission will be transcribed by the researcher herself without involvement of the third party.
- I understand that I may request a copy of the raw data collected during the interview and researcher transcription to be reviewed and edited as I wish and provide further feedback to the researcher if necessary.
- I understand the confidentiality of the research and any data collected from any employee and organisation member will not be disclosed to any other party, even the organisation authorities.
- I wish/ do not wish to receive the summary of findings (Please provide email if you wish to receive summary of findings).
- I understand that I'm free to withdraw participation and at any time and to withdraw any data traceable to me up to two months after the data collection period.

| | |
|---|---|
| Name | Position |
| Email | Phone number |
| Signature | Date |

If you have any queries, please contact;

**Researcher's Name and Contact Details**
Nazanin Kordestani, PhD student,
School of Built Environment
Email: N.kordestani@massey.ac.nz
Phone: +64 21 09114881

**Supervisor's Name and Contact Details**
Senior Lecturer Mostafa Babaiean
School of Built Environment
Email: M.B.Jelodar@massey.ac.nz

**General Questions**

1) What are the challenges for Offsite Construction (OSC) in NZ?
2) How advanced or popular is OSC in New Zealand?
3) What are the most frequent applications/ methods of OSC in NZ, and why?
4) In what ways we can improve the situation for different OSC methods?
5) What are the Building Information Modelling (BIM) challenges in NZ?
6) What are the levels of BIM currently being applied in NZ?

***Second Section:*** specific questions around (20 to 30 minutes)

**Integration Questions**

7) How effective do you think BIM is in reducing OSC challenges?
8) What are the challenges for BIM and OSC integration in NZ?
9) How do you see the levels of BIM in OSC integration in NZ construction projects?
    a. Follow-up: Are there any strategies, actions, etc. for integration of BIM and OSC?
    b. Follow-up: How advanced are current integration strategies?

**Stakeholders and lifecycle questions**

10) In your opinion, how much stakeholders are interested in using OSC and BIM in NZ?
    a. Follow-up: what is the difference in interests or perspectives amongst different stakeholders.
    b.
11) How do you see BIM and OSC implementation in the life cycle construction projects?
    a. Follow up: Interaction of different stakeholders, (design management, implementation, and collaboration)
    b. What is the current state of integration of BIM and OSC at different stages?
    c. What would be your priority project lifecycle stage for integrating BIM and OSC.

**Actual experiences Questions:**

12) Organisational level: how can organisations apply BIM in enhancing OSC in construction?

    Follow-up: Are you aware of any strategies, or actions within your organisation or other organisations, is so what are these?
    Follow-up: Can you provide some recent examples?

13) Project level: how can projects apply BIM in enhancing OSC in construction?

    Follow-up: Are you aware of any strategies, or actions within your projects or other projects, is so what are these?
    Follow-up: Can you provide some recent examples?

14) BIM application for OSC in a recent project

# Appendix 5

## Survey

**School of Built Environment**
**Massey University, Auckland**
**Private Bag 102904**
**North Shore**
**Auckland 0745**
**New Zealand**

**Participant Information Sheet**

**Title of Project:** Offsite Construction and BIM Integration Challenges and Strategies in New Zealand Construction Industry
**Name of Researcher:** Nazanin Kordestani
**Degree:** PhD candidate
**Department:** School of Built Environment Research
**Supervisors:** Dr Mostafa Babaiean Jelodar, Dr Daniel Paes, Professor Monty Sutrisna, and Dr Diyako Rahmani

**About Research Project**

You are invited to participate in the above-mentioned research title regarding research currently undertaken for a PhD study at Massey University. The current research addresses the implementation of Building Information Modelling (BIM) as a tool in Offsite construction to improve integration in the New Zealand construction industry. The research endeavours to test the framework consisting of the challenges and strategies- for BIM integration into offsite construction, and the level at which these factors would be applied to actual projects within the construction industry. Furthermore, it will assist in identification of critical challenges for Offsite construction (OSC) and BIM integration in New Zealand. The study will try to determine which strategy would help the industry to reduce the OSC and BIM challenges.

**Data Collection**

The average time to complete the questionnaire is 15 minutes. The survey is anonymous, and individual data will not be identifiable. However, data cannot be withdrawn after completion of the survey. The Massey University data repository will securely keep all the information gathered through this questionnaire, and only the researchers involved in this project will have access to it.

**Ethics Notification (No: 4000024955)**

Peer review evaluation determined this project to be low risk. The ethical conduct of this research is the responsibility of the researchers listed above. Please contact Prof. Craig Johnson, Director of Research Ethics, if you have any issues with how this study was conducted that you want to discuss with someone other than the researchers. Telephone (06) 356 9099 x 85271, email humanethics@massey.ac.nz

**Funding**

The researcher has been awarded the Massey University Doctoral Scholarship for three years.

***Statement of Consent***

I understand that participation in this study is voluntary. I understand that I can stop and withdraw my consent at any time. I understand that the data I provide is confidential and that I will not be identified in any publications of findings from this research.

○ I have read the information above and consent to participate in the study.

○ I do not consent; I do not wish to participate.

*Skip To: End of Survey If Statement of Consent I understand that participation in this study is voluntary. I understand that... = I do not consent; I do not wish to participate*

Q3 **Challenges for Offsite Construction and BIM Integration**

In the following section, you will be asked to choose the challenges based on your recent experience in implementing BIM in OSC projects. Please rank the challenges you had in your projects using the scale from "extremely not important" to "extremely important". This section will be followed by some supplementary questions regarding your chosen challenges.

