SUPPLY CHAIN INTEGRATION IN PREFABRICATED RESIDENTIALCONSTRUCTION IN NEW ZEALAND

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DEDICATION

I dedicate this thesis to my parents, my sister, and my loving husband

for their endless love, support and encouragement through my pursuit for education.

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This research study involved much dedication and ready assistance received from many people and organisations who contributed in plentiful ways to its completion. Therefore, I take this opportunity to convey my gratitude to all of them.

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ABSTRACT

Prefabrication has long been reported as an effective alternative to conventional construction, with wide-ranging benefits. It serves as a valuable source of providing time, cost, quality, productivity, health and safety and environmental benefits to residential construction. Although prefabrication has gained much attention, the residential construction industry appears to be taking minimal advantage of prefabrication due to barriers associated with this methodology. Inefficiencies in the supply chain are one of the major issues that hinder the wider uptake of prefabrication in residential construction. However, there has been little research in the literature considering the supply chain and supply chain integration in prefabricated residential construction.

Therefore, this research aims to improve supply chain integration in prefabricated residential construction. The objectives of the research include 1. review and analyse the nature of the processes and supply chain relationships of module and panel manufacturing in New Zealand residential construction; 2. identify the barriers to implementing effective supply chain practices in module and panel manufacturing in New Zealand residential construction; 3. identify the enablers for effective supply chain practices in module and panel manufacturing in New Zealand residential construction; 5. develop and validate a framework to measure and improve the current supply chain practices in module and panel manufacturing in the New Zealand housing sector.

The research used a multi-tiered qualitative approach for data collection. Firstly, twelve semi-structured interviews were conducted to collect data. The collected data was analysed using thematic analysis. Based on the literature review and analysed data maturity model was developed. The developed model was validated through focus group interviews. After validation, three case studies were conducted to benchmark the supply chain integration based on the maturity model.

Key findings emerged from the study: a standardised supply chain network for prefabricated residential construction and module and panel manufacturing was developed; 13 barriers (both internal and external) for supply chain integration in module and panel manufacturing were identified. Enablers (9 enablers) were identified to mitigate the barriers to supply chain integration in module and panel manufacturing; a maturity model was developed to improve supply chain integration continuously. The recommendation can make to improve the maturity model widening the scope and applicability for future research. The content of this thesis is beneficial for prefabrication manufacturers to assess their supply chain practices throughout the performance improvement process, for the residential construction industry to encourage residential prefabrication manufacturers to adopt and improve supply chain practices, for government and interested organisations to encourage residential prefabrication manufacturers by implementing favourable regulations and policies relevant prefabrication residential construction.

Keywords**:** Prefabrication; Residential construction; module and panel manufacturing; supply chain integration; maturity

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACC	Accident compensation corporation
BIFNZ	Business industry federation New Zealand
BIM	Building information modelling
BRANZ	The building research association of New Zealand
CHRANZ	Centre for Housing Research Aotearoa New Zealand
CSC	Construction supply chain
CSCM	Construction supply chain integration
ERP	Enterprise resource planning
ETO	Engineer to order
EU	European Union
GC	General Contractor
HUD	Housing and urban development
IBS	Industrialised building systems
ICT	Information and communication technology
JIT	Just in time
KPA	Key process areas
MBI	Modular building institute
MBIE	Ministry of business, innovation and employment

NZ	New Zealand
NZPC	New Zealand productivity commission
OSM	Off site manufacturing
OSP	Off site production
SC	Supply chain
SCI	Supply chain integration
SCM	Supply chain management
SME	Small and medium enterprises
TQM	Total quality management
UK	United Kingdom
US	The United States

CHAPTER ONE

INTRODUCTION

1.1 Background

Housing is considered a human need and directly relates to economic and social conditions (New Zealand Productivity Commission Report, 2013). The housing sector plays a major role in the development of a country. Houses are one-off projects accompanied by a production process which is complex and volatile in nature and generally results in unpredicted costs (Bildsten, 2011). Housing construction as an industry, is characterised by its cyclical nature, poor information transmission, fragmentation and, particularly, its dominance by small-scale firms (Cervero & Duncan, 2002). In general, the industry undergoes recessions and recoveries (Mayer & Somerville, 2000), influencing the current house prices and having repercussions on the economy.

In New Zealand, the housing sector is a key contributor to the economy, contributing 15% of the Gross Domestic Product (GDP) with a growth of $19.6 billion worth construction between 2009 to 2019 (Statistics, 2021). Despite the significance of the housing sector to the economy, its productivity performance has steadily declined (Shahzad, 2016). Acute capacity pressures, including strong demand and capacity constraints, a sharp increase in construction costs (by 6.9%) in 2021 across New Zealand (Rider Levett Bucknells Forecast Report 99, 2021).

The poor performance of the housing sector has influenced growing building costs and poor building quality (MBIE, 2013) and has resulted in a deterioration in housing supply owing to policy, social and cultural changes (Bassett & Malpass, 2013). Moreover, this is trigged by anti-development attitudes, tighter building regulations, poor and inappropriate designs, lack of focus on enhancing capacity, lack of innovation, lack of standardisation, and artificial restrictions on land supply (New Zealand Productivity Commission Report, 2013). Furthermore, the problems related to residential facilities have increased due to demographic and social changes such as; population growth, migrations between countries, migration from rural to urban centres, deinstitutionalisation of people with psychiatric and intellectual disabilities, changes in the composition of household units, and ageing (Gray et al., 2011).

To overcome these prevailing issues, industry, government and academics have proposed and implemented various solutions (New Zealand Productivity Commission Report, 2012; PrefabNZ, 2014; Masood et al., 2016; Masood et al., 2021). Among the proposed strategies, modular building construction and prefabrication have been identified as one of the promising approaches which would reduce construction costs (Shahzad, 2016; Samarasinghe, 2014; Mullens & Kelley, 2004). It has the potential to increase the supply of housing at an affordable price for the low-income group (Mostafa, et al., 2014; PrefabNZ, 2014; McDonald, & Temple, 2013).

A study by Mostafa et al. (2014) recommends prefabrication technology for builders as a more responsive and efficient solution to the rising demand for houses in Australia. In the UK construction industry, prefabrication is used in housing construction to provide houses at reasonable prices (Pan & Goodier, 2012). Japan is applying the same methodology (Barlow & Ozaki, 2005). Similarly, Curtis (2011) suggested housing standardization through prefabrication for New Zealand's housing construction sector so as to reduce construction costs. The Building and Construction Productivity Partnership Task Force (2013) recommended prefabrication as a strategy to reach a 20 per cent increase in productivity in the New Zealand construction industry by 2020. According to PrefabNZ (2014), prefabrication is the fastest way to provide higher quality houses to cope with the demand for more quality and cost-effective houses in New Zealand. The use of prefabrication for a one-off small/medium building project could reduce construction time by 60 per cent, cost by 9.3 per cent, and increase industrial productivity by 2.5 per cent (PrefabNZ, 2014).

In New Zealand (NZ), the usage level of prefabrication in the construction industry is quite low (Prefab, 2018; Shahzad, 2016). According to Shahzad (2016), this is caused by the bespoke nature of building construction, lack of skill and experience, and the implications of logistics, site operations, the supply chain and procurement. Similarly, extensive project planning from an early stage, lack of coordination and communication, and transportation constraints are found to be other barriers to the uptake of prefabrication in housing construction (PrefabNZ, 2014). Additionally, market failures have also influenced the wider uptake of prefabrication in the New Zealand construction sector (Building Research Association of New Zealand (BRANZ), 2013).

The prefabrication construction sector needs to address the above challenges if it is to compete effectively and efficiently with traditional on-site construction projects (Pan & Goodier, 2012; Doran & Giannakis, 2011). In line with this, Stroebele and Keissling, (2017) endorse the requirement of a well-working supply chain in prefabricated residential construction so as to achieve the benefits of prefabrication. As prefabricated residential construction involves extensive efforts in planning and coordination, the design of the supply chain is an essential requirement (Meiling et al., 2012). Coordination of the procurement and production in prefabricated residential construction could save time and cost in housing construction (PrefabNZ, 2014). According to Lessing (2006), the coordination of the partners of the supply chain in residential construction is another key attribute in terms of cost, time and quality. Therefore, managing the supply chain of prefabricated housing construction is a requisite for addressing the issues related to New Zealand's residential construction sector.

Supply chain management (SCM) is a manufacturing concept, However, the construction industry has started to apply SCM principles in order to achieve the same efficiency and productivity gained in the manufacturing industry. The fundamental attention of SCM is designing and improving the relationships between supply chain members (Storey, et al., 2006). This focuses on utilising the processes of suppliers, technologies, and capabilities to enhance competitive advantage (Farley, 1997), and coordinating the functions like manufacturing, logistics, materials and distribution within an organization (Lee & Billington, 1992). In supply chain management, a standardised information sharing system among supply chain members is a key attribute, especially for planning and process monitoring (Mentzer et al., 2001; Cooper et al. 1997). Fundamentally, SCM seeks to improve transparency and align inter and intra-organisational business processes (Love et al., 2004; Cooper & Ellram, 1993).

Unlike the manufacturing system, the one-off product in construction is assembled on the construction site from the materials delivered through temporarily set-up supply chains with less or no repetition (Vrijhoef & Koskela, 2000). This is similar to Engineer-To-Order (ETO) supply chains (Gosling et al., 2016; Gosling et al., 2009;

Winch, 2003) where the product is developed on a one-off basis (Rahim & Baksh, 2003). ETO supply chains are specifically designed for a single project to meet customer requirements (Gosling et al., 2016). The discount nature of the supply chains in construction is different from a production standpoint (Fearne & Fowler, 2006). However, SCM is a recommended approach to achieving efficiency and productivity in construction (Dubois & Gadde, 2000; Vrijhoef & Koskela, 2000; Egan, 1998).

However, construction supply chain practices are at a tactical level in New Zealand because of critical aspects such as high expectations, low economic size and physical isolation (Ying et al., 2015). At the tactical level, short-term decisions are made, and the supply chain processes are defined to control cost and minimise risk (Schmidt & Wilhelm, 2000). The fragmented nature of the housing construction sector has increased the potential for coordination problems, development of adversarial relationships, time delays and rework (Basnet et al., 2003). This has resulted in huge construction costs and lower building quality.

Bygballe et al. (2010) highlighted the necessity to improve the entire supply chain, from the planning stage to the delivery of the house, so as to minimise construction cost and time. Any improvement in the performance of the supply chain will directly result in positive consequences for the problems associated with the housing sector (Jeong et al., 2006). Unlike conventional housing construction, prefabricated housing construction has a complex process and requires better coordination and planning from the design stage onward. In prefabricated housing construction, a standardised communication system is required to share information, thus avoiding delays caused by the off-site manufacturing of modules, on-site preparation and transportation of modules (Stroebele & Keissling, 2017). Reforming the supply chain practices efficiently and effectively in prefabricated residential construction is therefore required to achieve the benefits of prefabrication and to eliminate issues related to residential construction.

1.2 Research Problem

There is a resurgence in focus on prefabrication in the New Zealand housing construction industry, driven by its benefits (Stroebele & Kiessling, 2017; Mostafa et al., 2014; PrefabNZ, 2014; Chiang et al., 2006). While countries like UK, US, Japan, Australia, Hongkong, Malaysia, Singapore have started to realise the benefits of off-site manufacturing techniques in housing construction, New Zealand appears to be taking minimal advantage of prefabrication due to inefficiencies in its supply chain (PrefabNZ, 2014). In line with that, several researchers have identified the significance of supply chain management in overcoming the barriers in prefabrication (Stroebele & Kiessling, 2017; Masood et al., 2016; Samarasinghe et al., 2013; PrefabNZ, 2014; Lessing, 2006).

Concerning these facts, studies have been carried out to explore the benefits of prefabrication (Pan et al., 2012; Lawson & Ogden, 2010; Pasquire & Gibb, 2002), improving the prefabrication supply chain (Stroebele & Kiessling, 2017; Doran & Giannakis, 2011; Naim & Barlow, 2003; London & Kenley, 2001), prefabrication and lean manufacturing (Arbulu & Ballard, 2004), and lately, the integration of supply chain strategies to prefabrication (Lessing et al., 2015; Mostafa, et al., 2014). However, there is little research into the nature of supply chains and its relationships and barriers to integrating supply chain practices in prefabricated residential construction.

According to Jeong et al. (2006) and Masood et al. (2023) improvements to the current prefabricated housing supply chains could have the potential contribution of improving overall efficiency in the housing construction process. This has the potential to reduce construction costs. Furthermore, improving supply chain integration prefabrication residential construction is a solution to the housing supply shortage (Doran & Giannakis, 2011; Masood et al., 2023).

Although prefabrication and integrated supply chain management practices have been identified as solutions to the issues in the New Zealand housing sector, no significant research has been directed in the field of prefabricated housing construction focusing on integrating supply chains in prefabricated module/panel manufacturing. Further, Masood et al. (2021) identified the requirement of performance improvement in prefabricated residential construction. Furthermore, the study highlights the significance of investigating performance barriers for applying prefabrication at the company level Masood et al. (2021).

This research, therefore intends to fill the gap in prefabrication residential construction, firstly, by identifying barriers for supply chain integration in prefabrication residential construction and following from this, to provide a model to measure and improve the current supply chain practices so as to increase the efficiency of prefabricated residential construction in New Zealand.

1.3 Research aim, questions and objectives

The aim of the research is to improve supply chain integration in prefabricated residential construction by developing a maturity modole measure supply chain practices.

To accomplish the above aim, the following objectives are identified:

Research Questions

The following research questions were developed based on the knowledge gaps discussed in section 1.2;

Question 1: What is the nature of the prefabricated residential construction and module and panel manufacturing processes?

The study identified the nature of supply chains including information flows and material flows.

Question 2: What are the relationships in the SC of prefabricated residential construction?

The study identified the relationship between the participants of the supply chains (including external participants) in prefabricated residential construction and module and panel manufacturing.

Question 3: What are the barriers for SCI in module and panel manufacturing in New Zealand residential construction?

The study identified the major issues and challenges associated with the supply chain of module and panel manufacturing in residential construction from the initial stage to the installation of the product.

Question 4: What are the enablers to SCI in module and panel manufacturing in New Zealand residential construction?

Solutions to eliminate and mitigate the barriers and challenges for supply chain integration of module and panel manufacturing in residential construction in New Zealand was identified.

Question 5: How to measure the current supply chain practices and improve supply chain integration in module and panel manufacturing in New Zealand residential construction?

The study focused on developing a model to assess and improve supply chain practices and supply chain integration.

Research objectives

1. Review and analyse the nature of the processes and supply chain relationships of module and panel manufacturing in New Zealand residential construction
2. Identify the barriers to supply chain integration in module and panel manufacturing in the New Zealand residential construction
3. Identify the enablers to supply chain integration in module and panel manufacturing in New Zealand residential construction
4. Develop and validate a model to measure the current supply chain practices in module and panel manufacturing in New Zealand residential construction

1.4 Methodology

The overview of the research process is shown in Figure 1.1. As the first step of the research, a comprehensive literature review was conducted in the areas of prefabrication and supply chain management to identify the gaps and to develop the conceptual framework. Considering the gaps identified from the literature review research questions and objectives were formed. To achieve the research objectives, a multi-tiered qualitative approach including; semi-structured interviews, focus group discussions, and case studies, were proposed to collect data. Semi-structured interviews were conducted to review and investigate the nature and relationships in prefabricated residential construction and to identify the barriers and enablers for supply chain integration. Based on the data collection and literature review, a maturity model for supply chain integration in prefabricated residential construction was developed. The developed model was validated through focus group interviews. Case studies were conducted to benchmark the supply chain practices based on the developed model.

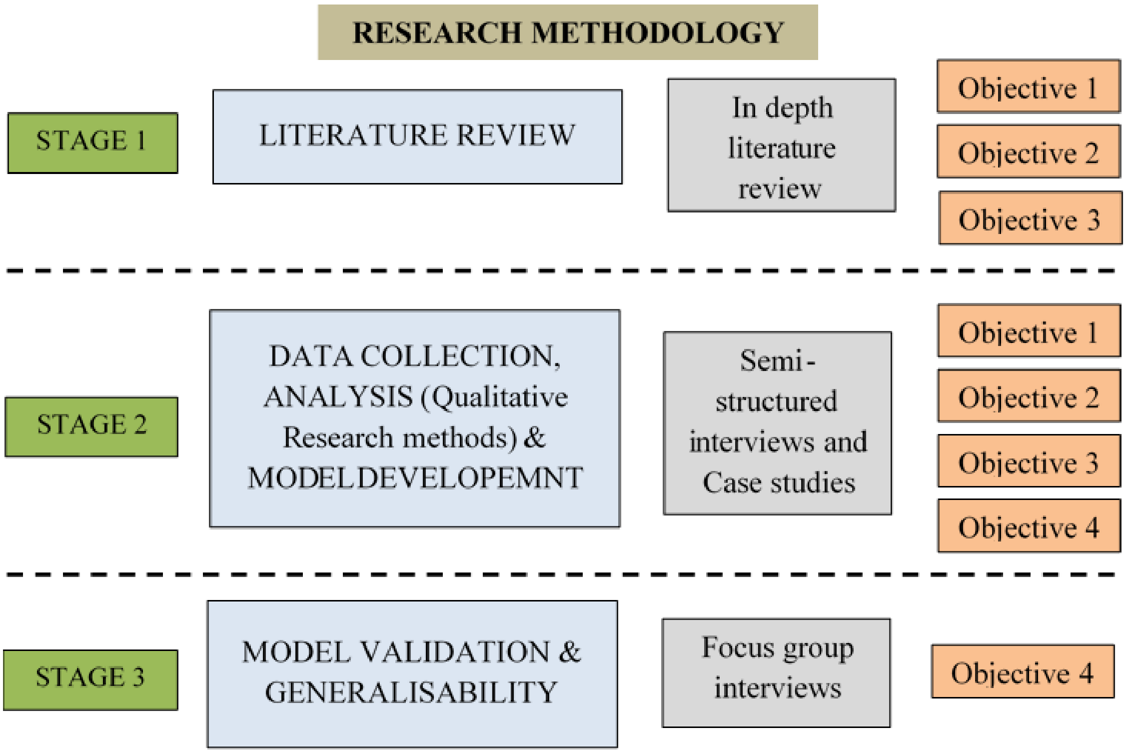

Figure 1.1: Research design

1.5 Research significance and contribution

As the shortage of housing supply and poor productivity performance of the residential sector transforms into an upstream level of condition, there is more pressure placed on the government, the industry and researchers to come up with potential solutions. Prefabrication has been identified as a breakthrough strategy to improve housing affordability through productivity improvements (PrefabNZ, 2014). However, the prefabrication residential construction supply chain needs to reform in order to utilise the benefits of prefabrication (Stroebele & Keissling, 2017; Masood et al. 2016). In the meantime, the Productivity Commission Report (2014); Doran and Giannakis, (2011) advocate that the configuration of the construction supply chain directly supplements positive consequences to the housing shortage.

This research reviewed the prefabricated residential supply chain, bathroom pod manufacturing and wall panel manufacturing process and their relationships. The supply chain processes developed in this study is new knowledge to the literature. Some of the previous studies identified the barriers for supply chain integration in both construction and prefabrication. However, this is the first identifiable study that came up with barriers to supply chain integration in module and panel prefabricated residential construction. The research further, provides a categorisation of barriers to supply chain integration. The maturity model developed in the study contributes to the existing knowledge to continuously improve the process, relationships and information sharing in prefabricated residential construction. The maturity model developed for the study can be used as a benchmarking tool of the supply chain practices in prefabrication manufactruing compnies in New Zealand. And further, it can be utlise as a model to improve the supply chain integration of manufactruing companies.

This research is significant in providing guidance to improve the supply chain practices in prefabricated residential construction. This will improve the efficiency and the performance of the supply chains in modular elements manufacturing. The ultimate goal is to develop a maturity model to improve supply chain integration in prefabricated residential construction. This model could assist module and panel manufacturers in improving supply chain practices. Further, this study will of benefit to the existing literature and to the New Zealand residential construction industry and its stakeholders as follows:

- Provide a tool for the organisations to measure their current supply chains and to improve the current supply chain practices into an integrated level to realise efficiency in the construction process
- Provide a base for organisations and stakeholders to assess their communication and coordination capacity
- Improve the productivity and performance of the house construction process through time reduction and quality enhancement
- Provide a solution to the imperative need for affordable housing

1.6 Scope and limitations of the research

The research scope is limited to the manufacturing process of prefabricated elements used in housing construction in New Zealand. The aim of the study was focused to develop a model to measure and improve the supply chain practices in the prefabricated residential construction process. Wall panel and bathroom pod manufacturing were considered from initial inception to project completion, including the stages design, planning, manufacturing, transportation and assembling.

Prefabrication construction is classified into five types: component-based prefabrication, panelised prefabrication, modular prefabrication, whole-building prefabrication, and hybrid prefabrication. Of these, panelised prefabrication is one of the most well-established and most common types of prefabrication in New Zealand (PrefabNZ, 2013, Burgess, Bucket, & Page, 2013, Bell, 2009) with module manufacturing, spefically bathroom pods and laundry pods becoming a trend in residential apartments building. Therefore, in this research, the manufacturing processes of bathroom pods under the module category and wall panels under the panel category were considered.

As the research is based on multi-tier qualitative methods, the validity of the research findings is based on the accuracy of the opinions provided by the participants. The semi-structured interviews were limited to 12 participants as the data-saturated once 12 interviews were conducted. As a small scale industry, the population size of experts in prefabrication residential construction is quite small. The participants included manufacturers, builders, developers and architects engaged in residential construction in New Zealand.

1.7 Structure of the thesis

Chapter 1

This chapter provides an overview of the thesis. In the beginning, the chapter provides a discussion on the research background, current gaps in the knowledge, and the aim and objectives of the study. Then the chapter presents a summary of the research methodology and contribution of the study. Finally, the chapter ends with the structure of the thesis.

Chapter 2

This chapter provides a critical review of the literature on prefabrication and supply chain management. This includes different types of prefabrication, prefabrication residential supply chains, advantages and disadvantages of prefabrication, supply chain integration, construction supply chain integration, barriers for supply chain integration, enablers for supply chain integration, New Zealand construction industry, supply chain maturity and conceptual framework.

Chapter 3

This chapter provides an overview of the research methodology. This chapter begins with the research philosophy and then focuses on the research design adopted for the study. Finally, the chapter discusses the validity and reliability of the study.

Chapter 4

This chapter presents the findings of semi-structured interviews. The chapter covers demographic information of the interview participants, prefabricated residential supply chain process, barriers and enablers for supply chain integration.

Chapter 5

This chapter presents the maturity model development. This chapter covers the model development process including maturity levels, key process areas and sub-criteria. At the end chapter highlights the scope and the limitation of the model.

Chapter 6

This chapter discusses the validation of the maturity model. The chapter begins with the results of the model validation through focus group interviews. Then the chapter focuses on the amendments to the model based on the suggestions received from the focus group interviews. Then the chapter discusses the results based on the benchmarking of supply chain practices against the developed model in three case studies.

Chapter 7

This chapter presents a discussion of the emerging themes of the research within the context of literature.

Chapter 8

This chapter summarises the research findings, contribution to knowledge, research limitations and recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

The second chapter of the thesis provides an overview of the literature review, structured into two main sections: prefabrication construction, and supply chain management. The figure 2.1 illustrates the synthesis of the literature review using a Venn diagram. The chapter begins with an introduction to prefabrication and residential construction. It outlines the concept and types of prefabrication. This is followed by the usage and benefits of prefabrication in residential construction in general and the New Zealand context.

Then, the chapter describes the concept of supply chain management (SCM) directed towards achieving efficiency, productivity, and supply chain integration (SCI). Under the main heading of SCM, supply chain integration, barriers for SCI, enablers for SCI and SCI in prefabrication residential construction are reviewed. Then, the chapter focuses on the aspects of maturity assessment, one of the innovative ways to assess and manage supply chains. Subsequently, it discusses different maturity models developed for the construction industry and summarises the key features, scope and limitations of the identified models.

Finally, the chapter synthesises the findings of the two sections, prefabrication and SCM, to discuss the gaps in the literature pertaining to the prefabricated house building supply chain. Subsequently, it illustrates the relationship between SCI and enablers for SCI aiming to improve efficiency in prefabricated house building.

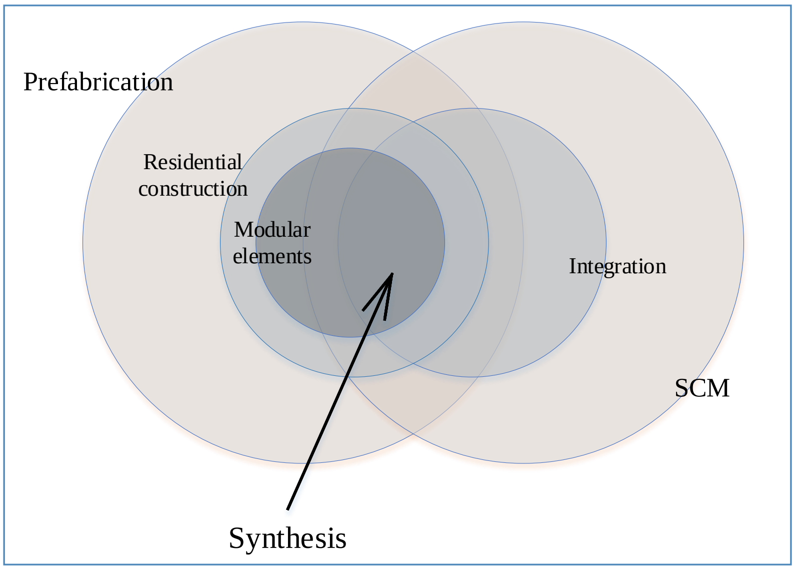

Figure 2.1: Literature synthesis Venn diagram

2.1.2. Overview of prefabrication

The notion of prefabrication is an innovative technique that has been adopted to improve cost-effectiveness in the construction industry. There are various overlapping terms and terminologies to describe prefabrication. Some terms used in the construction industry to define prefabrication include; off-site Manufacturing (OSM), off-site prefabrication, off-site production (OSP), pre-assembly, industrialised building system (IBS) and modularisation. Term prefabrication is used in this research, as it was commonly used across the New Zealand construction industry.

The term prefabrication can be described as the off-site production of standardised or customised components or complete structures (Page & David, 2014). According to Goodier and Gibb (2007), prefabrication involves the manufacturing and pre-assembly of building components, elements or modules before installation into their final locations. In simple terms, it is a manufacturing process of modules or components off-site (Sparksman et al., 1999). In practical terms, the prefabrication process begins with the confirmation of the client (Stroebele & Kiessling, 2017). Compared with the manufacturing supply chain, the key difference in prefabrication in construction is the on-site assembling and therefore, a higher degree of the supply chain is finalized during the production (Stroebele & Kiessling, 2017).

In prefabrication methodology, simultaneous activities in on-site construction and off-site production enhance project performance with improvements in value for money, profitability, predictability and productivity (Kamali & Hewage, 2016; Pasquire & Gibb, 2002). Apart from industry performance, prefabrication could reduce environmental impacts plus health and safety concerns (Gorgolewski, 2005). Therefore, compared to traditional construction, prefabrication provides benefits that could lead the construction industry to consider using prefabrication.

2.1.2 Types of prefabrication

Prefabrication can be categorised according to materials, technologies, market sector or extent of prefabrication. The extent of prefabrication is commonly considered in classifying prefabrication. The typologies and types of prefabrication, based on the extent of prefabrication, are described here.

In 1999, Gibb (1999) categorised prefabrication into three types; as non-volumetric off-site fabrication; volumetric off-site fabrication and modular building. According to Gibb's (1999) categorisation, he defines non-volumetric as elements that are not enclosed for use as spaces. These include cladding, partitions, parts of building services, and ductwork/pipework. The volumetric off-site fabrication category comprises units that enclose usable space, which does not constitute a whole building (Gibb, 1999). Examples of this category include bathrooms/toilets, plant rooms and lifts. Modular building prefabrication is defined as a unit that forms a complete building or part of a building, including the structures and envelope (Gibb, 1999).

Following this categorisation, Gaze et al., (2007) created a classification of five categories including; component, panel, module, hybrid and complete buildings. Categories of prefabrication have evolved over time and the categorisation created by PrefabNZ in 2014 is used for this study. The following section discusses the categorisation of PrefabNZ.

2.1.2.1 Component based prefabrication

Components are pre-cut, pre-sized, pre-moulded or pre-shaped elements that are assembled or installed on-site. Components are relatively small-scale items that are invariably assembled offsite, such as light fittings, windows, and door furniture. It includes structural members (trusses and frames), fittings, fixtures, and joinery that is cut, sized or shaped away from the site for assembly on site. The use of pre-nailed components has become an accepted part of the traditional construction process by the full range of home building companies in New Zealand (Bell, 2016). Kitset housing, pre-cut framing and build-up windows are few common forms of component-based prefabrication in New Zealand (Burgess, Buckett & Page, 2013). In New Zealand residential construction, 91 percent of walls and 95 percent of roof are pre-cut wall frames and prefabricated roof trusses, respectively (Burgess et.al., 2013).

2.1.2.2 Panelised/non-volumetric prefabrication

These are planar units that do not enclose usable space, such as panel systems and cladding panels. This is essentially an assembly of two-dimensional "area" elements (Burgess, Buckett & Page, 2013). They may include windows, doors or integrated services, and are either open-framing or closed-in with cladding and/or lining. They are transported to site as flat-packs.

The panelised prefabrication is the most common type of prefabrication using in New Zealand (Burgess et. Al., 2013) and it is a well-established in New Zealand construction industry (PrefabNZ, 2013).

2.1.2.3 Module/volumetric prefabrication

Volumetric prefabricated units are enclosed usable spaces and are then installed within or onto a building or structure. These units are also known as modules and pods and are assembled as three-dimensional units (Burgess et. Al., 2013). They are typically fully finished internally, such as toilet/ bathroom pods or plant-rooms.

In New Zealand, modular prefabrication is gaining attention regardless the challenges in transportation and customisation. Even though, the adoptability of modular prefabrication in residential construction is criticised, modular bathroom pods are currently using in apartments and commercial buildings. Further Kinga Ora, as New Zealand largest residential builder, initiated using modular bathroom pods and laundry rooms in residential construction across Auckland.

2.1.2.4 Hybrid prefabrication

Hybrid prefabrication is denoted as semi-volumetric prefabrication. It consists of a mixture of volumetric or modular units and non-volumetric or panelised units (module plus panel). Hybrid prefabrication can be suitable for both residential and other type of buildings (Langdon, 2004). The Hybrid system has the potential to achieve both the speed of construction and design flexibility (Shahzad, 2016).

2.1.2.5 Complete building prefabrication

Fully-finished volumetric construction is considered a complete building prefabrication. In New Zealand, complete building prefabrication includes the traditional transportable housing industry. This type of prefabrication is also known as 'transportable prefabrication' and 'portable prefabrication' (Shahzad, 2016). Complete building prefabrication can achieve higher quality, building standards, speed of construction and enhanced life cycle (Shahzad, 2016).

2.1.3 Prefabricated residential construction

In the conventional housing construction scenario, the entire work associated with the erection of a house is performed on the construction site (Kamali & Hewage, 2016). In contrast, this method wholly turns into upside down level by the prefabrication housing supply chain where a high degree of completion is carried out in the factory. In residential construction, prefabrication can be utilised one of three forms: prefabrication components, modular housing, and manufactured housing (Zhao & Riffat, 2007). Prefabrication components have been widely used in the construction industry and today, with the growth of the technology, prefabrication provides growing a range of products into residential construction. According to Mostafa et al. (2014), the application of prefabrication in house construction has been endorsed to achieve a greater housing supply while acknowledging customer demand. Similarly, the US Department of Housing and Urban Development (HUD) ratified the benefits of incorporating prefabrication in the construction faster, better and low-cost houses (PATH, 2002). Similarly, in the UK construction industry, this technique is used in house building to provide low to zero carbon homes at affordable prices (Goodier & Pan, 2012). The adoption and usage of prefabrication in other countries are discussed in the next section.

Prefabrication has the potential to enhance industry performance with improvements in environment, health and safety, value for money, profitability, predictability and productivity (Pasquire & Gibb, 2002). Although, many academics and practitioners have strived to explore these insights into prefabrication and residential construction, clients are resistant to standardising the houses (Georgiadou, 2019; Lessing, 2006). This, coupled with architect/designer perception barriers and the fragmented structure of the supply chain, hinders the application of prefabrication (Lu & Liska, 2008). According to Zhang and Skitmore (2012), the adoption of prefabrication in housing construction is limited to two types of construction companies; renowned mega residential property developer enterprises and certain proactive housing product manufacturing specialists. So for many of those engaged in the construction process, the benefits of using prefabrication technique is not well realised (Lu & Liska, 2008).

2.1.3.1 Prefabricated residential construction-country context

Internationally, there is a growing trend towards using prefabrication in residential construction to overcome the issues associated with affordability (Masood et al., 2016; PrefabNZ, 2014; Forum, 2002) sustainability (Kamali & Hewage, 2016; Gorgolewsk, 2005) and productivity and waste minimisation (Mokhtar & Mahmood, 2008; Tam et al., 2005).

This section provides an overview of the state of prefabrication uptake in some countries across the world. The following figure 2.2 shows an international overview of the uptake of prefabrication (in residential construction). Sweden demonstrates the highest uptake (90% of the total residential construction) of prefabrication in residential construction while Australia records the lowest level which is 3% out of the total residential construction. In New Zealand, the uptake of prefabrication in residential construction is recorded as 32%.

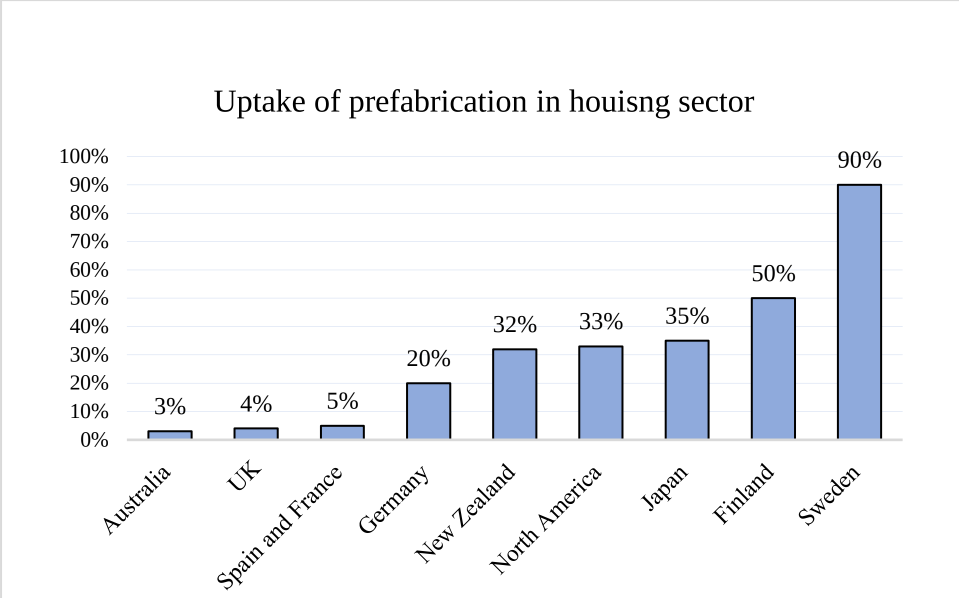

Figure 2.2: Uptake of prefabrication in housing construction

Adapted from: (PrefabNZ, 2014)

Among other countries in the world, Sweden and Japan are considered leaders in prefabrication owing to the higher adoption rate of prefabrication in construction industry (Steinhardt & Manley, 2016). Japan's residential construction industry serves as model for delivering successful prefabricated and customised houses applying large-scale production and automation (Manley & Widén, 2016; Barlow et al., 2005). In Sweden construction industry, a higher prefabrication adoption rate is continuously denoted by residential construction in which, 88 percent of single-dwelling timber detached houses are prefabricated (Träoch Möbelföretagen, 2017, as cited in Steinhardt et al., 2020). Since, researchers have been focused on the approaches used in these two countries to enhance prefabrication (Steinhardt et al., 2020; Navarathnam et al., 2019; Manley & Widén, 2019).

Application of prefabrication in residential construction in US, UK, China and Australia claims around 5% (Bertram et al., 2019). In the UK, the lower adoption rate of prefabrication in the residential industry is criticised although, the benefits and potential of prefabrication adoption is widely reported (Pan & Goodier, 2012). In 2012, Pan and Goodier worked on identifying business models and relationships in prefabricated housing firms. Mark Farmer' modernise or die- a government-commissioned report also recommends working on business models to adopt more pre-manufactured approaches starting from the housing sector (Farmer, 2016). Further, European Union's (EU) ManuBuild and FutureHome programmes are focused on promoting industrialisation and robotization in residential construction (Martinez et al., 2008). Australian government and the construction industry also identified prefabrication to improve construction output and established innovative approaches to improve efficiency in prefabrication (Hampson & Brandon, 2020).

2.1.3.2 Prefabricated residential construction- New Zealand

The residential construction industry in New Zealand has been criticised for its fragmented nature. It is characterised by small-scale firms, causing time delays, less productivity, quality variations, less innovation and high cost (PrefabNZ, 2014; Building Industry Federation of NZ (BIFNZ), 2013; CHRANZ, 2011). Consequently, building materials and commodities are relatively expensive compared to Australia (Ying et al., 2015). Furthermore, owing to its geographical isolation and small population, New Zealand has less competition among suppliers (CHRANZ, 2011). To illustrate, Auckland housing demand and Christchurch rebuild projects have been subjected to fluctuations in the NZ housing construction sector (Samarasinghe et al., 2013). Additionally, the unique and customised nature of the houses in New Zealand (Mason, 2013) creates inefficiencies and added costs to the construction process (CHRANZ, 2011).

Prefabrication is one of the potential solutions to most of the problems associated with housing construction in New Zealand (PrefabNZ, 2014). It is one of the ways to improve the quality and accessibility to architectural designs for housing construction (Bell, 2012). However, in New Zealand, the usage of prefabrication is relatively low (Page, 2014; PrefabNZ, 2014). In New Zealand 17 percent of all construction taking place is prefabricated, so there is a huge potential of almost double the uptake of prefabrication (Burgess et al., 2013). According to the report of PrefabNZ (2014), the usage of prefabrication for non-residential buildings and residential buildings is 11 percent and 37 percent respectively. Mainly, prefabricated timber wall panels, roof frames, joinery and windows are used for housing construction in New Zealand (PrefabNZ, 2014). According to Bell (2012), prefabricated housing construction in New Zealand ranges from a single house to multi-unit, custom designed to replicable, and experiments. PrefabNZ has forecasted the uptake of prefabrication over the next 10 years as shown in Table 2.1. In 2018, the Minister of New Zealand Housing has been promised to supply 100,000 affordable houses over 10 years and among those houses half of the construction was planned to build using prefabrication (Trevett, 2018).

Table 2.1: Predicted uptake of prefabrication over the next 10 years

	Component	Panelised	Volume	Hybrid (Pad+ Panel)	Complete Building
In 10 Years	90%	30%	20%	10%	20%
In 5 Years	60%	15%	10%	5%	10%
Now	33%	5%	2%	1%	2%

Adapted from: (PrefabNZ, 2014)

Several successful housing projects have taken place in New Zealand using different forms of prefabrication. The Innovation Village at Canterbury Agricultural Park (HIVE) in Christchurch was established to deliver high quality, permeant, sustainable and affordable prebuilt homes as part of the recovery from the Canterbury earthquakes. Keith Hay Homes and Auckland architecture practice Architex collaboratively developed a two-bedroom house within 8-10 weeks to respond customers with their rapidly requirements.

Kāinga Ora and future prefabrication in New Zealand

Kāinga Ora is a government agency formed by merging Housing New Zealand, Homes Land Community Ltd (HLC) and KiwiBuild in October 2019, to deliver good quality, affordable housing choices in New Zealand. The organization is equipped with different approaches and programmes to uplift the supply of houses. The housing developments range from small to large-scale and include different types like stand-alone, duplexes, apartments, two or three-level walk-ups, and terraced houses. The designs of houses include both bespoke and standard designs. Apart from the construction activities, Kāinga Ora focuses on infrastructure developments to create a functional and attractive neighbourhood for the local community.

Prefabrication is incorporated in Kāinga Ora's approaches as a construction method to provide affordable and sustainable houses. Kāinga Ora doubled the usage of different prefabrication solutions in house building between 2019 to 2021 and aims to increase it by 20% year on year for both public and urban development housing. Recently, Kāinga Ora initiated delivering modular homes in Hobsonville and adopting bathroom and laundry pods across four sites in Auckland to achieve affordability issue in New Zealand.

2.1.4 Benefits of Prefabrication

The successful completion of a construction project, whether using prefabrication methods or traditional approaches, depends on the clear identification of the key factors driving the project, as well as an appreciation of the constraints affecting its efficient completion (Gibb & Isack, 2001). Although various industry and research initiatives have attempted to scrutinise the barriers and drivers of prefabrication methods, limited efforts are taken in adopting it into housing construction (Elnaas, 2014). In the literature, the benefits of using prefabrication in construction tend to focus on cost, quality and productivity (Jaillon & Poon, 2008). In fact, the main focus of prefabrication over traditional process is on profitability. However, other significant advantages associated with the use of prefabrication, adding value to the building are generally overlooked. Therefore, the economic, social and environmental benefits of adopting prefabrication in construction is briefly discussed here.