Q4 Please mark your level of agreement with each **integration challenge** you had, based on your recent direct or indirect project experience in Offsite Construction and BIM.

| | Not at all important | Low importance | Slightly important | Neutral | Moderately important | Very important | Extremely important |
|---|---|---|---|---|---|---|---|
| Lack of transparent practices during offsite manufacturing | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Lack of digital documentation | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Temporary and one-off nature of the project | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Lack of appropriate education and training | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Lack of planning (including resource planning and scheduling) | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Small size of New Zealand market | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| High Cost of training | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lack of collaboration and integration | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| High cost of Offsite Construction and BIM implementation | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Reluctance of industry to change | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Lack of government support (eg. mandatory Offsite Construction and BIM implementation | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Low level of understanding of Offsite Construction and BIM integration | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Industry is not prepared to deliver BIM | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Lack of standards and guidelines | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Transportation consideration and issues of logistics for Offsite Construction components | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Lack of clear orientation or adequate practical studies | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Lack of knowledge, limited skills, and experience | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Inadequate flow of information and periodical meetings | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Inability to provide good communication | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Q5 Which level(s) do challenges belong to? (You may choose more than one answer)

- ☐ Project
- ☐ Organisation
- ☐ Industry

*Display This Question:*

*If Which level(s) do challenges belong to? (You may choose more than one answer) = Project*

Q6 To what extent are these challenges due to your ***project*** *situation*?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Project | | | | | | | | | | | |

*Display This Question:*

*If Which level(s) do challenges belong to? (You may choose more than one answer) = Organisation*

Q7 To what extent are the challenges related to your ***organisation's*** conditions?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Organisation | | | | | | | | | | | |

*Display This Question:*

*If Which level(s) do challenges belong to? (You may choose more than one answer) = Industry*

Q8 To what extent are the challenges because of current ***industry*** conditions?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry | | | | | | | | | | | |

*Display This Question:*

*If Which level(s) do challenges belong to? (You may choose more than one answer) = Project*

Q9 To what extent do the challenges belong to different ***phases of project life cycle?***

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Design | | | | | | | | | | | |
| Programming and planning | | | | | | | | | | | |
| Execution | | | | | | | | | | | |
| Monitoring and controlling | | | | | | | | | | | |
| Closing | | | | | | | | | | | |

Q10 What other challenges have you had in your projects? (**Not listed above**)

________________________________________________________________

Q11 **Strategies for Mitigating the Challenges for Offsite Construction and BIM Integration**

In the following section, you will be asked to rank the strategies you applied to mitigate the challenges based on your recent project experience in implementing BIM in Offsite Construction. Please mark your level of agreement with each one of the statements using the scale from "extremely inappropriate" to "extremely appropriate". This question will be followed by some supplementary questions regarding your chosen strategies.

Q12 Please rank the **strategies** you have applied in your projects when you faced with challenges with Offsite Construction and BIM integration?

| | Never use | Rarely | Occasionally | Sometimes | Frequently | Usually | Every time |
|---|---|---|---|---|---|---|---|
| Educating and upscaling | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Graduate and internship programmes | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Providing client's business requirement documents | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Early engagement of stakeholders | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Providing clarity of outcomes and benefits | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Changing communication style | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Using digital twin | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Creating action plans and roadmaps for Offsite Construction and BIM integration | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Changes in project delivery process | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Developing standards document | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Providing resources through setting up a library of workflow and using BIM as a source of data | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Financial support from government (eg. tax subsidies) | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Mandating use of BIM in Offsite construction | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Use of contractual provisions | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Improving logistics and supply chain management awareness | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Use of government guidelines | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Q13 Which level(s) do ***strategies*** belong to? (You may choose more than one answer)

☐ Project

☐ Organisation

☐ Industry

*Display This Question:*

*If Which level(s) do strategies belong to? (You may choose more than one answer) = Project*

Q14 To what extent strategies are related to your ***project***.

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Project | | | | | | | | | | | |

*Display This Question:*

*If Which level(s) do strategies belong to? (You may choose more than one answer) = Organisation*

Q15 To what extent strategies are related to your ***organisation***.

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Organisation | | | | | | | | | | | |

*Display This Question:*

*If Which level(s) do strategies belong to? (You may choose more than one answer) = Industry*

Q16 To what extent strategies are related to the ***industry.***

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry | | | | | | | | | | | |

*Display This Question:*

*If Which level(s) do strategies belong to? (You may choose more than one answer) = Project*

Q17 To what extent do the ***strategies*** belong to different phases of the project life cycle?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Design | | | | | | | | | | | |
| Programming and planning | | | | | | | | | | | |
| Execution | | | | | | | | | | | |
| Monitoring and controlling | | | | | | | | | | | |
| Closing | | | | | | | | | | | |

Q18 Who is the responsible stakeholder(s) to apply the collection of chosen ***strategies***?

- ☐ Client
- ☐ Consultant
- ☐ Contractor
- ☐ Government
- ☐ Manufacturer

*Display This Question:*

*If Who is the responsible stakeholder(s) to apply the collection of chosen strategies? = Client*

Q19 To what extent does the ***client*** influence the implementation of selected strategies?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Client | | | | | | | | | | | |

*Display This Question:*

*If Who is the responsible stakeholder(s) to apply the collection of chosen strategies? = Consultant*

Q20 To what extent does the ***consultant*** influence the implementation of selected strategies?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Consultant | | | | | | | | | | | |

*Display This Question:*

*If Who is the responsible stakeholder(s) to apply the collection of chosen strategies? = Contractor*

Q21 To what extent does the ***contractor*** influence the implementation of selected strategies?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Contractor | | | | | | | | | | | |

*Display This Question:*

*If Who is the responsible stakeholder(s) to apply the collection of chosen strategies? = Government*

Q22 To what extent does the ***government*** influence the implementation of selected strategies?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Government | | | | | | | | | | | |

*Display This Question:*

*If Who is the responsible stakeholder(s) to apply the collection of chosen strategies? = Manufacturer*

Q23 To what extent does the ***manufacturer*** influence the implementation of selected strategies?

| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Manufacture | | | | | | | | | | | |

Q24 What other strategies have you applied? **(Not listed above)**

________________________________________________________________

Q25 In the following section, you will be asked to state your level of agreement regarding each statement. This section investigates BIM as a tool to help Offsite Construction delivery. For this study, we have specified BIM levels 0 (2D CAD drawings) to 4 (Full integration).