Economic benefits of using prefabrication

Prefabrication allows shorter onsite construction time (Goodier & Gibb, 2007) as site preparation and building construction take place simultaneously (Figure 2.3) (Kawecki, 2010). Besides, in prefabrication construction time spent on-site operations is minimal and it reflects on avoiding delays due to disruptions from weather extremes (Waskett, 2003). Similarly, inherent risks associated with traditional construction, such as conflicting crews and interferences with ongoing operations, is considerably low in prefabrication (Haas & Fagerlund, 2002). On the other hand, time reduction in prefabrication is replicated in lower site overhead cost, less interest on loans and early return on investment. On average, construction time is reduced by 40% in prefabrication constructions compared with traditional construction (Lawson & Ogden, 2010).

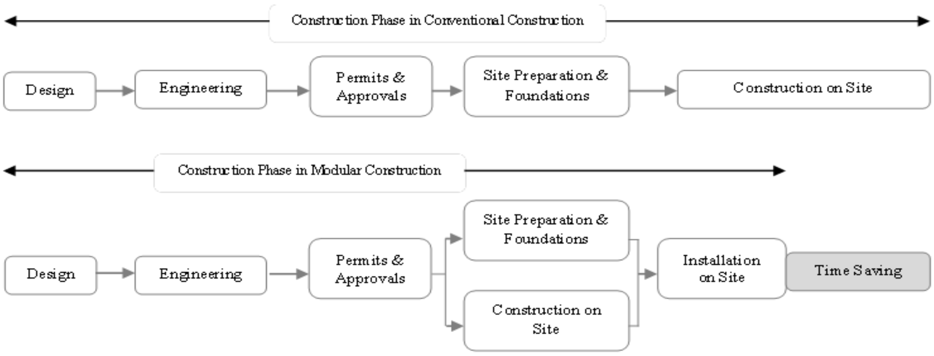

Figure 2.3: Time saving in prefabrication construction

Adapted from: (Kamali & Hewage, 2016)

By adopting prefabrication, problems related to poor workmanship and poor product quality can be reduced through a controlled manufacturing environment in which the components are built (Kamali & Hewage, 2016; Jaillon & Poon, 2008; Haas & Fagerlund, 2002). Furthermore, it facilitates the repetitive process and operations with automated machinery, thus, the quality of the product is easier to assure (Construction, 2011; O’Connor et al., 2014). According to Jaillon and Poon (2008), the use of offsite technologies in house building improves quality and offers more rigorous quality control, reduced defects and improves the durability of components; while onsite output quality is very much dependent on the workmanship of construction labourers and the supervision team. Moreover, in the manufacturing environment parallel activities are possible without disruption to the process, which enhance productivity (Lu, 2009; O’Connor et al., 2014). Improved quality reduces maintenance work and associated costs (Jaillon & Poon, 2008). On the other hand, prefabrication can offer opportunities for dealing with problems resulting from the declining skilled labour shortages on site and thereby reduce the labour cost of the project. In house building, builders can benefit from the use of prefabrication through a shorter construction time and reduction in life-cycle cost of the housing project (Kamali & Hewage, 2020). In addition, house builders can also benefit from adopting prefabrication through early project occupation due to short construction programme, reduced operational and maintenance cost during occupancy due to greater technical reliability, reduced energy-in-use, and improved margins due to more efficient site processes (Housing Forum, 2002, Kamali & Hewage, 2020).

Prefabrication could yield cost benefits over traditional construction owing to many related factors. In line with the results of the Construction Industry Institute (CII), in prefabrication construction projects, cost reduction was 10% on overall cost and 25% on the on-site labour cost (Lu, 2007). Cost reduction could be achieved through other factors, such as design standardisation, higher efficiency in installation and higher energy efficiency. Similarly, Badir et al. (2002) also found savings in labour and material costs to be a major benefit, with reduced construction site waste. This was also echoed by Mokhtar and Mahmood (2008), who consider the use of prefabrication to be one of the most effective waste minimisation methods possible in the construction industry.

In New Zealand, researchers have proven that the overall performance of New Zealand's economy can be influenced the potential benefits of using prefabrication (BRANZ, 2013, Shahzad, 2016). According to BRANZ (2012) reduction in construction time can save the cost between $1000-$1600 per week. Ian Page of BRANZ analysed the data obtained from a major house builder in New Zealand and presented it as shown in the figure 2.4. According to the analysis, cost of a prefabricated house can save 15 percent construction cost compared to traditional construction (Page, 2012). Further, PrefabNZ (2014) highlights the 9.3 percent of cost saving in small and medium projects due to 60 percent of time reduction of the construction programme in prefabrication. Early completion and commission also improve cashflows for the developer or contractor which is as 8 percent of the construction cost (PrefabNZ, 2014).

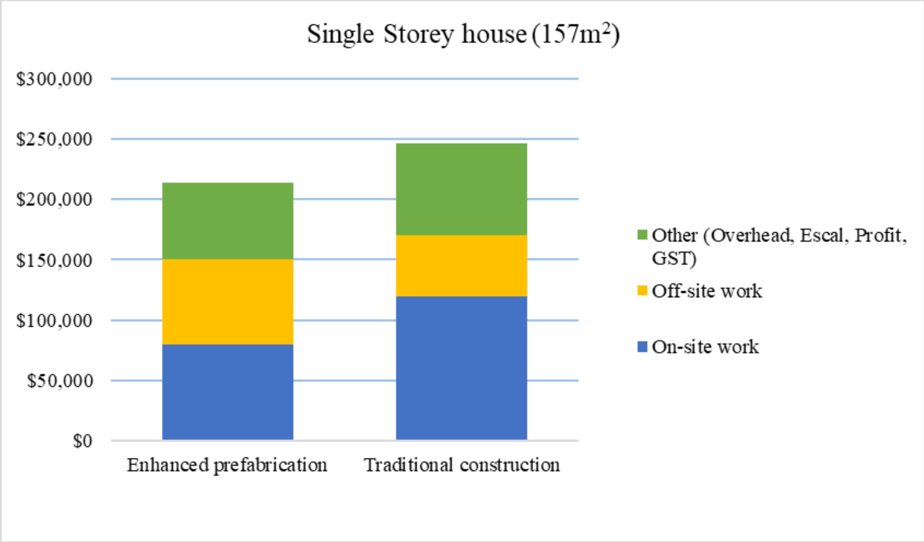

Figure 2.4: Cost comparison of traditional construction and enhanced prefabrication

Source: (Page, 2014)

Environmental benefits of using prefabrication

Prefabrication construction offers minimal site disturbance when compared with the traditional construction, where the construction site operations are vulnerable to noise, dust, congestion and waste (Mah, 2011; Jaillon & Poon, 2008; Lu, 2007). According to Jaillon and Poon (2008) waste reduction is one of the highlighted environmental benefits of using prefabrication in which pollution can be easily controlled in the factory environment. Prefabrication construction contribute to waste reduction in timber formwork, plastering and concrete works by about 74%–87%, 100% and 51%–60% respectively (Tam et al., 2005). Similarly, on-site greenhouse gas (GHG) emissions in prefabrication is minimal compared to traditional methods (Mah, 2011; Lu & Korman, 2010). Thus, with the use of prefabrication, material conservation and waste reduction are possible. In addition, at the end of the modular buildings' life cycle, modules can be disassembled, relocated or refurbished to be used in other projects instead of being disposed of.

In New Zealand, traditional construction produces 10 percent of material wastage while, manufacturing contributes 1-3 percent (PrefabNZ, 2014). Moradibistouni and Gjerde, (2017) also, highlighted that the prefabrication could reduce waste by 40%, carbon dioxide emissions and energy consumption by 40%, 35% and 55% respectively. As a timber-based industry, New Zealand construction industry can effectively reduce waste generation using more quality of prefabrication products and better supervision (Luo and Shahzad, 2020).

Social benefits of using prefabrication

Improved site safety is found to be a significant benefit of prefabrication when compared to conventional construction (Jaillon & Poon, 2008). Risks associated with working at height are avoided in the factory environment, thus improving workers' safety. Prefabrication also contributes to a reduction in construction noise and dust on-site, thus benefiting both the employees and the neighbouring communities (Jaillon & Poon, 2008). In addition, prefabrication improves quality and durability, tackling the maintenance problem with assurance in public safety (Iacovidou, et al., 2021). Using prefabrication in house building can offer potential improvement of working conditions, while factory-based jobs offer greater long-term security for individual workers and, better staff training (Ross, 2002). Furthermore, improved quality of manufacture and technical performance lead to better quality indoor and outdoor environments (Housing Forum, 2002). prefabrication also offers better quality which can lead to reduced maintenance costs and household energy bills, while better design can lead to flexibility for future changes and customers' satisfaction (Gibb & Pendlebury, 2006). Faster construction can also improve housing completion rates and satisfy higher levels of demand (Burwood & Jess, 2005).

As one of the highest of fatality rate sector in New Zealand, construction could reduce 75 percent of fatalities per unit of construction using prefabrication (BRANZ, 2013). This could save Accident Compensation Corporation (ACC) and other medical cost to the Government (Moradibistouni & Gjerde, 2017). PrefabNZ (2014) also, endorsed the potential for cost saving to builders due to the reduction of site injuries as a result of 60-80 percent reduction of workers on site. Further, prefabrication can reduce risks related to workers' health and safety issues, fire, and material damage caused by accidents (Shahzad, 2016).

2.1.4.2 Challenges for prefabrication

While the benefits of prefabrication encourage the use as an option, the decision is still influenced by challenges. Common challenges of using prefabrication construction; economic, social, environmental and other aspects are pointed out in the following section.

Economic limitations of using prefabrication

The higher initial cost to set up the manufacturing plants is a major economic limitation in adopting prefabrication (Nadim & Goulding, 2010; Goodier & Gibb, 2007; Pan et al., 2007). Moreover, the lack of skilful, knowledgeable and experienced experts in prefabrication construction has economic disadvantages (Haas & Fagerlund, 2002). Besides, costs for transportation, handling and storage facilities is another limitation associated with prefabrication (Stroebele & Kiessling, 2017). Transportation method of prefabricated elements can vary depending on size and weight of the modules and once the components reach the site, additional lift planning may be required, especially for heavier lifts (Haas & Fagerlund, 2002). Transportation and lifting of modules have an influence on construction schedule, site design, crane cost, availability and the cost of designing the plan (Boyd et al., 2012). However, these economic limitations could be offset by reduction of other factors, such as reduction in construction time, labour requirement on site, and waste and resources reductions (Jaillon & Poon, 2008). In line with this, Taylor (2010), similarly argued that, use prefabrication could reduce the construction cost, though it should be less volatile than traditional construction.

As New Zealand construction industry is mainly dominated by small and medium companies, prefabricated products are expensive (Nesarnobari et al., 2022). Transportation and hoisting of prefabricated elements and modules also resulting a significant cost due to Lack of technology and availability of hoisting machineries and equipment (Shahzad, 2011). Initial cost for setting up manufacturing prefabrication is another challenge due to complications in obtaining financial support via loans in New Zealand (PrefabNZ, 2018).

Environmental limitations of using prefabrication

In the prefabrication construction supply chain, transportation plays a vital role in achieving the combined aspects of the delivery time and the cost (Stroebele & Kiessling, 2017). Even though it causes air pollution, the impact could be negated as the major building works are carried out in factory premises (Jaillon & Poon, 2008).

Transportation of modules is a challenge in New Zealand due to its geography. In New Zealand, prefabrication companies are spread out in both North and South Island and therefore, logistic is more complex and expensive.

Social limitations of using prefabrication

Wider use of prefabrication could reduce on-site labour requirement by 43% (Tam, 2002). In line with this, Jaillon and Poon (2008) highlight the negative effect on the economy, as the unemployment rate increases with the wider usage of prefabrication. Although it increases the unemployment rate, it is an inevitable worldwide trend to move towards an innovative and advanced technology in public house construction (C. M. Tam, 2002). Another limitation of using prefabrication found in the literature is the public's negative perception, which considerably hinders the development of this innovative and advanced technology worldwide (Kamali & Hewage, 2016). The lack of awareness on the advantages and different opportunities offered by prefabrication could influence market demand (Chiang et al., 2006).

Lack of skill availability in prefabrication is issue in New Zealand housing supply (Rotimi et al., 2022). Public perception towards adopting prefabrication in residential house construction is another problem associated with the uptake of prefabrication in New Zealand (Masood et al., 2016).

Other Aspects

Effective and efficient means of coordination and communication is needed to throughout the whole process of delivering a prefabrication building, including project planning, procurement, supply chain scheduling, assembling and construction, and delivery (Kamali & Hewage, 2016). In order to deliver the project in time, the communication between the participants of the construction process must be standardised (Stroebele & Kiessling, 2017). Based on the study they advocate the use of Building Information Modelling (BIM) as a way to tackle the problem (Stroebele & Kiessling, 2017). In addition, intensive pre-project planning and engineering is required as modular design, fabrication and assembly is different from the conventional building design and construction (Kamali & Hewage, 2016). However, this early design and fabrication hinders the flexibility in design changes with the market trends (Jaillon & Poon, 2008). Besides the aforesaid aspects, the degree of infrastructure preparation (such as foundation setting on project site) might be critical with process optimization (Stroebele & Kiessling, 2017).

In New Zealand, obtaining building consent is complex and time-consuming compared Australia and the United Kingdom (Nesarnobari et al., 2022). Lack of supply chain capacity (Masood et al, 2016; Shahzad, 2011), volatility and small medium enterprise dominance in the market (Masood et al., 2021; Shahzad et al., 2015), lack of innovative approaches (Poshdar et al. 2019) are critical challenges for the uptake of prefabrication New Zealand.

Despite these challenges, in 2020, COVID-19 has been caused shortages of material, labour and created affordability issues in residential construction industry (Shooshtarian et al., 2021). However, according to the statistics report, the building work has been slightly dropped due to the pandemic and further to that the requests for building consents are increased by 55% during 2021 in Auckland (Chaston, 2021). To support the continuous building construction, government of New Zealand has initiated several strategies. New Zealand Government allowed to manufacture certain building products (Plasterboard, gypsum plaster, coated roofing steel and insulation) during COVID-19 lockdown to avoid the supply shortages (Harris, 2021). In New Zealand, information and advices related to safe construction were shared efficiently and effectively. In doing so, there were some minor discrepancies. Mostly, the information was consistent, easily digested and timely. Therefore, the building and construction sector remained resilient despite all these issues (Denny-Smith, 2021).

2.1.4.3 Comparison of traditional versus prefabricated conventional construction

Prefabrication construction has long been reported as an effective alternative to conventional construction, with wide-ranging benefits (Pan & Sidwell, 2011). It is one of the innovative and effective methods of delivering a sustainable construction when compared with the traditional construction (Zhai et al., 2014b). However, the barriers to use this innovative method have limited the wider uptake in the construction industry, specifically in the housing sector. These identified barriers and benefits are summarised in Table 2.2 as a comparison between traditional housing construction and prefabrication housing construction. In conventional construction, all the construction work carried out on site compared prefabricated construction. Therefore, the time required for the construction process is comparatively higher in conventional method.

However, it consumes more time for planning in prefabrication residential construction.

Traditional drivers of time, cost, quality, productivity, health and safety and environmental impact encourage the industry to make more use of prefabrication methods in housing construction compared to its traditional counterpart (Forum, 2002; Sparksman et al., 1999). All these predefined benefits are echoed in a recent cross-industry market survey (Goodier & Gibb, 2004) which states that the use of offsite technologies brings benefits centred on shorter onsite duration and increased quality, but also real or perceived additional cost compared to the traditional. Even though, the initial cost of establishing prefabrication is higher than the traditional construction, cost savings are possibly achieved through efficiency learning, innovation, partnering, and 'in-house' build management (Pan & Sidwell, 2011).

Table 2.2: Comparison between prefabrication and traditional housing construction

	Factor	Prefabrication Construction	Traditional construction
Benefits	Schedule	• Speed in construction process due to simultaneous site preparation and building construction, less disruption from weather and scheduling problems	• Time consuming and delays can be caused by weather and scheduling problems
	Product Quality	• Greater controlled manufacturing environment including automated machineries, repetitive process skilled workers and less climate obstructions which improve the product quality	• Exposure to climatic changes can result in less than expected quality in construction
	Cost	• Shorter on-site construction time results in less chances of cost overruns, less site overheads and congestion, on-site labour reduction, less material wastage, less	• Vulnerability to uncontrollable variables such as weather, unforeseen and scheduling circumstances can increase construction cost

		interest on loans and early return on investment • Greater control over manufacturing process improves the product quality which ultimately results in reduced maintenance cost	
	Environmental Influence and Site Safety	• Less waste generated at the site, minimal on-site disturbance from noise, noise, dust & congestion and reduction in greenhouse gas emission • Reduction in dangerous and elevated activities	• A significant amount of waste produced on site and high chance of environmental pollution due to on site construction • Vulnerable to on-site safety issues
	Workmanship and productivity	• Less on-site workforce requirement • Design standardisation, higher efficiency in installation and higher energy efficiency result in higher productivity	• More on-site workforce requirement
Challenges	Initial Cost	• A large amount of initial investment requirement to set up	• None
	Project Planning	• Need for extensive pre project planning	• Pre project planning requirement is less
	Coordination and Communication	• A detailed coordination in all stages of the project is required, including a well-structured communication plan among all stakeholders	• Project coordination and communication requirement arises when of the onsite construction starts
	Design Flexibility/ Versatility	• Less	• More

	Transportation and site constraints	• Transportation constrains due to module sizes and weights • Space availability in lifting, handling, assembling the modules for machinery on site • Lack of skilful, knowledgeable and experienced experts	• Less transportation constraints
	Negative Perception	• Public's negative perception towards innovation and standardisation	• Less negative perception due to high chance of design customisation

Adapted from: Stroebele & Kiessling, (2017); Kamali & Hewage, (2016); Pan & Sidwell, (2011); Jaillon & Poon, (2008); Goodier & Gibb, (2004)

The current manufacturing capacity and associated cost inherent in the uptake of the prefabrication construction in the housing sector, seems to be influenced by the optimization of production capacity by suppliers (Venables et al., 2004). The low level of partnering between builders and manufacturers and suppliers in housing construction appears to be one of the problematic issues (Pan et al., 2008). Thus, it is important to develop and use positive relationships between the developer and offsite suppliers to drive cost and design efficiency through collaborative working. It requires a long-term commitment of the organizations and continuous exploration of the offsite technology in collaboration with their supply chains.

Although prefabrication adds value in terms of onsite skill deficiency (Barker, 2003), the requirement for experts in technology aspects still remains a problem (Rotimi et al., 2022; Chiang et al., 2006). On the contrary, the craft-based traditional approach in housing construction; makes process control difficult, and the deficiency in supplying a skilled workforce has worsened the issue (Roy et al., 2005). According to Womack and Jones (2010), technology development is not adequate; working practices including workforce training, process standardisation and attention to process control needs to be improved. Public perception is another barrier which comes with adoption of prefabrication in housing construction. Lack of knowledge on prefabrication methods and its benefits (Chiang et al., 2006) has influenced this negative perception. This situation needs to be improved through industry and government level initiatives. These could overcome the problems related to innovation arising from the mismatch between market demand and technological possibilities (Tushman & Moore, 1988). Moreover, early involvement of the builders and manufacturers, with long-term partnerships, in the decision making process of prefabrication construction enables a thorough and well organized supply chain for utilizing prefabrication methods (Zhai et al., 2014a).

2.2. Construction supply chain and supply chain management

2.2.1. Overview of SC and SCM

After liberalization and the globalization, business entities are focusing on improving the performance and efficiency of their supply chains to survive in the competitive market. The construction industry also focused on managing their supply chains to improve efficiency. The following section discuss the definitions of SC and SCM.

Bridgefield Group (2006) also defines Supply Chain as "a connected set of resources and processes that starts with the raw materials sourcing and expands through the delivery of finished goods to the end consumer". Supply chain can be defined as set of organisations and individuals involved to supply and distribute goods and services, information and finance from a source to a customer or a destination (Mentzer et al., 2001). Mentzer et al. (2001) further explained three levels of supply chain based on complexity; a direct supply chain, an extended supply chain and an ultimate supply chain shown in figure 2.5. the simplest form of supply chain-a direct supply chain consists of a company and its suppliers (upstream) and customers (downstream). The extended supply chain is an extension to the direct supply chain, which includes suppliers of immediate suppliers and customers of immediate customers (shown in figure 2.5). The ultimate supply chain consists "all the entities involved in upstream and downstream flows of products, services, finances, and information from the ultimate supplier to the ultimate customer" (Mentzer et al., 2001).