Q26 **Applying BIM to Offsite Construction projects.**

To what extent do you agree with the following statements?

| | Strongly disagree | Disagree | Somewhat disagree | Neither agree nor disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| Projects have a high readiness level for facilitating Offsite Construction through BIM. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| There is a high level of understanding of BIM functions for Offsite Construction implementation. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Using BIM software facilitated Offsite Construction compliance to design. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Using BIM software facilitated Offsite construction. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Collaboration on a cloud-based BIM platform facilitated the design process. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Collaboration on a cloud-based BIM platform facilitated the Offsite Construction manufacturing process. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Collaboration on a cloud-based BIM platform facilitated the transportation. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Collaboration on a cloud-based BIM platform facilitated real-time change management. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Collaboration on a cloud-based BIM platform facilitated installation process. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| 3D modelling facilitated the design process. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Applying BIM facilitated the identification of Offsite Construction requirements. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Applying BIM facilitated schedule collaboration between manufacturing and installation. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Applying BIM facilitated management of Offsite Construction constraints (e.g., maximum size, transport schedule, packing, storage). | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Applying BIM facilitated project monitoring process. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Overall execution time reduced proportional to the applied level of BIM (Level 0-4). | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |

Q27 How many years of experience do you have in the construction industry?

- ◯ 0-5 Years
- ◯ 6-10 Years
- ◯ 11-15 Years
- ◯ 16-20 Years
- ◯ More than 20 years

Q28 What is your nature of organisation in the construction industry?

- ◯ Client
- ◯ Contractor
- ◯ Consultant
- ◯ Other (please specify)

________________________________________

Q29 What is the nature of the project you are dominantly involved in?

- ☐ Building and residential
- ☐ Industrial
- ☐ Commercial
- ☐ Civil engineering and infrastructure
- ☐ Other (Please specify)

________________________________________

Q30 What is your profession in the construction industry?

- ◯ Engineer
- ◯ Architect
- ◯ Planner
- ◯ Surveyor
- ◯ Project Management
- ◯ Other (Please specify)

________________________________________________

Q31 How many years of experience do you have in Offsite construction?

- ◯ 0-5 years
- ◯ 6-10 years
- ◯ 11-15 years
- ◯ 16-20 years
- ◯ More than 20 years

Q32 How many years of experience do you have in working with BIM)

- ◯ 0-5 years
- ◯ 6-10 years
- ◯ 11-15 years
- ◯ More than 15 years

# Appendix 6

## Case Study Interview Questions

**School of Built Environment**
**Massey University, Auckland**
**Private Bag 102904**
**North Shore**
**Auckland 0745**
**New Zealand**

**Participant Information Sheet**

**Title of Project:** Examine real-world OSC projects to uncover additional integration challenges, effective strategies, and responsible stakeholders withing New Zealand Construction Industry.

**Name of Researcher:** Nazanin Kordestani

**Degree:** PhD candidate

**Department:** School of Built Environment Research

**Supervisors:** Dr Mostafa Babaiean Jelodar, Dr Daniel Paes, Professor Monty Sutrisna, and Dr Diyako Rahmani

**About Research Project**

You are invited to participate in the above-mentioned research regarding a PhD study currently undertaken at Massey University. This research addresses the implementation of Building Information Modelling (BIM) as a tool in offsite construction (OSC) to improve integration in the New Zealand construction industry. The research aims to identify the challenges and mitigation strategies for BIM integration into OSC and the responsible stakeholders to apply these strategies within the construction industry in New Zealand. It will assist project stakeholders in targeting their resources, reducing costs, and improving integration by identifying critical challenges. Moreover, the study will try to determine which strategies would help projects reduce integration challenges.

**Data Collection**

The interview will last 40 minutes to 1 hour. The interview is anonymous and individual and project data will not be identifiable. The Massey University data repository will securely keep all the information gathered through this interview, and only the researchers involved in this project will have access to it.

**Ethics Notification (No: 4000024955)**

Peer review evaluation determined this project to be low risk. The ethical conduct of this research is the responsibility of the researchers listed above. Please contact Prof. Craig Johnson, Director of Research Ethics, if you have any issues with how this study was conducted that you want to discuss with someone other than the researchers. Telephone (06) 356 9099 x 85271, email humanethics@massey.ac.nz

**Funding**

The researcher has been awarded the Massey University Doctoral Scholarship for three years.

***Statement of Consent***

I agree to voluntary take part in this research study undertaken by Nazanin Kordestani. I have read the participant information sheet (PIS). I understand the nature of the research and the basis on which I have been selected. I have had the opportunity to ask questions and have them answer to all my satisfaction.

- I understand that any participation in the research is voluntary and where my employer's consent for my participation is required, my employer has provided an assurance that my participation or non-participation will not affect my employment status and relationship in any way.
- I understand that the raw data gathered during the data collection procedures will be kept confidential and stored securely without access of any other party except the research team members for three years and subsequently be destroyed by appropriate means.
- I understand estimated time duration of the interview/survey questionnaire stated in the PIS.
- I agree/ do not agree for the interview to be audio- recorded.
- I understand that I may choose to have the recorder turned off anytime during the interview.
- I understand that any audio recording or data collection done under my permission will be transcribed by the researcher herself without involvement of the third party.
- I understand that I may request a copy of the raw data collected during the interview and researcher transcription to be reviewed and edited as I wish and provide further feedback to the researcher if necessary.
- I understand the confidentiality of the research and any data collected from any employee and organisation member will not be disclosed to any other party, even the organisation authorities.
- I wish/ do not wish to receive the summary of findings (Please provide email if you wish to receive summary of findings).
- I understand that I'm free to withdraw participation and at any time and to withdraw any data traceable to me up to two months after the data collection period.

| | |
|---|---|
| Name | Position |
| Email | Phone number |
| Signature | Date |

1) Can you describe your experience with integrating offsite construction (OSC) and BIM in your projects?
2) What specific benefits have you seen from the integration of OSC and BIM in your projects and organisation?
3) What are some of the most important considerations for successful integration of OSC and BIM in your projects?
4) Can you provide some examples of offsite components that you have used in your projects and how they were integrated with BIM?
5) What guidelines, documents, or standards do you use to ensure successful integration of OSC and BIM in your projects?
6) How do different parties involved in your projects interact with each other, particularly regarding the integration of OSC and BIM?
7) Do you have any specific strategies for working effectively with other parties in the project, such as your team and the client team, to ensure successful integration of OSC and BIM?
8) How do you gather information on the offsite components that you plan to use in your projects?
9) Who do you typically communicate with to ensure successful integration of OSC and BIM in your projects?
10) What file formats do you typically use for the offsite components and BIM files, and how do you share and access them?
11) How do you and your clients handle modifications to the offsite components and BIM files throughout the project?
12) How frequently do you hold meetings with your team and clients to discuss the integration of OSC and BIM, and who are the key stakeholders involved in these meetings?