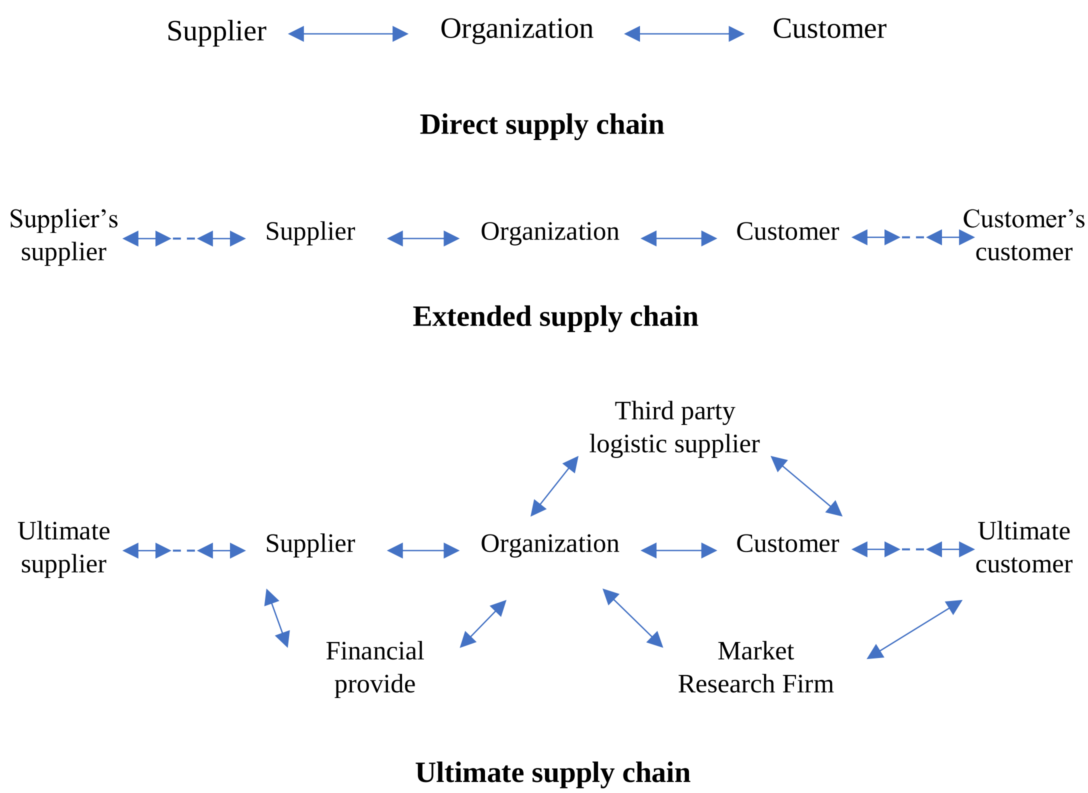

Figure 2.5: Types of channel relationships

Source: (Mentzer et al., 2001)

The concept of SCM first appeared in the manufacturing industry in the 1980s (Oliver & Webber, 1992) as a part of the Toyota Production System (Shingo, 1988). Later, this concept flourished from innovations such as 'Just in Time' (JIT) (Vrijhoef & Koskela, 2000) and the fields of quality control and total quality management (TQM) (Wong & Fung, 1999). Moreover, rapid changes in the practices of global business have influenced the evolution of SCM theory (Harland et. al, 1999) owing to its benefits in inventory investment, customer service, and improving competitive advantages for the company (Cooper & Allram, 1993). Kaufman et al. (2000), explains the purpose of SCM as the elimination of barriers to communication and loopholes in coordination. However, Mentzer et al. (2001), have a defined SCM as:

"The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole".

SCM focuses on improving productivity and reducing inventory and cycle time in the short-term, and its long-term attention is directed towards market share, customer satisfaction and profit gaining (Tam, 2002). Mainly, SCM reflects the integration of different business processes to safeguard the satisfaction of stakeholders and customers as shown in Figure 2.6 (Cooper et al., 1997). The supply chain of business processes is directed by eight different components of management. These eight processes act as an integral part to form efficient and effective supply chains, which ultimately promote cross-organizational collaboration of the process-based industry (Behera et al., 2015).

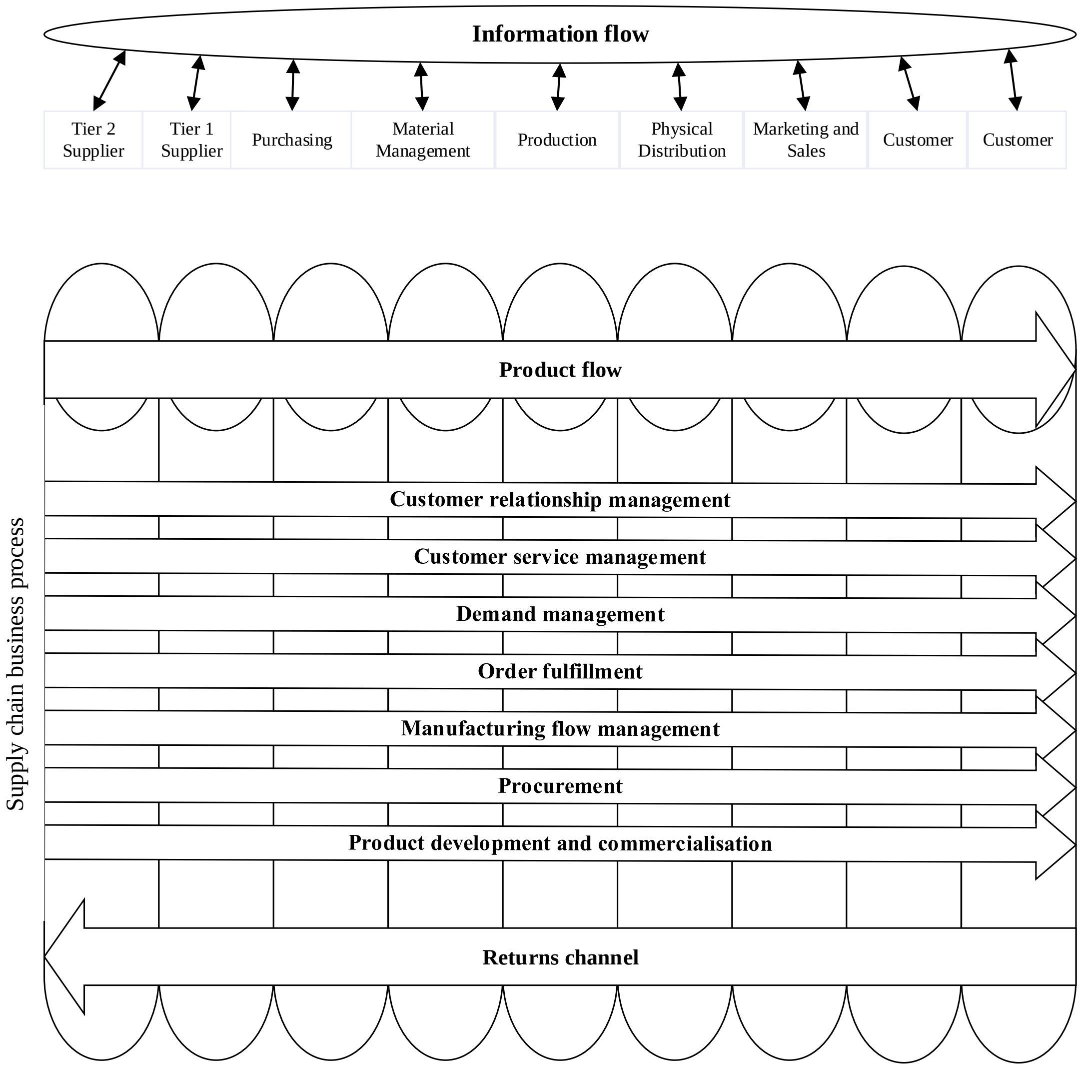

Figure 2.6: A framework for supply chain management

Source: (Cooper et al., 1997)

Figure 2.7 "house of SCM", explains the concept of SCM with two pillars, which symbolise integration and collaboration as the enablers of goals (Samarasinghe, 2013).

According to Stadtler and Kilger (2008) integration refers to a network of organisations connected with the supply chains, while coordination is based on information sharing. According to Power (2005), supply chain integration can reduce cost effectively and improve the level of customer services. The term integration is identified by a number of authors in different terms (Doran & Giannakis, 2011). The basis of integration is identified by Akkermans et al. (1999) as cooperation, collaboration, information sharing, trust, partnerships, and shared technology.

Collaboration enables opportunities for the partners to predict product demand and to derive realistic strategies to address the future demand (Sahay, 2003). Further to the studies of Sahay (2003), there are three types of collaborative relationships, namely; manufacturer/supplier relationship, manufacturer/ customer relationship and relationship of logistics providers. As a strategic tool, a collaboration of the partners of the value chain is crucial for SCM.

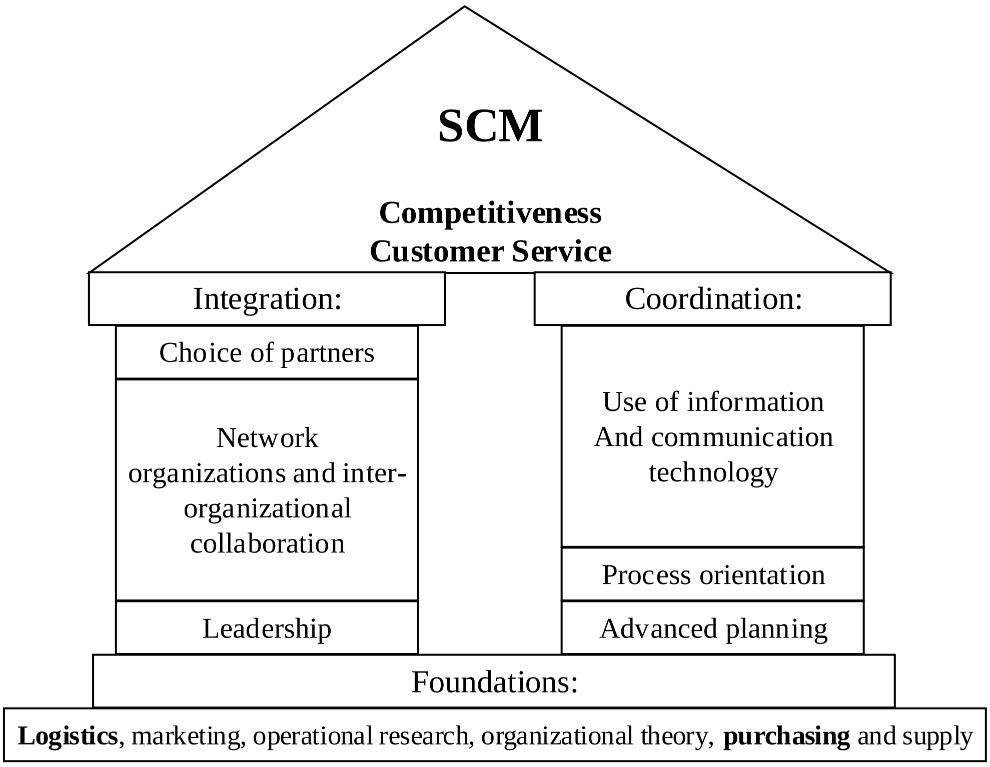

Figure 2.7: House of SCM

Source: (Stadtler, 2008)

Strategic corporate planning is crucial (Tan, 2002) to forecasting future demand for the products and to coordinate the functions within an organisation and its suppliers and customers in SCM (Zhou & Benton, 2007). The strategic planning of SCs is used for internal operations and information sharing among suppliers and customers (Zhou

& Benton, 2007). Information sharing between the partners of the supply chain enhance material flow, reduces inventory cost (Li & Lin, 2006), integrate the SCs (Jarrell, 1998), improve whole system performance (Yu et al., 2001), and ultimately, influence customer satisfaction (Spekman et al., 1998). In addition to information sharing, trust among the partners is also essential for effective project planning (Kwon & Suh, 2004). According to (La Londe 2002, p. 10), "Issues of trust and risk can be significantly more important in supply chain relationships because supply chain relationships often involve a higher degree of interdependency between companies".

Logistic management is an important part of SCM and it includes transportation management, integration of information, inventory management, warehousing management, and packaging and utilisation (Islama et al., 2013). Implementation of Just in Time (JIT) strategies into logistics operations provides maximum labour efficiency; minimum inventory; maximum machine utilisation; high quality and minimum space (Daugherty & Spencer, 1990).

2.2.2 Supply chain integration

Integration, one of the main themes in supply chain management has been considered as a key factor in improving performance (Sabir & Irfan, 2014; Awad, 2010; Briscoe & Dainty, 2005; Power, 2005). According to (Power, 2005), Clancy described supply chain integration as follows:

"attempting to elevate the linkages within each component of the chain, (to facilitate) better decision making and to get all the pieces of the chain to interact in a more efficient way (and thus) … create supply chain visibility (and) identify bottlenecks (Clancy, cited in Putzger, 1998, p. 55)."

Flynn et al. (2010, p. 58) also defined SCI as:

"The degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra and inter-organizational processes, in order to achieve effective and efficient flows of products and services, information, money and decisions, to provide maximum value to the customer"

Jørgensen and Emmitt (2009) further defined supply chain integration as "the comprehensive collaboration among supply chain network members in strategic, tactical and operational decision-making". Handfield and Nicholas (1995), have listed three drivers of supply chain integration as: information revolution, inventory management and inter-organizational relationships. According to Lee (2000) there are three dimensions to supply chain integration as information integration, organisational relationship, and coordination and resource sharing. Similarly, Fabbe-Costes and Jahre (2007) identified four area of integration as; process, technologies and systems, information, financial and physical flows, and organizations and members of the SC.

2.2.3 Concept of SCM and SCI in construction

The construction industry has started embracing the application of SCM philosophies (Saad et al., 2002; Dainty et al., 2001; Koskela, 2000). Unlike the manufacturing industry, the construction industry has been slow and reluctant to adopt SCM practices (Jones & Saad, cited in Knight et al., 2009) owing to less product standardisation (Morledge et al., 2009). However, the issues of the traditional approach can be eliminated through the adoption of SCM practices (Ofori, 2000). Together with the concepts of total quality management and partnering, construction SCM is a promising means of achieving the issues related to the industry (Kanji & Wong, 1998). In particular, Proverbs and Holt (2000) recommend the adoption of SCM practices as a way to reduce overall construction cost. According to the study, they suggest the early involvement of suppliers and subcontractors in the project so as to obtain their expertise, which could save cost and improve communication between the parties involved (Proverbs & Holt, 2000).

Serpell and Heredia (2004) highlight the benefits of applying SCM principles in the construction organizations as the development of capacities to compete effectively and efficiently, the development of strategies to deliver better services and products and the effective management of the information and resources flows to improve the performance. However, the unique nature of the construction industry has a direct influence on the management of supply chains (Vrijhoef & Koskela, 2000). Unlike the manufacturing system, the one-off product is assembled on the construction site from the materials delivered through temporarily set up supply chains with less or no-repetition (Vrijhoef & Koskela, 2000). This is similar to Engineer-To-Order (ETO) supply chains (Gosling et al., 2014; Gosling et al., 2007; Winch, 2003) where the product is developed on a one-off basis (Rahim & Baksh, 2003). ETO supply chains are specifically designed for a single project to meet customer requirements (Gosling et al., 2014). The discount nature of the supply chains in construction seems to be far from a production standpoint (Fearne & Fowler, 2006). However, Egan (1998) and Dubois and Gadde (2000) recommended to integrate the processes and products in the construction sector to achieve the value for the client.

There has been a number of earlier studies carried out to identify the restrictions for SC integration in the construction industry (Table 2.3). Akintoye, McIntosh and Fitzgerald (2000) identified major barriers to SCM implementation in their study. These barriers include lack of senior management commitment, lack of understanding the concept of supply chain management, inadequate organizational structure to support the supply chain management system, low commitment of partners, uncertain strategic benefits, and a lack of appropriate information technologies (Akintoye et al., 2000). Similarly, Akintoye et al. (2000) have identified the difficulties related to supply chain management implementation while Briscoe et al. (2001) have grouped the barriers for SC coordination and integration in the construction industry. Briscoe and Dainty (2005), states that the construction industry is typified by fragmentation, adversarial and unstable relationships, loopholes in information flows and, especially, the dependency between tasks. According to Latham (1994), the industry fragmentation results in poor performance in the supply chain. Similarly, the separation between design and construction causes problems in supply chain integration (Samarasinghe et al., 2013). The literature has recommended the SCM principles like partnering, alliancing, and public partnership in order to solve these issues (Samarasinghe et al., 2013). Thus, it is essential to change the limitations of adversarial culture and traditional relationships instead of introducing a change in management framework at the operational level in order to implement SC integration in the construction industry (Khalfan et al., 2004).

Awad (2010) has identified three perspectives that researchers considered to categorise barriers to SCI. These perspectives include technical, managerial and relationship where technical refers to the technical barriers that arise between the SCM systems and strategies, managerial refers to the barriers that arise in planning and execution of strategies and relationship refers to the barriers affect from the relationships between the inside and out participants of the organisation (Awad, 2010). Even though, the construction industry identified barriers to SCI, these barriers are not properly categorised.

Table 2.3: Barriers to SC integration in construction

Issues	Akintoye (2000)	(Vrijhoef, Koskela, & Howell, 2001)	(Briscoe, Dainty, & Millett, 2001)	Ahmed et al. (2002)	(Barratt, 2004)	Wong et al. (2004)	Albaloushi and Skitmore (2008)	Deshmukh et al. (2014)	Olaniyl et al. (2015)	Salami et al., (2016)
Lack of understanding the concept of supply chain management	✓	✓	✓	✓	✓	✓		✓	✓	✓
Inadequate organizational structure to support the supply chain management system	✓	✓	✓	✓		✓			✓	✓
Low commitment of partners	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lack of appropriate information technologies	✓	✓	✓	✓	✓	✓			✓	✓
Lack of trust within and outside the company		✓		✓	✓		✓		✓	✓
Lack of guidance to create alliances with supply chain partners	✓	✓	✓			✓		✓		✓
Failure to develop measures for monitoring the alliance		✓							✓	✓

Organizational resistance to the concept of supply chain management		✓		✓		✓	✓		✓	✓
Financial/cost related problems			✓							
Unrealistic and uncertain supply time of materials and equipment			✓							
Uncertain strategic benefits	✓		✓							
Lack of communication			✓			✓	✓	✓	✓	✓
Lack of understanding of customer requirements						✓	✓	✓	✓	✓

Adapted from: (Akintoye, 2000; Vrijhoef, Koskela, & Howell, 2001; Briscoe et al., 2001; Barratt, 2004); Wong et al., 2004; Albaloushi and Skitmore, 2008; Deshmukh et al., 2014; Olaniyl et al., 2015; Salami et al., 2016)

Although the construction process is different, SCM can be useful and effective in construction (O'brien, 1999). Construction SC is a network of relationships and organisations together with the flow of information, the flow of materials, services or products, and the flow of funds between owner, designer, general contractor (GC), subcontractors, and suppliers (Muya et al., 1999). In line with that, Samarasinghe et al. (2013) state that the performance of the SC operations depends on the parties, the material, and information flows among them. According to Fisher and Morledge (2002) and Albaloushi and Skitmore (2008), construction SC is the coordination of decision making between the organizations and the integration of the business processes and key partners involved. Hatmoko and Scott (2010) defined construction supply chain management (CSCM) as 'a system where suppliers, contractors, clients and their agents work together in coordination to install and utilise information in order to produce and deliver materials, plant, temporary works, equipment and labour and/or other resources for construction projects. The concept of construction SCM implicates the development of a construction project through management of information, activities, tasks and processes, of the organisations (Figure 2.8).

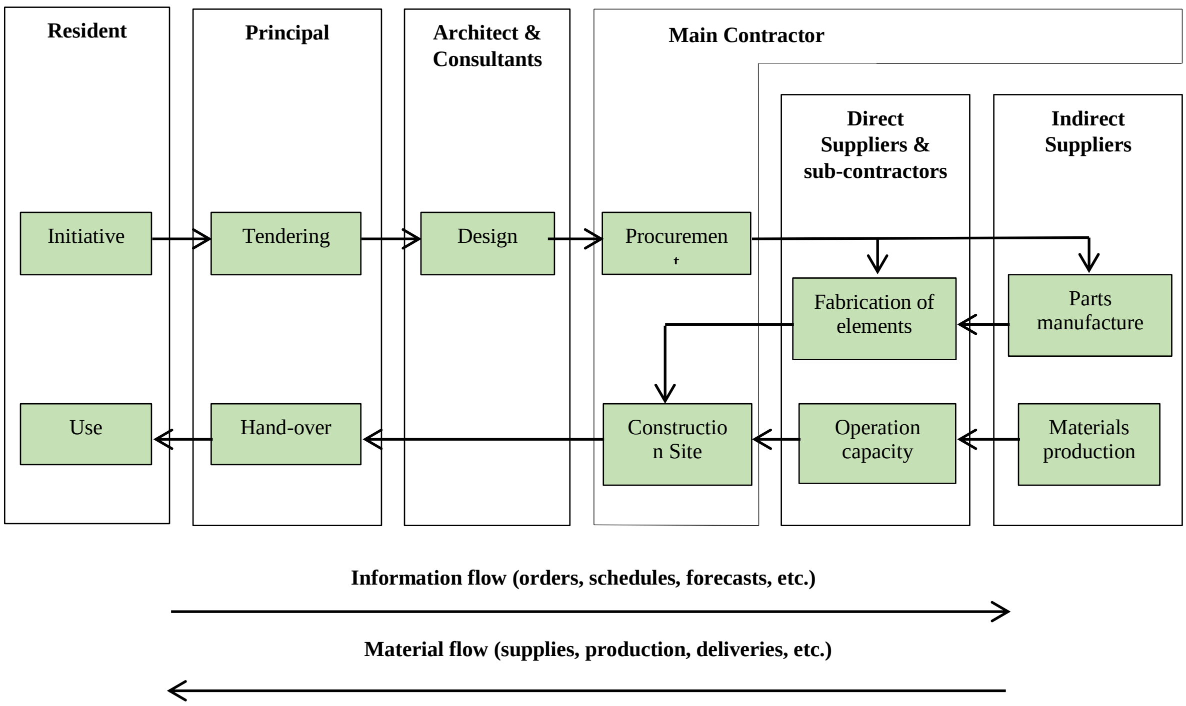

Figure 2.8: Typical configuration of a traditional construction supply chain

Source: (Vrijhoef & Koskela, 2000)

Efficient and accurate communication plays a major role in any supply chain (Hu, 2008). According to the study of Albaloushi and Skitmore (2008), construction SC has three types: the primary supply chain, which transports materials required for the production of construction; the support chain, which provides equipment and materials that facilitate construction; and the human resource SC which involves the supply of labour. Vrijhoef and Koskela (2000) identified the levels of implementing SCM in construction (as in Figure 2.9) based on whether the focus is on the supply chain, the construction site, or both.

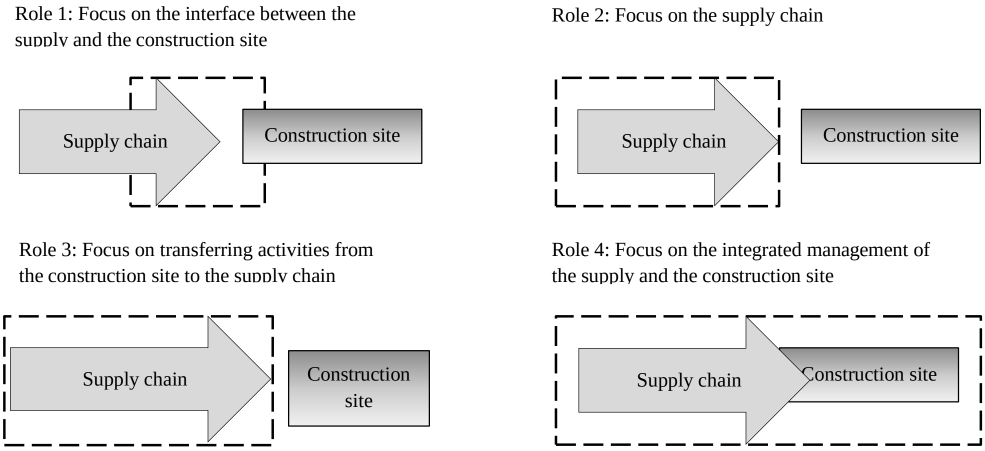

Figure 2.9: The four roles of SCM in construction

Source: (Vrijhoef and Koskela, 2000)

The study identifies the practical initiatives and limitations of each role as represented in Table 2.4. Even though the implementations of the levels are not mutually exclusive, they are often pursued jointly (Morledge et al., 2009). According to (Vrijhoef & Koskela, 2000), the identified subjective limitations have to be eliminated while the objective limitations require much attention. Even though the subjective limitations can be eliminated, objective limitations need to be recognized with more effective and efficient solutions (Vrijhoef & Koskela, 2000). In line with that, Lockamy and Smith (1997) state the necessity of developing SC practices in the construction industry to provide value for the money the client has spent on the project.

Table 2.4: The four roles of SCM in construction

Role	**Goal**	**Responsible person**	**Practical initiatives for the advancement**	**Subjective limitations**	**Objective limitations**
Role 1- Focus on the interface between the supply	Reduce cost and duration of site activities through	Contractor	Logistic management	Failure to address the impact of supply chain	Narrow focus

chain and the construction site	dependable material and labour flows to the site			variability on-site assembly due to the stress of the logistics initiatives on cost	
Role 2 - Focus on the supply chain	Reducing costs related to logistics, lead-time and inventory	Material and component suppliers	Development of specific supply chains (prefabricated concrete elements) The trade-off between transportation, inventory and production cost		Erratic and undiscipline d nature of customer activities (Koskel & Leikas, 1997)
Role 3 - Focus on transferring activities from the construction site to the supply chain	Reducing cost and duration, avoiding the inferior conditions on site, achieving wider concurrency between activities	Suppliers or contractors	Industrialisatio n	Lack of basic SCM	Complex and vulnerable to variability
Role 4 - Focus on the integrated managemen t of the supply chain and the construction industry	Integrated management and improvemen t of the supply chain and the site production	Clients, suppliers or contractors	Open building The sequential procedure Pre-engineering Design-build arrangements	Partial or superficial integration	Stable chains and standardised product

Source: (Vrijhoef and Koskela, 2000)

Although there have been many changes in the construction industry as a result of the development of technology and culture over the last decades, construction supply chains (CSCs) do not seem to have changed much (Xue et al., 2005). Vrijhoef and Koskela (2000), suggest the development of the practical methods for SCM implementation, considering the characteristics and the specific situation of construction. According to Cushman et al. (2002) construction is a complex, multi-disciplinary activity in which the design and management processes need to integrate with the people who bring knowledge and skill. Thus, construction SCs are more complex and subjected to constant change with the competitive nature of the industry itself. The challenge of integrating SC practices in the construction industry becomes more crucial where joint ventures, partnerships and sub-contracting agreements are involved.

According to Chen et al. (2021), shared resources and mutual objectives, streamlined workflows and process automation, information visibility and responsiveness are required to overcome the barriers associated with SC coordination. Real-time information sharing using integrated ITC tools is another enabler for supply chain integration (Ahmed et al. 2020; Wong et al., 2015; Frohlich & Westbrook, 2001). Furthermore, the literature emphasis the automation of the construction process focusing on using more prefabricated elements/components with efficient logistic systems to improve the CSC performance (Gosling et al., 2014; Pero et al., 2015; Doran & Giannakis, 2011; Meng et al., 2011) endorse the importance of trust and long-term commitment of the SC participants as construction industry highly relies highly on transactional and short-term relationships.

2.2.4. Supply chain practices in New Zealand residential construction industry

The New Zealand residential construction industry has been criticised for its fragmented nature, characterised by small scale firms, causing time delays, less productivity, quality variations, less innovation and high cost (BIFNZ, 2013; CHRANZ, 2011). Building material prices are quite higher in New Zealand due to its geographical isolation and less competitive behaviour of the suppliers and material production and small population (CHRANZ, 2011).

On the other hand, Auckland housing demand and Christchurch rebuild projects have been subjected to the fluctuations in the New Zealand residential construction sector (Samarasinghe et al., 2013). This has increased the level of activities to undergo over a short period of time (BIFNZ, 2011). Consequently, the demand for building materials has increased with the current peak in commercial and residential activities (CHIRANZ, 2011). However, the unique and customised nature of the houses in New

Zealand (Mason, 2013) creates inefficiencies and adds costs to the construction process (CHIRANZ, 2011).

New Zealand construction industry is recognised as a small-medium enterprise dominant industry (Building and Construction Sector Productivity Partnership, 2012) where the labour force has a relatively lower skill level compared to other sectors (Ying et al., 2015). Furthermore, the New Zealand construction industry generally is not quickly responsive to innovation (Masood et al., 2016; Ying et al, 2014; Ying et al., 2015). The industry is fragmented vertically with a reliance on an increasing number of different sub-trades and, therefore, integration of sub-contractors into the supply chain is complex and challenging (Ying et al., 2015). This will lead to adversarial relationships, the consequence of which is ultimately transferred to the consumer in the form of additional costs (Hinton, 2011). Further Ying et al. (2015) highlights that the New Zealand construction supply chain practices are at tactical level due to physical isolation, higher expectations and low economic size.

These unique factors associated with New Zealand construction industry make more challenges for developing excellences in the construction supply chain. Therefore, it is important to understand the current nature of the construction supply chain practices to address the key issues and challenges of supply chain integration.

2.2.5. Supply chain integration of prefabricated residential construction

Prefabricated housing construction is more likely to be challenging compared to the conventional practices and therefore requires greater attention to integration the supply chains of construction (Pan & Goodier, 2012). Integration of the entire construction processes at the organizational level is an important aspect in order to achieve substantial growth in the uptake of prefabrication in residential construction (Pan & Goodier, 2012). This is because residential building organizations including manufacturers are focused on eliciting profit rather than the actual construction process. This means there is a low propensity within the organization – and the industry generally - in terms of communication, knowledge sharing and learning. In line with that, Stroebele and Keissling, (2017) endorse the requirement of an efficient functioning supply chain in prefabrication housing construction to achieve the benefits of prefabrication. Coordination of the partners of the supply chain of house building is a key attribute in terms of cost, time and quality (Grundke & Wildemann, 2015;

Lessing, 2006). However, the fragmented nature of the construction supply chain of house building creates management issues resulting in poor quality and cost overruns (New Zealand Productivity Commission (NZPC), 2012). Further, Shahzad (2011) also highlights the lack of SC capacity in New Zealand. Therefore, improving SCI in residential construction is paramount to improve the efficiency in prefabricated residential construction.

Government, industry and academics are focusing on improving the CSC capacity in New Zealand. KiwiBuild, is a government initiative started to increase the supply of housing using more prefabrication (PrefabNZ, 2018). The purpose of this initiative is to improve the efficiency and speed up the construction process while building affordable houses. KiwiBuild is working together with Kainga Ora and the Ministry of Housing and Urban Development enabling more home ownership opportunities for New Zealanders. Further, Kainga Ora's approaches on New Zealand housing supply focuses on improving housing supply adopting innovation in SC in terms of processes, technology and product. Long-term partnering agreement, standardised designing, and usage of advanced technology in designing are some of the initiatives taken by Kainga Ora to improve the efficiency of CSC. Furthermore, Kainga Ora focuses on expanding the usage of prefabrication and modular designing to achieve affordable houses with greater operational efficiency.

However, New Zealand is still utilising minimal benefits of prefabrication due to inefficiencies in its supply chain (Masood et al., 2021). Therefore, barriers for improving supply chain integration and potential enablers to mitigate these barriers and a performance framework for prefabricated residential construction remains a gap in the literature (Masood et al., 2021).

2.2.6 Maturity profile approach

Assessment and management models are required to achieve improvements in supply chains (McDermotti & Khalfan, 2012). Maturity model is one of the innovative performance measurement systems developed to quantify the performance and maturity levels of the supply chains (McDermotti & Khalfan, 2012).

The term maturity denotes and implies the state of being complete (Schumacher, Erol, & Sihn, 2016). According to Schumacher et al. (2016), maturity models are commonly used as a tool to conceptualize and measure maturity of an organization or a process regarding some specific target state. McCormack et al. (2008) defines a maturity model as a methodology including the components related to definition, measurement, management and business process control. Kohlegger et al. (2009) defines maturity models as: "*A maturity model conceptually represents phases of increasing quantitative or qualitative capability changes of a maturing element in order to assess its advances with respect to defined focus areas*". Even though the origin of the maturity is not directly connected to supply chains, currently there is growing interest towards the use of maturity models by academics and industry (Pedrini & Frederico, 2018; Smits et al., 2017; Kwak & Ibbs, 2002). The application areas of this model are wide-spread and range from cognitive science applications to business and engineering applications(Kohlegger et al., 2009).

2.2.6.1. Existing maturity models

Model 1- Maturity model for supply chain relationships in construction

Meng et al. (2011) developed a maturity model for supply chain relationships that aims to improve the relationship between supply chain members as construction supply chain members are usually complex and multifaceted. This model is developed based on the general principle of the capability maturity model for the specific requirements of key relationships in a construction supply chain. It consists of four maturity levels, eight assessment criteria, and 24 detailed sub-criteria. A framework matrix provides detailed descriptions of every criterion at different maturity levels as follows. Meng et al. (2011) proposed four maturity levels of relationships including price competition, quality competition, project partnering and strategic partnering/alliancing. These maturity levels are formed to improve the relationship of the SC participants from a traditional relationship to a collaborative relationship. The maturity model focuses on improving eight main criteria which includes procurement, objectives, trust, collaboration, communication, problem solving, risk allocation and continuous improvement

Model 2- Conceptual framework for construction supply chain maturity

Vaidyanathan and Howell (2007) developed a conceptual maturity model for construction supply chain management to assess the current SC practices and to advance maturity levels. This model was developed based on the manufacturing maturity model proposed by PRTM. The construction supply chain maturity model builds on the idea that process maturity is achieved in stages by incrementally controlling and managing the CSC business process along the three dimensions; business function, project, and firm. There are four maturity levels in the model as ad-hoc, defined, managed and controlled. Process, technology, value and strategy criteria were assessed under the four maturity levels.

Model 3- SPICE

SPICE (Standardised Process Improvement for Construction Enterprises) developed a maturity model to improve construction process. This model was developed based on the Capability Maturity Model (CMM) from software industry. The model provides an evolutionary framework for business process improvement and an assessment tool for organisational maturity. This model is specially developed for one company and therefore cannot be applicable for multi-enterprises (Sarshar et al., 2000). Figure 2.10 presents the maturity levels considered in this model. The model was developed considering seven key process areas including; brief and scope of work management, project planning, project tracking and monitoring, sub-contractor management, project change management, risk management and project team coordination. Each key process area was further considered under five enablers-commitment, ability, verification, evaluation and activity.

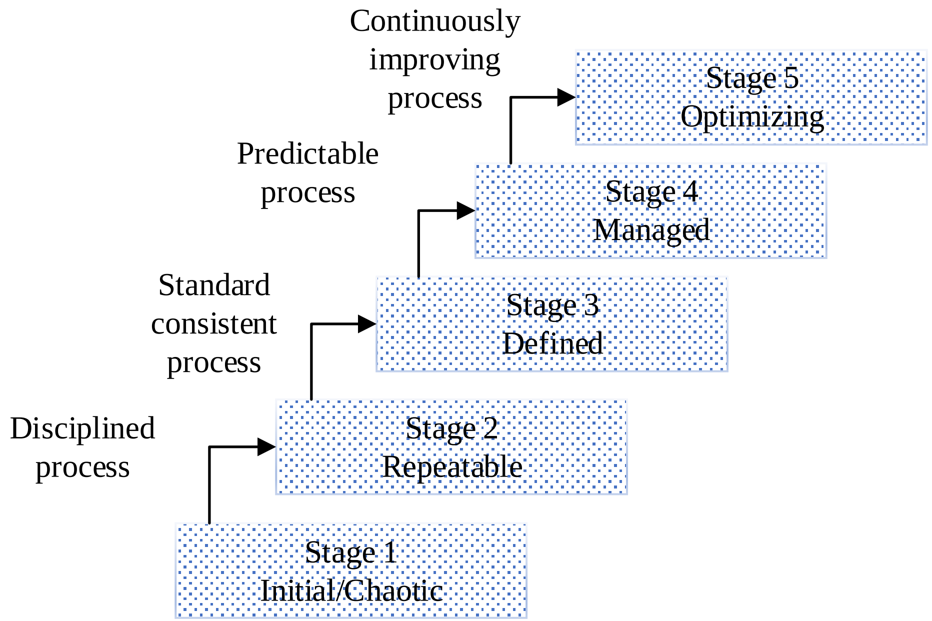

Figure 2.10: CMM levels

Source: (Sarshar et al., 2000)

Model 4- Maturity model for industrialised housing

Lessing (2015) developed this maturity model for industrialised housing construction in Sweden. This model is developed considering eight characteristic areas; planning and control of processes; developed technical systems; off-site manufacturing of building parts; long-term relations between participants; logistics; customer focus; use of information and communication technology (ICT); and performance measurements. The purpose of this categorisation is to highlight the areas of strengths and weaknesses of the companies who are associated with industrialised housing. The categorization model has been tested on two leading Swedish industrialised housing companies working with different frame systems and a different organisational set up. The maturity levels are developed based on strategic choice or level of implementation (Lessing, 2015).

Model 5 -PMOMIM-MCPs

This model was developed by Jia et al. (2011) to improve the capability of all the main management subjects; the owner, the general design contractor, and the general construction contractor, which is a temporary program management team of Mega Construction Programmes (MCPs) in China. It is developed to improve the capability of the temporary program management team in the life cycle of MCPs.

These models have its own strengths as well as weaknesses. Table 2.4 illustrates a comparison of the above-mentioned maturity models.

Table 2.4: Comparison of maturity models

Model	Developer	Focus	Scope	Maturity levels	Key process areas/criteria
Model 1	Xianhai Meng, Ming Sun, and Martyn Jones	SC relationships in construction	Whole supply chain	4	8 main criteria and 24 detailed sub-criteria
Model 2	Vaidyanathan and Howell	supply chain management and assessment tool for	Whole supply chain	4	4 criteria - process, technology, value and strategy

		continuous improvement			
Model 3	SPICE	Business process improvement and an assessment tool for organisational maturity	Whole supply chain	5	7 key process areas detailed under 5 sub-criteria
Model 4	Lessing	Industrialised house building	Whole supply chain	5	8 criteria
Model 5	Guangshe Jia, Yuting Chen, Xiangdong Xue, Jianguo Chen, Jiming Cao and Kewei Tang	Capability of the temporary program management team	Life cycle of mega construction project	4	10 knowledge areas

Source: (Jia et al., 2011; Meng et al., 2016; Lessing, 2016; Vaidyanathan and Howell, 2007; Sarshar, 2000)

The above-mentioned maturity models were developed for construction industry for different purposes. The models are developed based on capability maturity model and manufacturing maturity model developed by PRTM. Model 1 focuses on improving relationships in the SC while model 2 and model 3 focuses on supply chain management and business process improvement respectively. Even though, model 4 was developed to improve the industrialised house building SCs for Sweden, unique problems related to designing, procurement, working relationship of participants and on-site assembly were not addressed. Further, the three enablers of SCI-people, process and information have not been entirely considered in any maturity model developed for construction sector. Therefore, there is gap in the existing literature on continuous improvement of SCI in prefabricated residential construction.

2.2.7 Conceptual framework

Considering the literature review, a conceptual framework for this research is set up (Figure 2.11).

In the literature review, project planning, coordination and communication, design flexibility, transportation, initial cost, and lack of skill and knowledge are identified as main challenges to the wider uptake of prefabrication. These inherent barriers limit the usage of prefabrication in residential construction. According to the literature reforming supply chain, supply chain management and supply chain integration could reduce the impact of these barriers (Masood et al., 2021; Stroebele & Kiessling, 2017; Masood et al., 2016; Lessing, 2016; New Zealand Productivity Commission; 2012).

Prefabrication as an innovative methodology to improve the supply of residential construction requires to eliminates barriers associated with its SCs. Supply chain integration can improve these barriers in terms of people, process and information sharing. The conceptual framework was developed based on ABB corporate research centre’s supply chain management maturity model and PRTM manufacturing maturity model. According to the framework, maturity levels represent a progression of enablers-people, process and information while improving the integration from functional integration to cross-enterprise integration. These four levels of integration include functional integration, internal integration, external integration and cross-enterprise integration (Lahit et al., 2009).