13) Who is responsible for managing contracts and communications related to OSC and BIM integration in your projects?
14) What are some of the first steps you typically take when starting a new project involving OSC and BIM integration?
15) How does your process for integrating OSC and BIM differ from that of other companies or projects that you are aware of?
16) Which type of projects do you tend to use OSC components in more often, vertical, or horizontal, and are the components typically imported or locally manufactured?
17) If the components are manufactured in New Zealand, where do you typically source the materials and in what forms?
18) What challenges have you encountered when using BIM for OSC projects, and how have you addressed these challenges?
19) What do you believe is the best approach for effectively using BIM in OSC projects?
20) How would you rate the current level of BIM integration in your company, and what steps are you taking to continue improving this integration?

✓ Could you please share the project description, project documents, and meeting notes if you have them (provided they are not highly confidential)?

# Appendix 7

## One-Way ANOVA Results for Chapter 8

One- way ANOVA (participants in terms of OSC experience)

| ANOVA | | | | | | |
|---|---|---|---|---|---|---|
| | | Sum of Squares | **df** | **Mean Square** | **F** | **Sig.** |
| CH1 | Between Groups | 8.465 | 3 | 2.822 | 3.984 | .010 |
| | Within Groups | 79.331 | 112 | .708 | | |
| | Total | 87.796 | 115 | | | |
| CH2 | Between Groups | 1.107 | 3 | .369 | .415 | .743 |
| | Within Groups | 99.612 | 112 | .889 | | |
| | Total | 100.719 | 115 | | | |
| CH3 | Between Groups | 5.237 | 3 | 1.746 | 2.007 | .117 |
| | Within Groups | 97.400 | 112 | .870 | | |
| | Total | 102.637 | 115 | | | |

Post Hoc Tests Results (Comparing different groups of participants in terms of OSC experience)