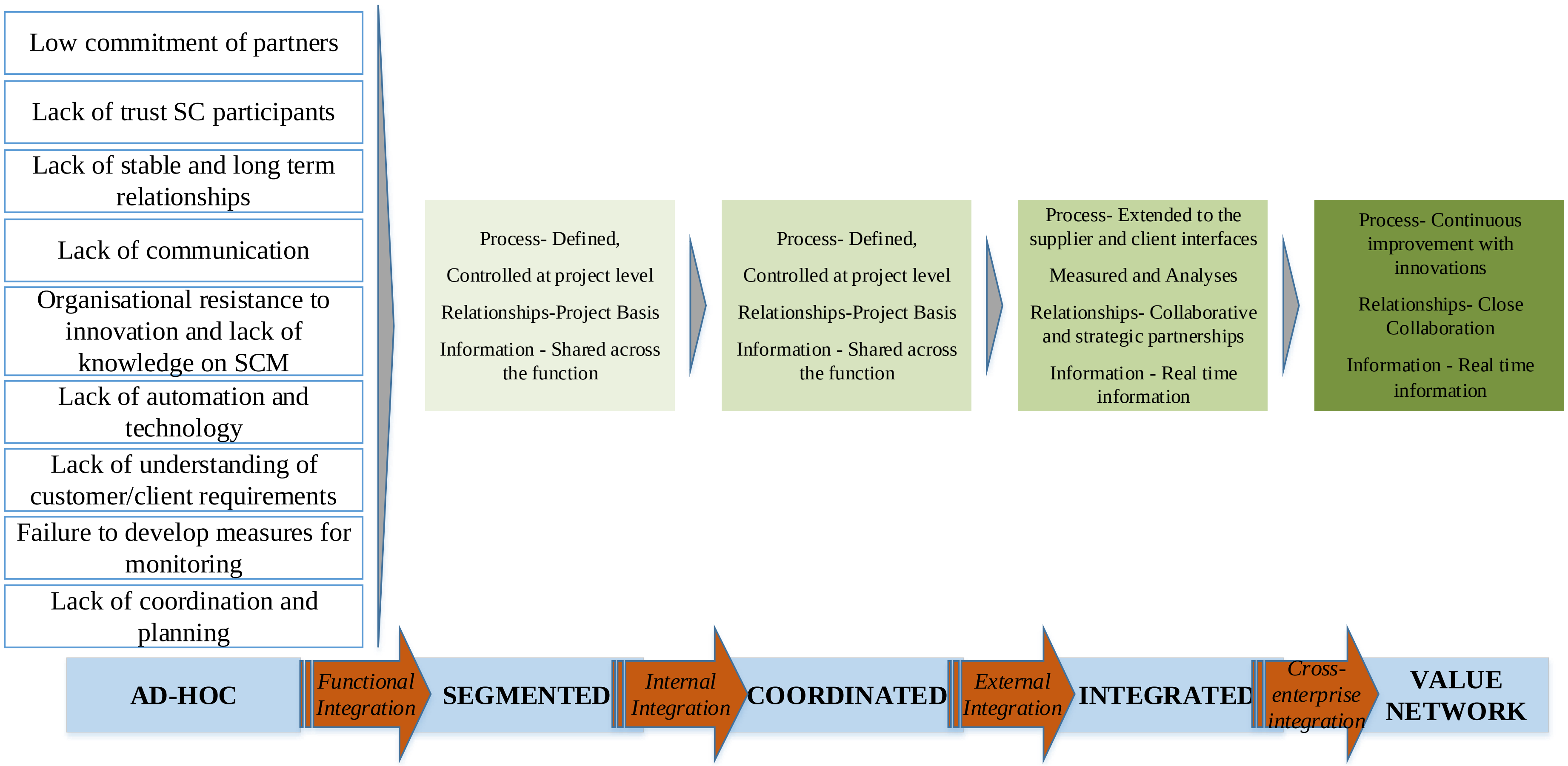

Figure 2.11: Conceptual Framework

Based on these findings, the framework will be further improved in order to measure and improve the current practices of housing construction projects.

2.2.8 Summary

The unique nature of the construction industry, geographical isolation, market volatility, negative perceptions and lack of innovation of New Zealand has created challenges for developing excellences in prefabrication construction supply chains. On that account, it is important to understand the current nature of the construction supply chain practices in order to addressing the key issues and challenges for supply chain integration. Due to distinctive and complex arrangements of supply chains in prefabricated residential construction, configuration of a supply chain process is required to identify the issues (*Objective 1-Review and analyse the processes and supply chain relationships module and panel manufacturing in the New Zealand residential construction*).

There are economic, social, and environmental challenges associated with prefabrication residential construction. According to the literature findings, logistic management, trust and commitment, continuous manufacturing, and information sharing would minimise the challenges associated with prefabrication residential construction. However, there is gap in the existing literature on SCI in prefabricated residential construction in terms of barrier and enablers. Even though, prefabrication is identified as an innovative methodology for NZ residential construction, still there are challenges that hinder the wider uptake of prefabrication. Therefore, it is required to identify the barriers and enablers specific to prefabricated residential construction. (*Objective 2 &3 - Identify the barriers and enablers for supply chain integration in module and panel manufacturing in the New Zealand residential construction*).

Maturity model concept is a manufacturing concept, that can be adopted to improve the integration of SCs in prefabricated residential construction (*Objective 4- Develop and validate a model to measure and improve the current supply chain integration in module and panel manufacturing in the New Zealand residential construction*). The conceptual framework developed based on the literature review guided to improve the supply chain integration step by step. The following chapter discusses the methodology adopted to address the research gap identified in the literature.

CHAPTER THREE

RESEARCH PARADIGM

3.0 Overview

This chapter outlines the methodology proposed to carry out the research. The chapter begins with the research questions, aim and objectives of the research. Then, the beliefs of the researcher on the nature of the reality, applied in the research is outlined with comparisons of the different perspectives of each philosophy. Based on the proposed philosophical stance, the design of the research was designed and discussed. Under the design of the research, research methods, strategies and data collection and analysis techniques are outlined. This follows a comprehensive discussion on research design proposed to execute the research. The chapter also discusses the ways of ensuring validity and reliability of this research. A description of the ethical considerations of the research is discussed at the end of the chapter.

3.1 Research Questions

The following research questions were developed based on the knowledge gaps discussed in Chapter 1;

Question 1: What is the nature of the prefabricated residential construction and module and panel manufacturing processes?

The study identified the nature of supply chains including information flows and material flows

Question 2: What are the relationships in the SC of prefabricated residential construction?

The study identified the relationship between the participants of the supply chains (including external participants) in the prefabricated residential construction and module and panel manufacturing.

Question 3: What are the barriers for SCI in module and panel manufacturing in New Zealand residential construction?

The study identified the major issues and challenges associated with the supply chain of module and panel manufacturing in residential construction from initial stage to the installation of the product.

Question 4: What are the enablers for SCI in module and panel manufacturing in New Zealand residential construction?

Solutions to eliminate and mitigate the barriers and challenges for supply chain integration of module and panel manufacturing in residential construction in New Zealand was identified.

Question 5: How to measure the current supply chain practices and improve supply chain integration in module and panel manufacturing in New Zealand residential construction?

The study focused on developing a model to assess and improve supply chain practices and supply chain integration.

3.2 Research Aim

This research aimed to improve supply chain integration in prefabricated residential construction.

3.3 Research Objectives

To accomplish the above aim, the following objectives are identified:

1. Review and analyse the nature of the processes and supply chain relationships of module and panel manufacturing in New Zealand residential construction
2. Identify the barriers to supply chain integration in module and panel manufacturing in the New Zealand residential construction

3. Identify the enablers to supply chain integration in module and panel manufacturing in New Zealand residential construction
4. Develop and validate a model to measure and improve supply chain integration in module and panel manufacturing in New Zealand residential construction

3.4 Research Methodology

Research is a systematic process of discovering novel things (Saunders et al., 2007). "Research methodology can be considered as the strategy to achieve the aim and objectives of the research" (Sutrisna, 2009). Thus, research methodology depends on the nature and the location of the subject matter, the existing theory and literature, research questions, techniques and methods of gathering data, and methods of analysing data (Fellows & Liu, 2015). The philosophical stance of the researcher, reasoning of the research, required data and analysis of the data are considered as the main dimensions of the research methodology (Sutrisna, 2009). Therefore, this chapter discusses philosophical stance that influenced the researcher in designing the research approach and selecting the research methods used in this study.

3.5 Research Philosophy

A system of assumptions and beliefs on knowledge development is referred to as research philosophy (Saunders, Lewis, & Thornhill, 2009). A reliable research philosophy with well-thought-out assumptions reinforces the methodological choice, research strategy, data collection, analysis techniques and interpretation of the research findings (Saunders et al., 2009). According to Remenyi and Williams (1998), in developing a research design, researchers should consider and understand the research community they belong to, and epistemological, ontological and ethical assumptions of their research. Identification of the philosophical belief will help to develop the methodology and methods that are going to be applied to the research. Figure 3.1 illustrates the relationship between ontology, epistemology and methodology, methods and sources.

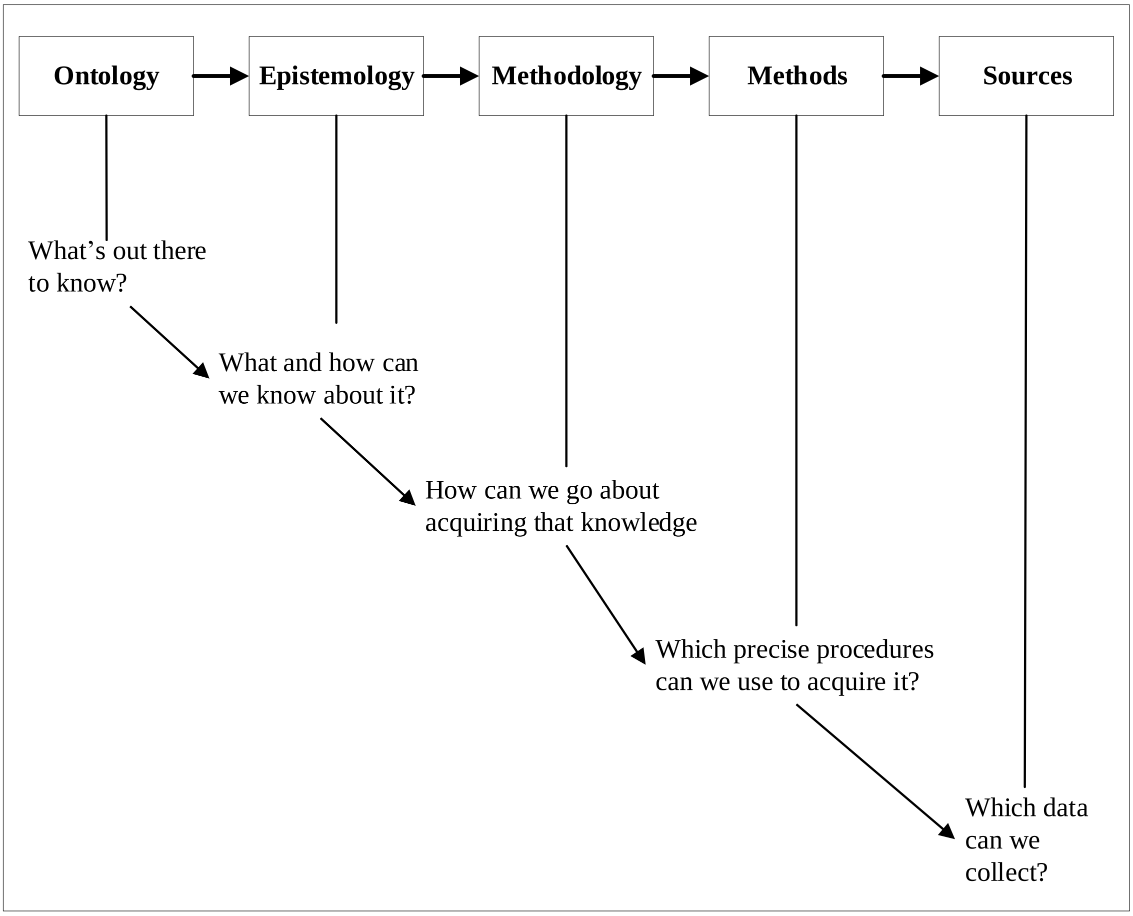

Figure 3.1: The directional relationship between ontology, epistemology, methodology, methods and sources

Source: (Grix, 2002)

Furthermore, the following sections (3.5.1, 3.5.2 and 3.5.3) discuss the terms ontology, epistemology and axiology. Then finally, section 3.5.4-establishment of an appropriate paradigm for the study denotes the researcher's perspectives on these terms and how it relates to establishing a philosophical stance for this study.

3.5.1 Ontology

Ontology is concerned with establishing assumptions of existence, mainly the conceptual reality. It shapes the way of seeing and studying the research objects and therefore, helps to determine the choice of research (Saunders et al., 2016). Generally, ontology is the investigation of how things are/were, framed through either objectivism, which implies that social phenomena will exist independently, or constructivism, in which the social phenomena are determined by observation and scientific study (Bryman & Bell, 2011). Thus, objectivism refers to how these two ontological perspectives are compared in Table 3.1.

Table 3.1: Comparison of ontological perspectives

	Objectivism	**Constructionism**
Organizational nature	Tangible object	Constructed with the human interaction
Organizational drivers	Set of standardised procedures, rules and regulations, organisational hierarchy, division of labour and a mission statement	Less extensive and rigorous rules negotiated order Constantly changing social order with the human interactions
Organizational culture	Shared values, beliefs and customs of the employees	Constantly changing the culture with human interactions

Source: (Bryman and Bell, 2011)

3.5.2 Epistemology

Epistemology is associated with the methods, origins, nature and limits of human knowledge. According to Burrell and Morgan (1979), it refers to assumptions about legitimate and valid knowledge and the way of communicating it to others. The two positions of epistemology are positivism and interpretivism. Positivism strives for the use of logical and mathematical evidence while interpretivism uses the social reality of interpretive understanding and causal explanation of the focal actors. These two epistemological perspectives are compared as shown in Table 3.2.

Table 3.2: Comparison of epistemological perspectives

	Positivism	**Interpretivism**
Basis	Natural Sciences	Human interactions
Approach to social science	Explanation and generalisation of human behaviour	Causal explanation and interpretive understanding of human behaviour

Subject matter	Nature	Social reality
The subject's actions	Inanimate and unmotivated	Meaningful and engaged
Data collection	Observation, codification and measurement	Understand the nature of the human subjects
Research & theory	Mostly deductive	Strong inductive learning

Source: (Bryman and Bell, 2011)

3.5.3 Axiology

The nature of the values and ethics considered in the research process is denoted as axiology (Saunders et al., 2009). This incorporates the way the researcher dealt with both the researcher’s values and the participants’ values (Saunders et al., 2016). According to Heron (1996), the decisions regarding the topic and the methodology of the research reflect the researcher’s values. In other words, the choice of the research topic, data collection and analysis methods bespeak the personal values of the researcher. Data collection through interviews emphasises the researcher’s preferences towards personal interaction more than the views from an anonymous questionnaire (Saunders et al., 2016).

Various authors have defined other dimensions of research philosophies. Based on these different perspectives, interpretivism and positivism are most influential (Gray, 1996). According to Samarasinghe (2014), most of these paradigms stand in between the two extremes of interpretivism and positivism. Saunders et al. (2016), recognizes five major philosophies: positivism, critical realism, interpretivism, postmodernism and pragmatism. According to the classification of Easterby-Smith et al. (2012), philosophies include critical realism, critical theory, feminism, hermeneutics, postmodernism, pragmatism and structuration theory. Based on the aforementioned philosophical stances, the next section describes the philosophical position of this research.

3.5.4 Establishment of an Appropriate Paradigm for the Study

The identification of ontological and epistemological perspectives served as a guide to choose the suitable research methods and influence the proposition of the study (Cicmil, 2006; Samarasinghe, 2014). This research focused on improving the efficiency and integration in the the prefabrication house building supply chain using the maturity model concept. The research gap and the research questions were developed based on the literature review and the opinions of the industry practitioners of the prefabrication house building and the prefabrication manufacturing sector. As the research problem was established based on the people engaged in prefabrication manufacturing, a philosophy of complete positivism is not applicable for this research. The research approach aimed to disclose the practical consequences of the social interactional phenomena. In other words, as the research focused on the supply chain practices of prefabricated housing construction, the nature of the reality is being constantly constructed through the organisational culture of the manufacturing sector. Therefore, the problem was subject to the viewpoints of the individuals engaged in the prefabrication manufacturing sector. Therefore, this research aligned with subjectivist ontology as the objects of investigation, prefabrication and SCM, are influenced by social and psychological factors and are constant.

In addition, this study explored the acceptable knowledge related to the barriers of contemporary supply chain practices in prefabrication module manufacturing, including; enablers for supply chain integration; key process areas in the supply chain process of prefabricated house building, and goals and objectives to be achieved to improve the supply chain integration in the network of prefabricated house building. The viewpoints of industry practitioners were most crucial in collecting the data related to these aspects. The research intended to apply a less-structured methodology, without forming any hypothesis, so as to gain richer and more profound information (Sutrisna, 2009). In discussing the nature of the research, researcher beleived that the focus of the research, prefabricated house building and SCM are constantly being constructed differently. Further research intended to focus on a prevailing issue in the construction industry and to informed solutions for future practice. Therefore, the researcher believed that the research aligned with pragmatism.

Since human beliefs and experiences became an influential factor in the process, this research aligned into a value-driven axiology-integral and reflexive perspective.

3.6 Research Method

The research design is considered as a logical flow representing the research plan and includes data collection, measurement and data analysis (Gray, 2013; Yin, 1994). According to Saunders et al. (2016), research design acts as a plan for answering research questions of the study. It helps to establish the link of research questions/objectives, with the data collection and analysis techniques (Easterby-Smith et al., 2012). The research methods are categorised as quantitative, qualitative and a mix of both, based on the data collection and analysis techniques (Tashakkori & Creswell, 2008). Further, Saunders et al., (2016) categorise methodological choice into more categories as shown in the Figure 3.2. The following section describes these different methods.

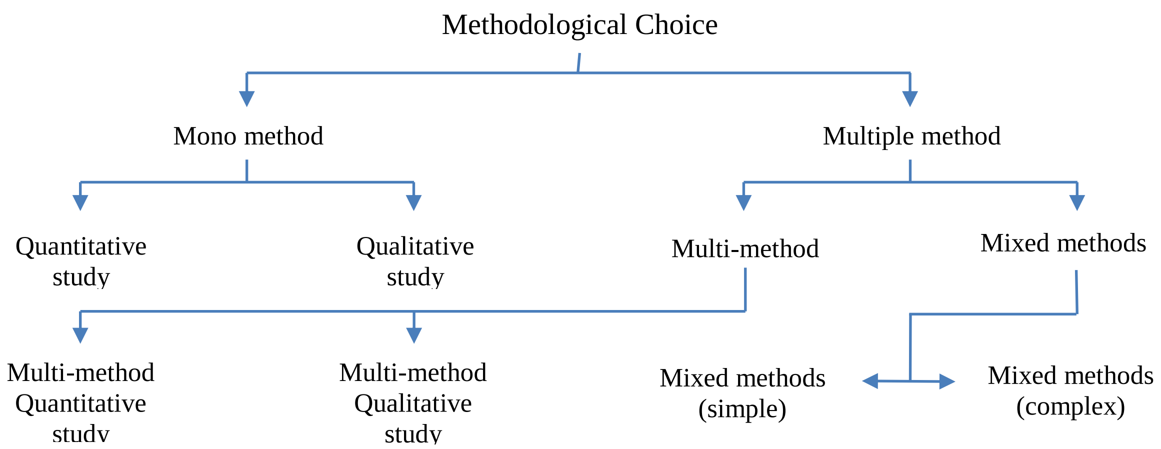

Figure 3.2: Methodological choice

Source: (Saunders et al., 2016)

3.6.1 Quantitative Method

Quantitative research is a deductive approach, associated with positivism to data collection and analysis (Saunders et al., 2009). It allows measuring relationships between variables numerically and analysis by means of statistical and graphical methods (Saunders et al., 2009). Thus, viewing the reality as objective. According to Golafshani (2003), quantitative methods are more reliable and deal with the hypothetical generalisations and measurable facts. Survey and experimental research strategies are associated with this method (Saunders et al., 2009).

3.6.2 Qualitative Method

Qualitative research is an inductive approach, associated with interpretivism of data collection and analysis (Saunders et al., 2009). It allows the interpreting of social phenomena subjectively (Saunders et al., 2009). The qualitative methods are more powerful in collecting real-life data while dealing with the behaviours, opinions and emotions of the people and natural surroundings (Gray, 2013). This method is associated with a variety of research strategies such as case study research, action research, ethnography, narrative, and grounded theory research (Saunders et al., 2009).

Table 3.3 outlines the major differences between quantitative and qualitative approaches based on these characteristics.

Table 3.3: Comparison of quantitative and qualitative approaches

	Quantitative	**Qualitative**
General framework	• Seek to confirm hypotheses about phenomena • Instruments use the more rigid style of eliciting and categorizing responses to questions • Use highly structured methods such as questionnaires, surveys, and structured observation	• Seek to explore phenomena • Instruments use more flexible, iterative style of eliciting and categorizing responses to questions • Use semi-structured methods such as in-depth interviews, focus groups, and participant observation
Analytical objectives	• To quantify variation • To predict causal relationships • To describe characteristics of a population	• To describe variation • To describe and explain relationships • To describe individual experiences • To describe group norms

Question format	• Closed-ended	• Open-ended
Data format	• Numerical (obtained by assigning numerical values to responses)	• Textual (obtained from audiotapes, videotapes, and field notes)
Flexibility in study design	• The study design is stable from beginning to end • Participant responses do not influence or determine how, and which questions researchers ask next • The study design is subject to statistical assumptions and condition	• Some aspects of the study are flexible (for example, the addition, exclusion, or wording of particular interview questions) Participant responses affect how and which questions researchers ask next • The study design is iterative, that is, data collection and research questions are adjusted according to what is learned

Source: (Mack et al., 2005)

3.6.3 Mixed Method

Both qualitative and quantitative methods are used for data collection and analysis. According to Caracelli and Greene (1997), on some occasions, qualitative and quantitative methods depend on each other, particularly quantitative methods which could be used to confirm the findings of a qualitative outcome (Caracelli & Greene, 1997). This leads towards a mix of qualitative and quantitative methodologies resulting in a mixed method approach which creates a sound platform to collect a comprehensive set of data (Creswell, 2012; Gray, 2013). The inductive, deductive or abductive approach may be used in mixed methods research (Saunders et al., 2009).

3.6.4 Selection of Research method

After contemplating the different research methods and philosophy of the above research, a multi-tier qualitative method was proposed as this research focuses on subjective and socially constructed phenomena. Moreover, it uses the inductive approach for theory development. In this research, the research questions were developed based on “How” and “What”. This led the research into an exploratory study that focuses on discovering what is happening and trying to gain insights into the topic by asking open questions. This therefore, led towards qualitative methods, resulting in an exploratory study which created a sound platform to collect a comprehensive set of data (Creswell, 2012; Gray, 2013). Contemporary supply chain practices in module and panel manufacturing and barriers for SCI in the sector required a rich set of qualitative data collection. Further, as the focus of this research tended to develop a model to guide module and panel manufacturers. To validate the model focus group interviews were selected as it provides an in depth. Finally, three case studies were selected to benchmark the supply chain practices using the developed model. validated model was Once the model was developed. The benchmarking was implemented to test the model. Therefore, this research ultimately led into qualitative approach.

3.7 Research Design

The logical sequence of the research design is shown in Figure 3.3, involving the literature review, data collection, data analysis, research findings, and validations. Research objectives of the study were indicated based on the stage in which each of the objectives were achieved. The next section describes the main stages of the research including the approaches used and outcomes. Accordingly, the research was designed under three main stages: literature review, semi-structured interviews and validation and case studies.

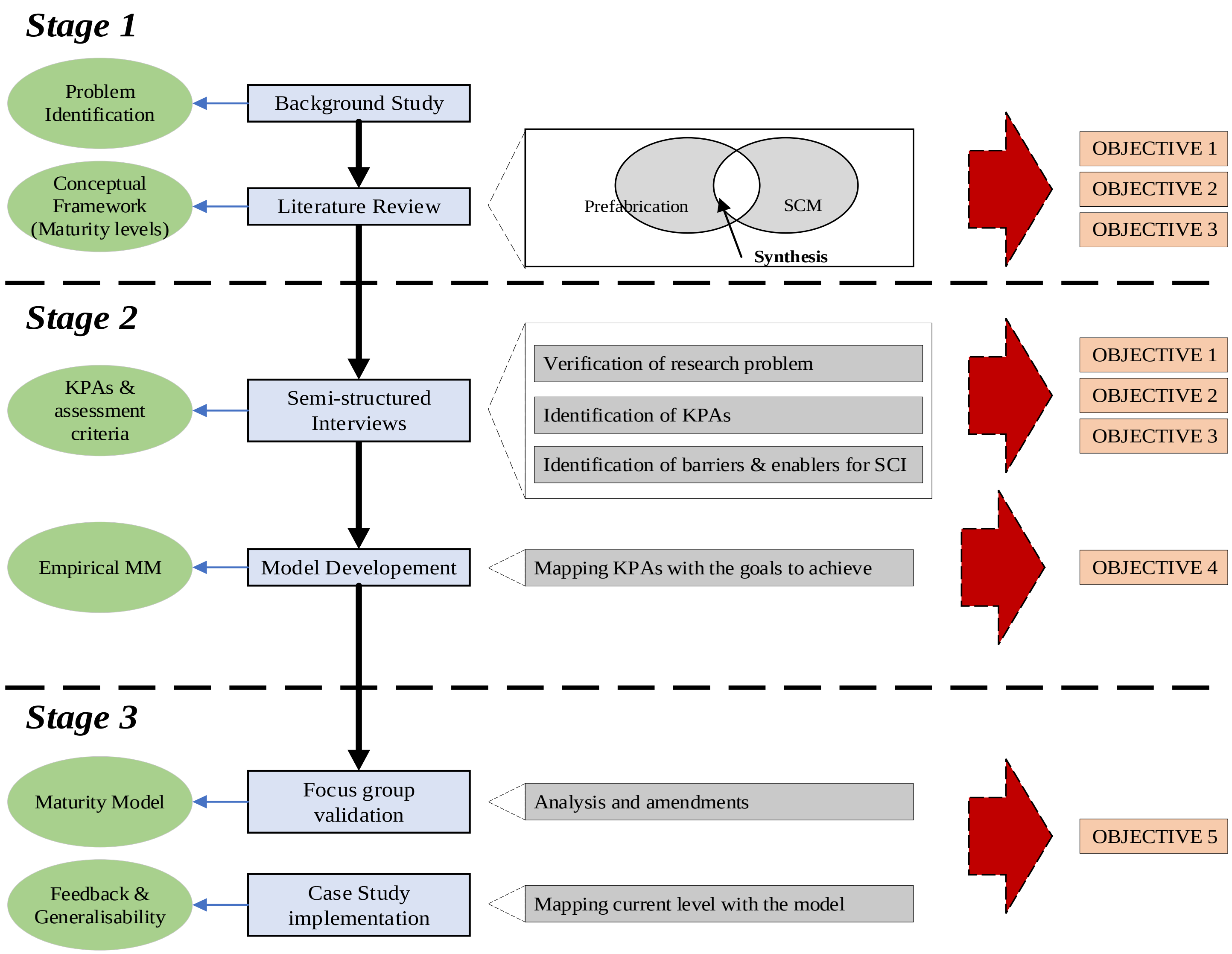

Figure 3.3: Research Design

3.7.1 Data Collection and Analysis

The study used qualitative data collection and analysis techniques. As Figure 3.2 illustrates, the data collection was carried out in three stages: literature review, semi-structured interviews and case studies and validation. An in-depth literature review was conducted as the first phase of the research to develop the research problem and to identify the research gap. The nature of the research is inductive and therefore, exploratory research strategy that involved the data collection strategies of semi-structured interviews and case studies was applied. The semi-structured interviews aimed to verify the research problem, identify the nature of SC processes, participants, barriers and enablers for supply chain integration. Three case studies were conducted to identify the current performance level (based on the developed model) of the manufacturing companies and to gain their feedback on the model. At the final stage, focus group interviews were conducted to validate the developed model. The following sections discuss these main stages in detail.

3.7.1.1 Stage1- Literature Review

A literature review is a vital stage in a research study which confirms the existing knowledge gaps (Fellows & Liu, 2008). An in-depth literature review was conducted based on the books, journals, articles, and reports to partially accomplish the first three objectives. These include the nature and relationships in the SCs of prefabricated house building in New Zealand, barriers for SCI in prefabricated house building in New Zealand and the enablers for contemporary supply chain practices of prefabricated house building in New Zealand. Moreover, it has provided a clear platform to identify and understand the basic concepts of prefabrication and SCM, specifically supply chain integration. Based on an in-depth investigation of the aforementioned key areas, the link between them was explored and mapped into the conceptual framework.

3.7.1.2 Stage 2 - Semi-structured Interviews

Semi-structured Interviews

In the first phase semi-structured interviews were conducted to gather information on the prefabricated house building, wall panel manufactuirng and bathroom pod manufacturing and to aid the development process of the maturity model and the set of questions for case study investigation. The justification for using semi-structured interviews is discussed as follows:-

Interviews as a qualitative data collection method provide a pathway to access in-depth views of people`s behaviour (Seidman, 2013). According to Kumar (2005), interviews provide a high response rate compared to the questionnaire survey. Interviews can be categorised into unstructured, semi-structured and structured (Saunders et al., 2016). A different classification of interviews is illustrated in Figure 3.4.

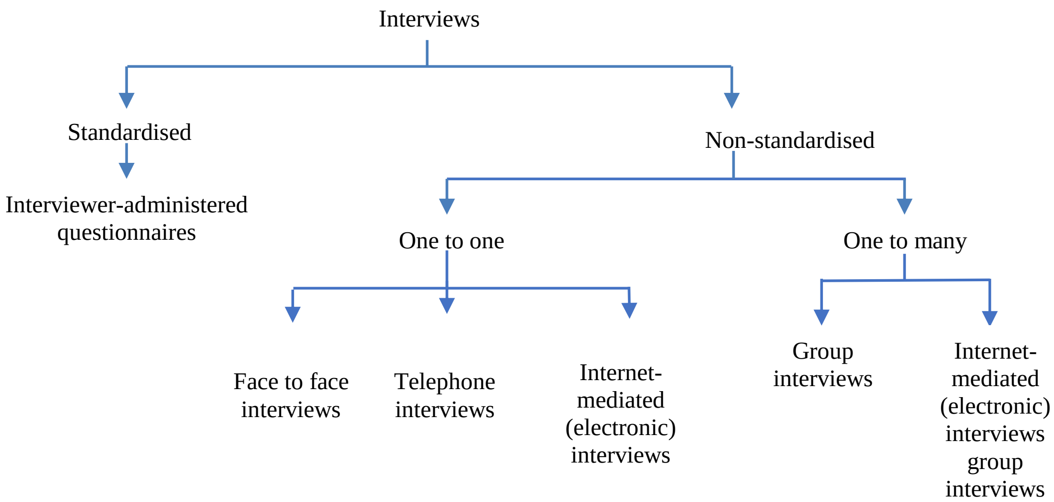

Figure 3.4: Forms of interview

Source: (Saunders et al., 2016)

Interviews can be conducted with individuals or groups, using telephone, face-to-face or video conferencing methods (Collis & Hussey, 2009). Structured interviews are conducted using a pre-planned and prepared questions (Collis & Hussey, 2009) while unstructured interviews are used where a general discussion is continued picking up issues and points as they evolve during the interview (Bennett, 1991). Unstructured interviews can be conducted without a prepared set of questions. In semi-structured interviews, the interviewer has the flexibility to raise important questions related to the subject to gain precise information (Dawson, 2009). Sekaran (2003) emphasised that, when interviews are conducted in a semi-structured manner, this enables the researcher to adapt the questions as necessary, to clarify doubts and to ensure that the response is properly understood by repeating and rephrasing the questions. According to Fellow and Liu (2008), in semi-structured interviews, questions are structured to a certain extent and they allow more flexibility than structured interviews.

In this research, semi-structured interviews were adopted to collect data as it provides the opportunity to collect qualitative data through non-standardised questions (Saunders et al., 2016). Further, as the first step of data collection, the identification and verification of the research problem and investigation into the nature of the prefabricated residential construction in New Zealand were the main purposes of this data collection. Therefore, the method of semi-structured interviews permitted open-ended questions to explore the topic further with probing questions, despite the limited sample size used for interviews due to time constraints (Seidman, 2013). This enabled further enquiry and a better understanding of the subject matter-supply chain of prefabricated residential construction in New Zealand. It enabled gathering of rich data based on interviewees experience and feelings which cannot be grasp from a questionnaire survey where close-ended questions limit the response of participants opinions.

Sampling Method

Initially, purposive sampling technique was employed to select participants for the interviews as it facilitates capturing participants appropriate to the study based on the researcher's knowledge and opinion (David & Sutton, 2011; Tongco, 2007). As stated by Shahzad (2016), purposive sampling is the suitable approach where there is no database to capture the participants from a defined population. Therefore, participants were selected through the assistance of OffsiteNZ and academic networks. OffsiteNZ is a non-profit organisation established in 2010 to promote, educate and lead the innovation in offsite manufacturing in New Zealand.

However, due to poor responsiveness (32% responsiveness) snowball sampling was applied to recruit more participants. As stated by Walter (2010, p.138), snowball sampling is 'used to access respondents from hard-to-reach groups by asking respondents to suggest other prospective respondents to the researcher. This technique has become popular due to its flexibility and networking characteristics in recruiting hard-to-reach populations (Parker, Scott, & Geddes, 2019). Thus this process ensured that the selected interviewees were experienced and knowledgeable about supply chain practices in prefabricated house building.

An interview guideline was prepared based on the findings of the literature review. Interview questions included: interviewees' general view on the nature and relationships in prefabricated residential construction and wall panel and bathroom pod manufacturing processes; contemporary supply chain practices; barriers for supply chain integration; and solutions to improve integration and efficiency in prefabricated residential construction and wall panel and bathroom pod manufacturing. As interviews were semi-structured, questions varied according to the answers of respondents in order to obtain the holistic view of each interviewee on supply chain management and supply chain integration of prefabricated house building and wall panel and bathroom pod manufacturing in New Zealand.

The consent of the participants was taken prior to the interview through a Consent Form (Appendix A). Interviews were tape-recorded (with permission from the interviewee) to secure an accurate account of the discussions and to avoid losing data. This helped to avoid problems with note-taking such as; the impossibility of noting down everything due to the speed of conversation; questioning of the accuracy and reliability of the data; and the difficulty of concentrating on the conversation while note-taking (Hart, 1991). Some interviews were conducted via skype and Teams. Information sheet, interview questions and consent form were sent before the online interviews and during the interviews the discussions were recorded after seeking the consent of the participants. Audio recording facilitates the interviewer to concentrate more on the interview by asking useful questions (Dawson, 2009). Ultimately, interview transcripts were developed to generate a sensible adaptation of the interview data. To maintain confidentiality, the actual names of the projects and the interviewees will not be revealed.

The collected data was analysed using thematic content analysis, where main themes generated from the semi-structured interviews were selected and word count analysis was used to show the strength of some themes and sub-themes. Thematic content analysis is a category of content analysis and focuses on identifying themes/patterns from the qualitative data (Colorado State University, 2006).

3.7.1.3 Stage 3 - Model Validation

Stage 3 was conducted to accomplish research objective 4-validate the developed model. Firstly, the information gathered from the interviews and literature review were synthesised and a model to improve the SCI in bathroom pods and wall panel manufacturing was proposed. Then, the model was validated through focus-group interview research strategy. After validation, three case studies were conducted to identify the current level of their performances in line with the developed model. After benchmarking the performances of the case studies, three reports were developed and sent to the companies to get their feedback on the developed model.

Focus-group Interviews

Focus group interviews enable interactive discussion among the participants (Saunders et al., 2016). According to Saunders et al. (2016), focus interviews could be used for two distinct purposes. Interpretivist researchers use this to construct meanings through social interactions, while positivist or critical realist researchers use this to disclose pre-held views. The researcher, as the facilitator or moderator of the focus-group interviews, should keep the participants within the boundaries of the topic while leading and encouraging towards certain and interesting opinions relevant to the topic (Saunders et al., 2016). According to Sekaran et al. (2016), focus groups are relatively inexpensive and can provide fairly dependable data within a short time-frame.

Focus-group interviews were used in this research to validate the maturity model developed to measure and improve the supply chain practices in module manufacturing. As the framework was developed based on the pre-held views of the industry practitioners, focus group interviews were the best approach to validation. This method provided full flexibility for the researcher to control discussion within the topic boundaries and to lead to exciting opinions (Adams & Cox, 2008). Further, this is one of the most inexpensive methods to gather data even though it is time-consuming (Alshenqeeti, 2014). Based on these advantages, focus-group interviews were used for the validation of the framework.

In this research, two focus group interviews were conducted covering academic and industry experts. The focus-group discussion with academics who are experts in SCM and prefabrication was carried out as a pilot study and opinions of the academics from the pilot study was considered and amended before the second focus-group discussion. During the pilot focus group, positive feedbacks were received (discussed in Chapter 6). The second focus-group was carried out with the industry experts who were selected with the assistance of OffsiteNZ. All the participants were the best subject matter experts in New Zealand. The date, time and venue for this was selected considering the participants' preference and convenience. Copies of informed consent and information sheets were provided to each participant before the interview. The researcher acted as the facilitator to lead the group and to maintain the flow of discussion within the boundaries.

Sampling Method

To capture the participants for focus group interviews, convenience sampling was employed due to its usefulness for an unknown the population (David & Sutton, 2011). The focus group of the academics was conducted with Massey University, while OffsiteNZ assisted in capturing participants for the second focus group interview.

All the interviews were conducted via zoom platform due to the COVID-19 pandemic situation. During the discussion a presentation was conducted on the developed maturity model followed by questions. Participants' consent was taken before starting the discussion and tape-recording was used to record the whole discussion with the prior permission of participants.

Content analysis was used to analysis the discussions and necessary amendments were made where appropriate (See Chapter 6).

Case Studies Analysis

Based on the data collected from semi-structured interviews and the literature review, a maturity model was developed to improve the integration in supply chains of bathroom pods and wall panel manufacturing. Case study approach was employed to examine the level of maturity of bathroom pods and wall panel manufacturing in New Zealand so as to benchmark the current practices against the model and to get a feedback about the developed model from the manufacturing companies. According to Hartley (2004), a case study research is a detailed investigation of a phenomena to collect data over a period of time. Further, Lessing (2015) and Meng et al. (2011) also, used the case study approach to evaluate the maturity model for industrialised housing supply and to examine the proposed maturity model in practice, respectively.

The data for case studies can come from a variety of sources, including observation, interviews, questionnaires, reports, and archival records (Fellow & Liu, 2015). For this study, structured interviews were used to gather data for an evaluative case study approach where the case studies provide a holistic information based on the real cases to describe and explain the study area.

Sampling Method

Three case studies were selected based on purposive sampling method as there is no database to capture the participants from a defined population. Therefore, participants were selected through the membership of OffsiteNZ. The Covid 19 pandemic situation impacted capturing participants as face-to-face meetings were restricted from end of March 2020 to September 2020. However, researcher was able to visit one of the case studies before the Covid 19 lockdown. A multiple case study was chosen to achieve a wider relevance.

Set of questions were prepared under 5 major categories, including general information, inception and design stage, production planning stage, procurement stage, production stage, transportation stage and on-site assembly stage. The prepared interview questions were tested and reviewed by academics, industry experts and peers, before starting data collection (Appendix B). The feedback received by the experts was useful in detecting errors due to word ambiguities and in ensuring the appropriateness of the questions.

Consent for data collection was obtained before starting the interviews. Interviews were tape-recorded in order to concentrate on the discussion and to avoid technical errors later. The data collected was analysed using content analysis, and based on the analysis, supply chain practices of the three companies were mapped into a radar chart to benchmark the current position.

3.8 Research Reliability and Validity

Reliability and Validity are significant concepts in research as they are used for improving the accuracy and evaluation of a research (Franklin, & Ballan, 2001). According to Saunders et al. (2016), reliability and validity govern the quality of the research and its findings. The following section discusses the ways of ensuring validity and reliability of this research.

3.8.1 Validity/Credibility

The validity of research is a key factor for its success (Fellows & Liu, 2016). The interpretation of the validity of quantitative research and qualitative research is different (Golafshani, 2003). According to Amarathunga et al. (2002), the validity of a research can be assessed based on the accuracy of tools used for data collection and the degree of achievability of the intention of the investigation. There are two main aspects of research validity as internal and external validity (Sekaran et al., 2016). The internal validity of a research can be measured in terms of content validity, criterion-related validity, and construct validity (Saunders et al., 2011). Content coverage is the percentage of research questions covered by the survey questionnaire while capacity and attitude of the questionnaire is measured by the construct validity. Capability of the questions to provide accurate answers are measured by the criterion- related validity.

In this research, the research problem was developed based on the literature review and preliminary interviews. Thus, research questions were designed to address the research problem through semi-structured interviews, case study interviews and focus-group interview. The questions prepared for the interviews were verified by supervisors, peers and industry practitioners during the pre-testing process. Pre-testing of questions developed for semi-structured interviews, case study interviews and focus group discussion involved ensuring the design of the data collection and analysis aligns with the instruments used and to detect any language errors and interpretation errors in the questions. Questions developed for semi-structured interviews, case study interviews and focus group discussion were first tested by the supervisors and then the academics and subject matter experts were engaged to test the questions. Finally these three sets of questions were reviewed by peer PhD candidates to achieve the content validity in this research. The questions were modified based on the feedback received and then conducted the interviews.

3.8.2 Reliability/ Dependability

Reliability of a research refers to the consistency of the findings in the research (Saunders et al., 2016). Reliability is defined as the level to which measures are free from errors and bias to produce consistent results (Thanasegaran, 2009). The results of a research are considered reliable if consistent results have been obtained in identical situations but different circumstances (Twycross & Shields, 2004,).