| **Dependent Variable** | | | | **Mean Difference (I-J)** | **Std. Error** | **Sig.** |
|---|---|---|---|---|---|---|
| CH1 | **Tukey HSD** | 1.00 | 2.00 | 0.39480 | 0.19160 | 0.173 |
| | | | 3.00 | 0.78985 | 0.32981 | 0.084 |
| | | | 4.00 | -0.10137 | 0.20940 | 0.962 |
| | | 2.00 | 1.00 | -0.39480 | 0.19160 | 0.173 |
| | | | 3.00 | 0.39505 | 0.32405 | 0.616 |
| | | | 4.00 | -0.49618 | 0.20021 | 0.069 |
| | | 3.00 | 1.00 | -0.78985 | 0.32981 | 0.084 |
| | | | 2.00 | -0.39505 | 0.32405 | 0.616 |
| | | | 4.00 | -.89122* | 0.33489 | 0.044 |
| | | 4.00 | 1.00 | 0.10137 | 0.20940 | 0.962 |
| | | | 2.00 | 0.49618 | 0.20021 | 0.069 |
| | | | 3.00 | .89122* | 0.33489 | 0.044 |
| | **Bonferroni** | 1.00 | 2.00 | 0.39480 | 0.19160 | 0.250 |
| | | | 3.00 | 0.78985 | 0.32981 | 0.110 |
| | | | 4.00 | -0.10137 | 0.20940 | 1.000 |
| | | 2.00 | 1.00 | -0.39480 | 0.19160 | 0.250 |
| | | | 3.00 | 0.39505 | 0.32405 | 1.000 |
| | | | 4.00 | -0.49618 | 0.20021 | 0.088 |
| | | 3.00 | 1.00 | -0.78985 | 0.32981 | 0.110 |
| | | | 2.00 | -0.39505 | 0.32405 | 1.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 4.00 | -0.89122 | 0.33489 | 0.054 |
| | | 4.00 | 1.00 | 0.10137 | 0.20940 | 1.000 |
| | | | 2.00 | 0.49618 | 0.20021 | 0.088 |
| | | | 3.00 | 0.89122 | 0.33489 | 0.054 |
| | **Games-Howell** | 1.00 | 2.00 | 0.39480 | 0.15647 | 0.065 |
| | | | 3.00 | 0.78985 | 0.29120 | 0.088 |
| | | | 4.00 | -0.10137 | 0.24173 | 0.975 |
| | | 2.00 | 1.00 | -0.39480 | 0.15647 | 0.065 |
| | | | 3.00 | 0.39505 | 0.28763 | 0.543 |
| | | | 4.00 | -0.49618 | 0.23741 | 0.173 |
| | | 3.00 | 1.00 | -0.78985 | 0.29120 | 0.088 |
| | | | 2.00 | -0.39505 | 0.28763 | 0.543 |
| | | | 4.00 | -0.89122 | 0.34158 | 0.078 |
| | | 4.00 | 1.00 | 0.10137 | 0.24173 | 0.975 |
| | | | 2.00 | 0.49618 | 0.23741 | 0.173 |
| | | | 3.00 | 0.89122 | 0.34158 | 0.078 |
| CH2 | **Tukey HSD** | 1.00 | 2.00 | 0.12534 | 0.21470 | 0.937 |
| | | | 3.00 | 0.25989 | 0.36957 | 0.896 |
| | | | 4.00 | 0.24264 | 0.23464 | 0.730 |
| | | 2.00 | 1.00 | -0.12534 | 0.21470 | 0.937 |
| | | | 3.00 | 0.13454 | 0.36312 | 0.983 |
| | | | 4.00 | 0.11729 | 0.22434 | 0.953 |
| | | 3.00 | 1.00 | -0.25989 | 0.36957 | 0.896 |
| | | | 2.00 | -0.13454 | 0.36312 | 0.983 |
| | | | 4.00 | -0.01725 | 0.37526 | 1.000 |
| | | 4.00 | 1.00 | -0.24264 | 0.23464 | 0.730 |
| | | | 2.00 | -0.11729 | 0.22434 | 0.953 |
| | | | 3.00 | 0.01725 | 0.37526 | 1.000 |
| | **Bonferroni** | 1.00 | 2.00 | 0.12534 | 0.21470 | 1.000 |
| | | | 3.00 | 0.25989 | 0.36957 | 1.000 |
| | | | 4.00 | 0.24264 | 0.23464 | 1.000 |
| | | 2.00 | 1.00 | -0.12534 | 0.21470 | 1.000 |
| | | | 3.00 | 0.13454 | 0.36312 | 1.000 |
| | | | 4.00 | 0.11729 | 0.22434 | 1.000 |
| | | 3.00 | 1.00 | -0.25989 | 0.36957 | 1.000 |
| | | | 2.00 | -0.13454 | 0.36312 | 1.000 |
| | | | 4.00 | -0.01725 | 0.37526 | 1.000 |
| | | 4.00 | 1.00 | -0.24264 | 0.23464 | 1.000 |
| | | | 2.00 | -0.11729 | 0.22434 | 1.000 |
| | | | 3.00 | 0.01725 | 0.37526 | 1.000 |
| | **Games-Howell** | 1.00 | 2.00 | 0.12534 | 0.17794 | 0.895 |
| | | | 3.00 | 0.25989 | 0.31268 | 0.839 |
| | | | 4.00 | 0.24264 | 0.27024 | 0.806 |
| | | 2.00 | 1.00 | -0.12534 | 0.17794 | 0.895 |
| | | | 3.00 | 0.13454 | 0.30815 | 0.971 |
| | | | 4.00 | 0.11729 | 0.26498 | 0.971 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 1.00 | -0.25989 | 0.31268 | 0.839 |
| | | 3.00 | 2.00 | -0.13454 | 0.30815 | 0.971 |
| | | | 4.00 | -0.01725 | 0.36922 | 1.000 |
| | | | 1.00 | -0.24264 | 0.27024 | 0.806 |
| | | 4.00 | 2.00 | -0.11729 | 0.26498 | 0.971 |
| | | | 3.00 | 0.01725 | 0.36922 | 1.000 |
| | | | 2.00 | 0.28835 | 0.21230 | 0.528 |
| | | 1.00 | 3.00 | -0.21866 | 0.36545 | 0.932 |
| | | | 4.00 | 0.46563 | 0.23202 | 0.192 |
| | | | 1.00 | -0.28835 | 0.21230 | 0.528 |
| | | 2.00 | 3.00 | -0.50701 | 0.35907 | 0.495 |
| | **Tukey HSD** | | 4.00 | 0.17728 | 0.22184 | 0.855 |
| | | | 1.00 | 0.21866 | 0.36545 | 0.932 |
| | | 3.00 | 2.00 | 0.50701 | 0.35907 | 0.495 |
| | | | 4.00 | 0.68429 | 0.37107 | 0.258 |
| | | | 1.00 | -0.46563 | 0.23202 | 0.192 |
| | | 4.00 | 2.00 | -0.17728 | 0.22184 | 0.855 |
| | | | 3.00 | -0.68429 | 0.37107 | 0.258 |
| | | | 2.00 | 0.28835 | 0.21230 | 1.000 |
| | | 1.00 | 3.00 | -0.21866 | 0.36545 | 1.000 |
| | | | 4.00 | 0.46563 | 0.23202 | 0.283 |
| | | | 1.00 | -0.28835 | 0.21230 | 1.000 |
| | | 2.00 | 3.00 | -0.50701 | 0.35907 | 0.964 |
| | | | 4.00 | 0.17728 | 0.22184 | 1.000 |
| CH3 | **Bonferroni** | | 1.00 | 0.21866 | 0.36545 | 1.000 |
| | | 3.00 | 2.00 | 0.50701 | 0.35907 | 0.964 |
| | | | 4.00 | 0.68429 | 0.37107 | 0.407 |
| | | | 1.00 | -0.46563 | 0.23202 | 0.283 |
| | | 4.00 | 2.00 | -0.17728 | 0.22184 | 1.000 |
| | | | 3.00 | -0.68429 | 0.37107 | 0.407 |
| | | | 2.00 | 0.28835 | 0.16603 | 0.312 |
| | | 1.00 | 3.00 | -0.21866 | 0.17558 | 0.608 |
| | | | 4.00 | 0.46563 | 0.27103 | 0.328 |
| | | | 1.00 | -0.28835 | 0.16603 | 0.312 |
| | | 2.00 | 3.00 | -0.50701 | 0.18715 | 0.059 |
| | **Games-Howell** | | 4.00 | 0.17728 | 0.27866 | 0.920 |
| | | | 1.00 | 0.21866 | 0.17558 | 0.608 |
| | | 3.00 | 2.00 | 0.50701 | 0.18715 | 0.059 |
| | | | 4.00 | 0.68429 | 0.28446 | 0.094 |
| | | | 1.00 | -0.46563 | 0.27103 | 0.328 |
| | | 4.00 | 2.00 | -0.17728 | 0.27866 | 0.920 |
| | | | 3.00 | -0.68429 | 0.28446 | 0.094 |

One- way ANOVA (participants in terms of BIM experience)

| ANOVA | | | | | | |
|---|---|---|---|---|---|---|
| | | **Sum of Squares** | **df** | **Mean Square** | **F** | **Sig.** |
| CH1 | Between Groups | 4.460 | 3 | 1.487 | 1.998 | .118 |
| | Within Groups | 83.336 | 112 | .744 | | |
| | Total | 87.796 | 115 | | | |
| CH2 | Between Groups | 4.393 | 3 | 1.464 | 1.703 | .171 |
| | Within Groups | 96.326 | 112 | .860 | | |
| | Total | 100.719 | 115 | | | |
| CH3 | Between Groups | .367 | 3 | .122 | .134 | .940 |
| | Within Groups | 102.271 | 112 | .913 | | |
| | Total | 102.637 | 115 | | | |

Post Hoc Tests (Comparing different groups of participants in terms of BIM experience)

| **Dependent Variable** | | **(I) BIM** | **(J) BIM** | **Mean Difference (I-J)** | **Std. Error** | **Sig.** |
|---|---|---|---|---|---|---|
| CH1 | **Tukey HSD** | 1.00 | 2.00 | .26789 | .20674 | .568 |
| | | | 3.00 | .13726 | .28780 | .964 |
| | | | 4.00 | -.28273 | .20210 | .503 |
| | | 2.00 | 1.00 | -.26789 | .20674 | .568 |
| | | | 3.00 | -.13062 | .30855 | .974 |
| | | | 4.00 | -.55062 | .23068 | .085 |
| | | 3.00 | 1.00 | -.13726 | .28780 | .964 |
| | | | 2.00 | .13062 | .30855 | .974 |
| | | | 4.00 | -.41999 | .30545 | .518 |
| | | 4.00 | 1.00 | .28273 | .20210 | .503 |
| | | | 2.00 | .55062 | .23068 | .085 |
| | | | 3.00 | .41999 | .30545 | .518 |
| | **Bonferroni** | 1.00 | 2.00 | .26789 | .20674 | 1.000 |
| | | | 3.00 | .13726 | .28780 | 1.000 |
| | | | 4.00 | -.28273 | .20210 | .987 |
| | | 2.00 | 1.00 | -.26789 | .20674 | 1.000 |
| | | | 3.00 | -.13062 | .30855 | 1.000 |
| | | | 4.00 | -.55062 | .23068 | .112 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 1.00 | -.13726 | .28780 | 1.000 |
| | | 3.00 | 2.00 | .13062 | .30855 | 1.000 |
| | | | 4.00 | -.41999 | .30545 | 1.000 |
| | | | 1.00 | .28273 | .20210 | .987 |
| | | 4.00 | 2.00 | .55062 | .23068 | .112 |
| | | | 3.00 | .41999 | .30545 | 1.000 |
| | | | 2.00 | .26789 | .16984 | .399 |
| | | 1.00 | 3.00 | .13726 | .24589 | .943 |
| | | | 4.00 | -.28273 | .24319 | .653 |
| | | | 1.00 | -.26789 | .16984 | .399 |
| | | 2.00 | 3.00 | -.13062 | .25729 | .956 |
| | | | 4.00 | -.55062 | .25471 | .150 |
| | **Games-Howell** | | 1.00 | -.13726 | .24589 | .943 |
| | | 3.00 | 2.00 | .13062 | .25729 | .956 |
| | | | 4.00 | -.41999 | .31063 | .538 |
| | | | 1.00 | .28273 | .24319 | .653 |
| | | 4.00 | 2.00 | .55062 | .25471 | .150 |
| | | | 3.00 | .41999 | .31063 | .538 |
| | | | 2.00 | .48452 | .22227 | .135 |
| | | 1.00 | 3.00 | -.00530 | .30942 | 1.000 |
| | | | 4.00 | .16277 | .21728 | .877 |
| | | | 1.00 | -.48452 | .22227 | .135 |
| | | 2.00 | 3.00 | -.48982 | .33172 | .455 |
| | | | 4.00 | -.32175 | .24801 | .567 |
| | **Tukey HSD** | | 1.00 | .00530 | .30942 | 1.000 |
| | | 3.00 | 2.00 | .48982 | .33172 | .455 |
| CH2 | | | 4.00 | .16807 | .32840 | .956 |
| | | | 1.00 | -.16277 | .21728 | .877 |
| | | 4.00 | 2.00 | .32175 | .24801 | .567 |
| | | | 3.00 | -.16807 | .32840 | .956 |
| | | | 2.00 | .48452 | .22227 | .188 |
| | | 1.00 | 3.00 | -.00530 | .30942 | 1.000 |
| | **Bonferroni** | | 4.00 | .16277 | .21728 | 1.000 |
| | | 2.00 | 1.00 | -.48452 | .22227 | .188 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 3.00 | -.48982 | .33172 | .856 |
| | | | 4.00 | -.32175 | .24801 | 1.000 |
| | | 3.00 | 1.00 | .00530 | .30942 | 1.000 |
| | | | 2.00 | .48982 | .33172 | .856 |
| | | | 4.00 | .16807 | .32840 | 1.000 |
| | | 4.00 | 1.00 | -.16277 | .21728 | 1.000 |
| | | | 2.00 | .32175 | .24801 | 1.000 |
| | | | 3.00 | -.16807 | .32840 | 1.000 |
| | **Games-Howell** | 1.00 | 2.00 | .48452 | .19193 | .067 |
| | | | 3.00 | -.00530 | .27575 | 1.000 |
| | | | 4.00 | .16277 | .25179 | .916 |
| | | 2.00 | 1.00 | -.48452 | .19193 | .067 |
| | | | 3.00 | -.48982 | .28929 | .356 |
| | | | 4.00 | -.32175 | .26655 | .625 |
| | | 3.00 | 1.00 | .00530 | .27575 | 1.000 |
| | | | 2.00 | .48982 | .28929 | .356 |
| | | | 4.00 | .16807 | .33204 | .957 |
| | | 4.00 | 1.00 | -.16277 | .25179 | .916 |
| | | | 2.00 | .32175 | .26655 | .625 |
| | | | 3.00 | -.16807 | .33204 | .957 |
| CH3 | **Tukey HSD** | 1.00 | 2.00 | .08919 | .22903 | .980 |
| | | | 3.00 | .07575 | .31882 | .995 |
| | | | 4.00 | .13544 | .22388 | .930 |
| | | 2.00 | 1.00 | -.08919 | .22903 | .980 |
| | | | 3.00 | -.01343 | .34181 | 1.000 |
| | | | 4.00 | .04626 | .25555 | .998 |
| | | 3.00 | 1.00 | -.07575 | .31882 | .995 |
| | | | 2.00 | .01343 | .34181 | 1.000 |
| | | | 4.00 | .05969 | .33838 | .998 |
| | | 4.00 | 1.00 | -.13544 | .22388 | .930 |
| | | | 2.00 | -.04626 | .25555 | .998 |
| | | | 3.00 | -.05969 | .33838 | .998 |
| | **Bonferroni** | 1.00 | 2.00 | .08919 | .22903 | 1.000 |
| | | | 3.00 | .07575 | .31882 | 1.000 |

| | | | | | |
|---|---|---|---|---|---|
| | | 4.00 | .13544 | .22388 | 1.000 |
| | | 1.00 | -.08919 | .22903 | 1.000 |
| | 2.00 | 3.00 | -.01343 | .34181 | 1.000 |
| | | 4.00 | .04626 | .25555 | 1.000 |
| | | 1.00 | -.07575 | .31882 | 1.000 |
| | 3.00 | 2.00 | .01343 | .34181 | 1.000 |
| | | 4.00 | .05969 | .33838 | 1.000 |
| | | 1.00 | -.13544 | .22388 | 1.000 |
| | 4.00 | 2.00 | -.04626 | .25555 | 1.000 |
| | | 3.00 | -.05969 | .33838 | 1.000 |
| | | 2.00 | .08919 | .20766 | .973 |
| | 1.00 | 3.00 | .07575 | .27584 | .992 |
| | | 4.00 | .13544 | .25662 | .952 |
| | | 1.00 | -.08919 | .20766 | .973 |
| | 2.00 | 3.00 | -.01343 | .30216 | 1.000 |
| | | 4.00 | .04626 | .28472 | .998 |
| **Games-Howell** | | 1.00 | -.07575 | .27584 | .992 |
| | 3.00 | 2.00 | .01343 | .30216 | 1.000 |
| | | 4.00 | .05969 | .33768 | .998 |
| | | 1.00 | -.13544 | .25662 | .952 |
| | 4.00 | 2.00 | -.04626 | .28472 | .998 |
| | | 3.00 | -.05969 | .33768 | .998 |

# Appendix 8

## Focus Group Questions

**School of Built Environment**
**Massey University, Auckland**
**Private Bag 102904**
**North Shore**
**Auckland 0745**
**New Zealand**

**Participant Information Sheet**

**Title of Project:** Strategies Integration Framework for Offsite Construction and BIM in New Zealand Construction Industry Across Project Life Cycle

**Name of Researcher:** Nazanin Kordestani

**Degree:** PhD candidate

**Department:** School of Built Environment Research

**Supervisors:** Dr Mostafa Babaiean Jelodar, Dr Daniel Paes, Professor Monty Sutrisna, and Dr Diyako Rahmani

**About Research Project**

You are invited to participate in the above-mentioned research title regarding research currently undertaken for a PhD study at Massey University. The framework developed for Offsite Construction (OSC) and Building Information Modelling (BIM) integration is based on data collected from case studies and surveys. Within this framework, stakeholders can identify their level of integration using a characteristics checklist provided. By doing so, they can refer to the corresponding stage within the framework to access information that facilitates progress towards achieving higher levels of integration. The primary focus of the framework is to address challenges, with the ultimate objective being to mitigate these challenges. It is important to note that while challenges and strategies are mentioned, they are not detailed extensively. Each challenge and strategy contain more specific factors that will be discussed and explored during the focus group meeting.

**Data Collection**

This focus group meeting will last 3 to 4 hours. The participant information is anonymous and individual, or project data will not be identifiable. The Massey University data repository will securely keep all the information gathered through this questionnaire, and only the researchers involved in this project will have access to it.

**Ethics Notification (No: 4000024955)**

Peer review evaluation determined this project to be low risk. The ethical conduct of this research is the responsibility of the researchers listed above. Please contact Prof. Craig Johnson, Director of Research Ethics, if you have any issues with how this study was conducted that you want to discuss with someone other than the researchers. Telephone (06) 356 9099 x 85271, email humanethics@massey.ac.nz

**Funding**

The researcher has been awarded the Massey University Doctoral Scholarship for three years.

***Statement of Consent***

I agree to voluntary take part in this research study undertaken by Nazanin Kordestani. I have read the participant information sheet (PIS). I understand the nature of the research and the basis on which I have been selected. I have had the opportunity to ask questions and have them answer to all my satisfaction.

- I understand that any participation in the research is voluntary and where my employer's consent for my participation is required, my employer has provided an assurance that my participation or non-participation will not affect my employment status and relationship in any way.
- I understand that the raw data gathered during the data collection procedures will be kept confidential and stored securely without access of any other party except the research team members for three years and subsequently be destroyed by appropriate means.
- I understand estimated time duration of the interview/survey questionnaire stated in the PIS.
- I agree/ do not agree for the interview to be audio- recorded.
- I understand that I may choose to have the recorder turned off anytime during the interview.
- I understand that any audio recording or data collection done under my permission will be transcribed by the researcher herself without involvement of the third party.
- I understand that I may request a copy of the raw data collected during the interview and researcher transcription to be reviewed and edited as I wish and provide further feedback to the researcher if necessary.
- I understand the confidentiality of the research and any data collected from any employee and organisation member will not be disclosed to any other party, even the organisation authorities.
- I wish/ do not wish to receive the summary of findings (Please provide email if you wish to receive summary of findings).
- I understand that I'm free to withdraw participation and at any time and to withdraw any data traceable to me up to two months after the data collection period.

| | |
|---|---|
| Name | Position |
| Email | Phone number |
| Signature | Date |

**The framework consists of the following sections:**

1) Characteristics of Integration Maturity Levels:

| Level | Characteristics |
|---|---|
| Initial | Ad-hoc adoption of OSC and BIM technologies.<br>Limited awareness and understanding of integration challenges.<br>Projects are reactive, with minimal planning for OSC and BIM.<br>Lack of optimized guidelines and clear orientation. |
| Managed | Basic understanding of OSC and BIM integration challenges.<br>Some project-specific planning for OSC and BIM.<br>Limited communication and collaboration among stakeholders.<br>Integration activities are managed on a project-by-project basis. |
| Defined | Clear project-level integration strategies and plans.<br>Improved communication and collaboration among stakeholders.<br>Proactive identification and mitigation of integration challenges.<br>Standardised guidelines for specific phases of the project life cycle. |
| Quantitatively Managed | Integration activities are measured and quantified.<br>Continuous improvement initiatives are in place.<br>Key performance indicators (KPIs) are used to assess integration success.<br>Lessons learned are systematically documented and shared. |
| Optimized | Integration activities are continuously optimized.<br>Innovation and advanced technologies are explored for improvement.<br>Industry best practices are consistently applied.<br>Integration strategies are adaptive and responsive to changing needs. |

2) Challenges occurring at different maturity levels (from initial to optimized) and project life cycle stages (from initiation to closeout)
3) Strategies utilised to mitigate challenges across various stages, primarily involving stakeholders such as clients, consultants, and contractors (including manufacturers)

**The objective is to validate the framework by assessing whether the captured data:**

***Accuracy of the Data:***

Do you find the data presented in the framework to be accurate based on your experiences and knowledge?

Are there any aspects of the data that seem incorrect or misleading?

***Need for Modifications:***

Does the framework require any modifications or updates to better reflect real-world scenarios?

If modifications are necessary, what specific changes would you recommend?

***Relevance of Challenges to Stages:***

Are the challenges identified in the framework accurately linked to the appropriate stages of project maturity and life cycle?

Can you provide examples where the identified challenges either align or do not align with the stages mentioned?

***Identification of Additional Challenges:***

Are there any additional challenges that the framework has not mentioned but should be included?

How do these additional challenges impact BIM and OSC integration?

***Applicability of Strategies:***

Do the strategies listed in the framework effectively address the challenges they are meant to mitigate?

Are there any challenges that the current strategies fail to address adequately?

***Identification of Responsible Stakeholders:***

Are the stakeholders identified in the framework as responsible for implementing strategies correctly assigned?

Should any other stakeholders be considered, or should the roles of current stakeholders be adjusted?

***Addition or Removal of Strategies:***

Are there any additional strategies that you think should be included in the framework?

Are there any existing strategies that you feel are not relevant or effective and should be removed?

***Framework Title Clarity:***

Does the title of the framework clearly convey its contents and purpose?

If the title is not clear or descriptive enough, what alternative title would you suggest?

# Appendix 9

## Statement of Contribution forms

DRC 16

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

**STATEMENT OF CONTRIBUTION**
**DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS**

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

| | |
|---|---|
| Name of candidate: | Nazanin Kordestani Ghalenoei |
| Name/title of Primary Supervisor: | Mostafa Babaeian Jelodar |
| In which chapter is the manuscript /published work: | Chapter 2 |

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. and Sutrisna, M. (2022), "Challenges of offsite construction and BIM implementation: providing a framework for integration in New Zealand", Smart and Sustainable Built Environment, Vol. ahead-of-print. https://doi.org/10.1108/SASBE-07-2022-0139.

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:

- The percentage of the manuscript/published work that was contributed by the candidate: 90.00

- Describe the contribution that the candidate has made to the manuscript/published work:

Lead author, conducted study and wrote the manuscript

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

| | |
|---|---|
| Candidate's Signature: | Nzanin Kordestani — Digitally signed by Nzanin Kordestani Date: 2024.06.05 11:16:37 +13'00' |
| Date: | 01-Jun-2024 |
| Primary Supervisor's Signature: | Digitally signed by Nazanin Kordestani Date: 2024.07.02 12:15:04 +12'00' |
| Date: | 2-Jul-2024 |

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

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| | |
|---|---|
| Name of candidate: | Nazanin Kordestani Ghalenoei |
| Name/title of Primary Supervisor: | Mostafa Babaeian Jelodar |
| In which chapter is the manuscript /published work: | Chapter 3 |

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Ghalenoei, N. K., Jelodar, M. B., Paes, D., & Sutrisna, M. (2022, November). Exploring Off-site Construction and Building Information Modelling Integration Challenges; Enhancing Capabilities within New Zealand Construction Sector. In IOP Conference Series: Earth and Environmental Science (Vol. 1101, No. 4, p. 042008). IOP Publishing. doi:10.1088/1755-1315/1101/4/042008

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:

- The percentage of the manuscript/published work that was contributed by the candidate: 90

- Describe the contribution that the candidate has made to the manuscript/published work:

Lead author, conducted study and wrote the manuscript

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

| | |
|---|---|
| Candidate's Signature: | Nzanin Kordestani — Digitally signed by Nzanin Kordestani Date: 2024.04.05 11:10:37 +13'00' |
| Date: | 01-Jun-2024 |
| Primary Supervisor's Signature: | Digitally signed by Nazanin Kordestani Date: 2024.07.02 13:18:01 +12'00' |
| Date: | 2-Jul-2024 |

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| | |
|---|---|
| Name of candidate: | Nazanin Kordestani Ghalenoei |
| Name/title of Primary Supervisor: | Mostafa Babaeian Jelodar |
| In which chapter is the manuscript /published work: | Chapter 4 |

Please select one of the following three options:

○ The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

◉ The manuscript is currently under review for publication – please indicate:

- The name of the journal:

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. Sutrisna, M. Rahmani, D (2024), "The Challenges and Strategies of BIM for Offsite Construction Delivery; the Factors of Integration". Cleaner Production

- The percentage of the manuscript/published work that was contributed by the candidate: 90

- Describe the contribution that the candidate has made to the manuscript/published work:

Lead author, conducted study and wrote the manuscript

○ It is intended that the manuscript will be published, but it has not yet been submitted to a journal

| | |
|---|---|
| Candidate's Signature: | Nzanin Kordestani — Digitally signed by Nzanin Kordestani Date: 2024.04.05 11:16:37 +12'00' |
| Date: | 01-Jun-2024 |
| Primary Supervisor's Signature: | Digitally signed by Nazanin Kordestani Date: 2024.07.02 13:20:00 +12'00' |
| Date: | 2-Jul-2024 |

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|---|---|
| Name of candidate: | Nazanin Kordestani Ghalenoei |
| Name/title of Primary Supervisor: | Mostafa Babaeian Jelodar |
| In which chapter is the manuscript /published work: | Chapter 5 |

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. Sutrisna, M. Rahmani, D (2024), "A Comprehensive Evaluation of Factors Influencing Offsite Construction and BIM Integration in the Construction Industry ", Engineering Construction and Architectural Management

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:

- The percentage of the manuscript/published work that was contributed by the candidate: 90

- Describe the contribution that the candidate has made to the manuscript/published work:

Lead author, conducted study and wrote the manuscript

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

| | |
|---|---|
| Candidate's Signature: | Nzanin Kordestani — Digitally signed by Nzanin Kordestani Date: 2024.04.05 11:16:37 +13'00' |
| Date: | 01-Jun-2024 |
| Primary Supervisor's Signature: | Digitally signed by Nazanin Kordestani Date: 2024.07.02 13:21:07 +12'00' |
| Date: | 2-Jul-2024 |

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

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