To enhance the reliability of the research, the research should mitigate errors and biases of the participants and the researcher (Saunders et al., 2016). In this research, participants errors were minimised by selecting a comfortable time for interviewees and limiting it to a predetermined time period. The biases of the interviewees were minimised by choosing an enclosed space for the interviews. Finally, researcher's interpretations of interviews were minimised by sending the transcripts to the interviewees for verification.

3.9 Ethical Considerations

Ethical considerations are one of the essential elements in conducting research. It also enhances the 'scientific validity' of the research (Mathers, Howe & Hunn, 1998). Ethics in research referred as "the standards of behaviour that guide your conduct in relation to the rights of those who become the subject of your work" (Saunders et al., 2016, p.239). The ethical norms encourage the researcher to incorporate moral and social values while conducting the research. Therefore, a thorough understanding of ethics is fundamental and also depends on the nature and type of research. This research will consider principles of ethics from inception to completion, especially during data collection. The ethics approval of the Massey University has been granted under the low-risk category for this research (Ethics Notification Number-4000018285).

The collection of confidential data relates to construction projects as cost, design and participants, were possible ethical issues. This was addressed by receiving the consent for obtaining data from the authorised parties in the form of consent forms prior to the data collection. Names of the participants and companies were non-attributable in any published source or in the written reports. Safety measures of the construction sites and companies were learned, adhered to and acknowledged during the data collection. The collected data was kept in Massey University premises under password protection with access limited to the researcher and the supervisors.

All the participants were voluntarily engaged in the interviews, case studies and focus group discussions. The interview participants had the right to withdraw from the interviews at any time without giving any reason and without there being any negative consequences. Furthermore, the participants had the freedom to decline any questions during the interviews. During the discussions and interviews participants were able to ask questions. Before starting the interviews, participants had freedom to decide if the interviewer can tape record the interviews or not.

The Table 3. 4 presents the ethical issues of the research and actions to eliminate the issues.

Table 3.4: Ethical issues of the research and actions to eliminate the issues

Ethical issue	Actions to eliminate the issue
Integrity and objectivity of the researcher	Acted openly and accurately and avoided misrepresentation, dishonesty, recklessness and partiality.
Respect for others	Respected for the individuals' decision to participate or not. Participants were advised that they may withdraw from the process or decline to answer any question at any time.
Avoidance of harm (non-maleficence)	Avoided any potential embarrassment, discomfort, stress, discomfort, pain or conflict and terminate the process where the participant is not comfortable.
Privacy of the participants	Personal information of the participants was stored separately and restrained from publishing in any interim of the final report.
Informed and voluntary consent	Individuals were informed and advised of the aim and objectives of the research. This was provided through Information Sheet. The consent of the participants was taken prior to the interview through a Consent Form.

	The interviews were audio recorded with the approval of the participant.
Responsibility for data collection and analysis	Collected data and information of the participants were stored separately and data was stored in multiple places under password protection. Collected data was transcribed and provided with the audio recordings for the participants to get their approval before analysing.
Avoidance of falsifying data and findings and plagiarism	Respected and disclosed multiple perspectives of the participants accurately and honestly. Disclosed the sources of literature accurately.
Avoidance of conflict of interest	Declared any commercial relationships with the participants of the data collection.

3.8 Summary

This section outlines the research philosophy, research design; including methods, strategies, data collection and analysis techniques proposed to be adopted in the research. Adoption of qualitative methods was justified with the philosophical perspectives and the nature of the questions developed through the conceptual framework. The data collection and analysis techniques were highlighted with the research design. Semi-structured interviews and case study analysis were proposed for data collect data for the research. Focus group interviews were proposed to validate the maturity model. Methods to enhance reliability and validity of the research were discussed. Finally, the possible ethical issues of the research are addressed.

CHAPTER FOUR

BARRIERS AND ENABLERS FOR SCI IN PREFABRICATED RESIDENTIAL CONSTRUCTION IN NEW ZEALAND

4.1 Overview

This chapter outlines analysis of the data collected from twelve semi-structured interviews conducted with industry experts who are engaged in New Zealand prefabricated housing construction. The main aim of the interviews is to identify the barriers and enablers for SC integration in prefabricated house building and wall panel and bathroom pod manufacturing. Therefore, at first the chapter presents the nature of the prefabrication housing construction sector in New Zealand. Then the chapter discusses the processes and relationships in prefabricated residential construction and module manufacturing-bathroom pods and wall panel manufacturing, based on the collected data collected. The chapter also discusses the barriers and enablers for supply chain integration of module manufacturing, which seeks to examine the current level of supply chain management practices in the industry.

4.2 Semi-structured interviews

The aim of the study is to improve the efficiency of the supply chain in wall panel and bathroom pod manufacturing used to build houses in New Zealand. Therefore, the first two objectives of the research are to examine the nature of the processes and supply chain relationships of wall panel and bathroom pod manufacturing and identify the barriers and enablers for supply chain integration in wall panel and bathroom pod manufacturing in New Zealand house building. As previously mentioned (section 4.1), twelve semi-structured interviews were conducted with industry experts and based on the collected data, the following section outlines the demographic details of the interview participants.

4.2.1 Demographic data of participants

All the interviews were conducted with management-level professionals involved in designing, manufacturing, and constructing prefabricated houses, elements, and modules. The interviews were coded from P-01 to P-12, to ensure the privacy of the participants. The interviews were conducted through a combination of face-to-face and skype conversations. Figure 4.1 presents the participants' experiences in the New Zealand prefabricated housing construction industry. Of the composition of the participants, 58.33% represented prefabrication elements/modules manufacturing organisations, 33.33% represented prefabricated house building organisations and 8.33% represented prefabrication research organisations. Purposive sampling was employed as the sampling technique. It facilitates capturing participants appropriate to the study based on the researcher's knowledge and opinion (Tongco, 2007) However, as previously mentioned, due to poor responsiveness snowball sampling was applied to recruit more participants. E-mails and phone calls were used to contact participants considering their expertise in prefabrication, availability, and willingness to participate. In this research, all the industry and subject matter leaders were engaged to provide their opinion.

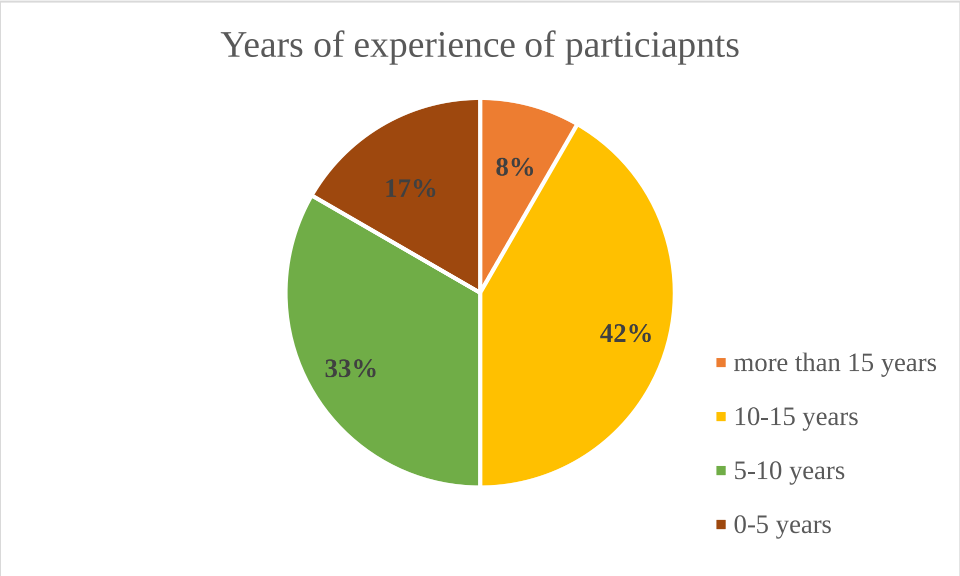

Figure 4.1: Years of experience of the participants

The duration of interviews was around one hour, and the first five minutes of the interviews were kept for the researcher to explain the background of the study. During the interviews, respondents were also encouraged to elaborate on their views by using practical examples and to discuss other issues that they believed were relevant to prefabricated house building, manufacturing as mentioned in section 3.7.1.2. Thematic content analysis was used to analyse collected data and based on the analysis the following sections were outlined considering the major themes, and sub-themes.

- The nature of prefabricated residential construction in New Zealand
- Supply chain and relationships in prefabricated residential construction
- Supply chains in bathroom pods and wall panel manufacturing
- Barriers for supply chain integration in bathroom pods and wall panel manufacturing
- Solutions for supply chain integration in bathroom pods and wall panel manufacturing

This allowed the participants to freely and comprehensively express their ideas related to prefabrication housing construction industry and bathroom pods and wall panel manufacturing in New Zealand.

4.3 The nature of prefabricated residential construction in New Zealand

The first part of the interviews focused on the current practices of prefabricated residential construction in order to get an idea of the nature, size and complexity of the industry. Attention to prefabrication is resurging in the New Zealand residential construction industry driven by its benefits. Although the benefits of prefabrication are widely understood, the adoption level is comparatively low compared to other countries such as Japan, China, Sweden and Poland (PrefabNZ, 2014). This is due to initial cost of implementation, lack of skills and experiences, bespoke nature of construction, negative perception towards innovation and complications in the supply chain (NZPC, 2012, PrefabNZ, 2014, Masood et al., 2016).

Besides, participants admitted that there is a current trend towards the construction of modular homes and container homes to provide solutions for the crisis in the affordable houses in New Zealand. However, the demand for modular and container homes remains controversial.

4.3.1 Commonly used types of prefabrication in residential construction

Participants were asked to comment on the types of prefabrication used in New Zealand residential construction. This question aimed at identifying the most commonly used types of prefabrication in the New Zealand residential construction sector. Based on the views of the participants to this question, the scope of the research narrows down into two types of prefabrication used in residential construction in New Zealand. Prefabrication can be classified into five categories: component based (prefabricated components like precast columns and beams), panelised (wall and floor panels), modular (modules or pods), hybrid (a combination of modular and panelised prefabrication) and whole building prefabrication (PrefabNZ, 2014; Shahzad, 2016) (See section 2.1.2). According to the participants, most commonly used types of prefabrication in residential construction are component-based prefabrication (12 out of 12) and module prefabrication (9 out of 12). Further, few participants (4 out of 12) agreed that there is a tendency towards whole building prefabrication and emphasized the growth in the establishment of Small Medium Enterprises (SME) for modular house manufacturing. This is reflected in the following statements made during the interviews.

"*Obviously all the windows and doors used in houses are prefabricated, and also people quite frequently manufacture transportable houses, pods which can be freight or transport*" (P-01)

"*In New Zealand, component-based prefab is the most common type, and then panel, trusses and modules like bathroom pods are quite popular prefab types used in housing construction. But when you get to three-dimensional prefab systems, there are not so many. But the market is preparing to produce to address the high demand for houses. For that bathroom pods and kitchen pods are an ideal solution that the industry is trying out*" (P-04)

This is emphasized in the recent reports published by OffsiteNZ where they indicated that timber wall panels, roof frames, joinery and windows are common types of prefabrication used in residential construction (PrefabNZ, 2015) and there will be a significant growth in panel and complete building manufacturing to survive the forecasted demand in coming years (PrefabNZ, 2018).

Therefore, considering participants views and industry predications (OffsiteNZ, BRANZ), the scope of the research was narrowed down to bathroom pods manufacturing and wall panel manufacturing and investigated the nature of the supply chain processes, barriers for supply chain integration and solutions to overcome the barriers in module bathroom and wall panel manufacturing.

4.3.2 Supply chain of prefabricated residential construction

Participants were asked to comment on the stages of the supply chain process and the nature of the relationship between participants. The opinions of the participants were helpful in mapping the stages with material and information flows. Further, identification of stages of whole supply chain, relationships between participants, material and product management and information flows was applied in defining interfaces for bathroom pods and wall panel manufacturing used for residential construction.

Firstly, Vrijhoef & Koskela (1999) developed a configuration for prefabricated construction supply chain considering the two phases: pre-assembly and on-site construction, that has different demands on the supply chain. Their view is that pre-assembly involves designing, material handling, manufacturing, and transportation while activities on the construction site include preparation for installation, foundation and installation (Vrijhoef & Koskela, 1999). Later, in New Zealand ministry of business, innovation and employment (MBIE) has developed a supply chain network for housing construction specific to this industry considering four main stages; design approval, manufacturing of modules/components off-site, transportation of modules to a final destination and assembly of modular units to form the finished building (MBIE, 2010).

Figure 4.2 and Figure 4.3 illustrate the supply chain process of a typical prefabricated residential construction with the material flow and information flow.

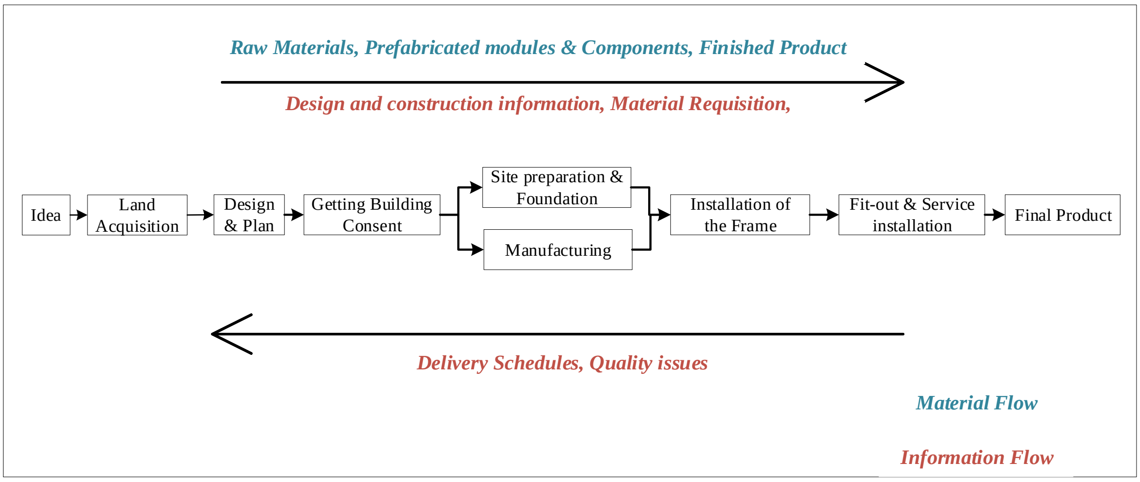

Figure 4.2: Prefabricated residential construction supply chain based on the stages

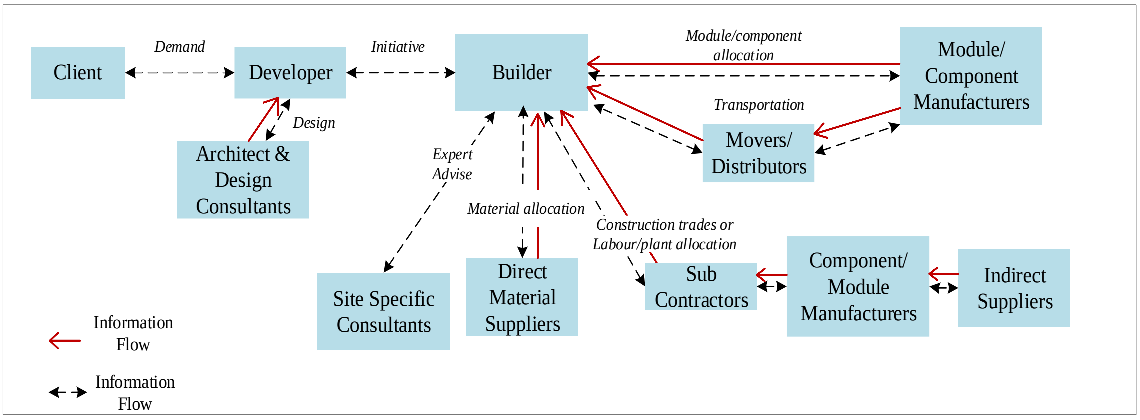

Figure 4.3: Prefabricated residential construction supply chain based on participants

In New Zealand, generally housing developers/builders start the process of residential construction after acquiring the specific land or plots of land. In prefabricated residential supply chain, different business entities, including manufacturers, suppliers, developers, contractors, and distributors directly and indirectly engaged to deliver the final output to the client/customer (Mostafa et al., 2014), processing forward flow of materials and a backward flow of information (Beamon, 1998). According to 7 out of 12 participants, design and planning stages are key milestones of the prefabricated residential construction as they involve design freezes, cost planning, methods of procurement and project planning and scheduling. Further P-02 participant highlighted the importance of the involvement of the builder in the design process in order to avoid design inefficiencies.

"If you can involve a competent, trustworthy builder at the beginning of the designing process to provide advice and leadership to get rid of the inefficiencies in the design" (P-02).

Designers need to develop a thorough understanding of the basic requirements and parameters of design and detailing prefabricated residential construction to subsequent approvals and to minimise the complications in the construction stage. After the development of the design according to the client's/customer's requirements "getting the building consent from them is the hard part in the whole construction process" (P-05 & P-07) as it is a time-consuming activity that highly impacts on the project timeline. Building consent is required for erection of foundation, assembly of modular components, service connections, and erection of the building on-site (PrefabNZ, 2018).

Once the building consent is granted, builder/contractor can commence the construction on-site starting from the foundation. Delivery of material and prefabricated components/modules/complete building is another important aspect considering the project timeline where "delays of delivery of materials and components to the site can make a significant effect on delaying the project completion dates" (P-10). Service installation and interior finishes are conducted after nesting the frame.

Amount of on-site construction activities varies with the types of prefabrication which is going to be used for a specific project. However, the above illustrated stages will remain as the major stages in the prefabricated residential construction process.

4.3.3 Bathroom and wall panel manufacturing processes

The next question focuses on wall panel and bathroom manufacturing, and the stages of these two processes. The bathroom manufacturing and wall panel manufacturing processes were developed based on the interviews. Participants were asked about the stages and relationships in the manufacturing processes. Identification of the stages of these manufacturing processes was applied in identifying the barriers according to the stages of the manufacturing process (section 4.4) and developing the key process areas in the maturity model (section 5.2.3).

The bathroom pods and wall panel manufacturing are aligned to the main supply chain process of the residential construction as exemplified (coloured in yellow) in Figure 4.4. Based on the requirements of a builder or a relevant sub-contractor, manufacturer starts to design and produce wall panels or bathroom pods and once the production is completed modules/elements are transported and installed.

When considering the development of the wall panel and bathroom pod manufacturing supply chain, six main steps were considered based on the participants views. These main steps include idea, design and planning, procurement, manufacturing, transportation and on-site assembly. The building consent stage is not considered in this process as it is the responsibility of developer/client at the designing stage of the proposed residential project. The manufacturer is entitled to demonstrate the building code compliance of the products they produce for the developer to get the building consent. This may be provided as a technical statement or membership of relevant industry schemes or independent testing and assessments or appraisals or product certification like CodeMark certificate. CodeMark is a certification scheme to ensure that a building or a construction method or design of a building or a building material aligns with the requirements of the New Zealand Building Code**.**

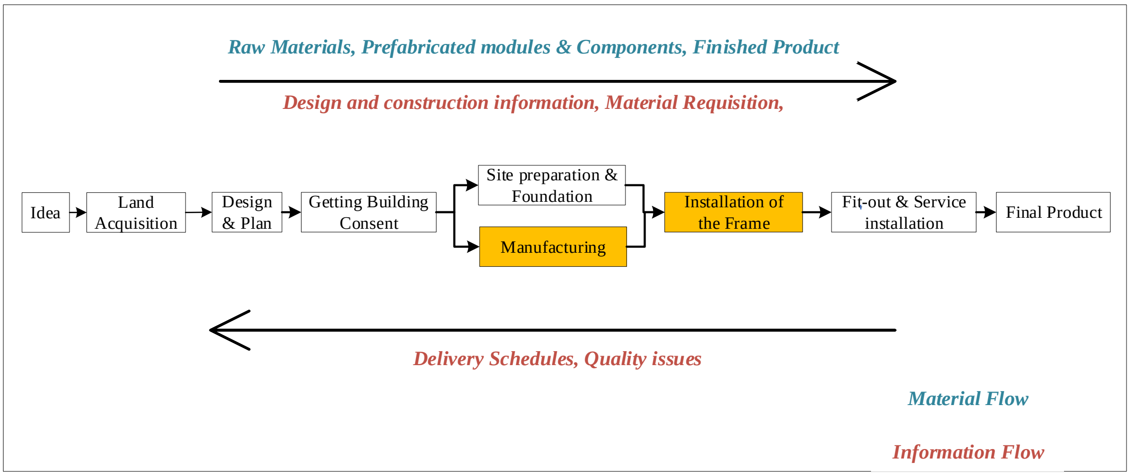

Figure 4.4: Alignment of the modules and panelised manufacturing in the supply chain of prefab residential construction

The processes of bathroom pod and wall panel manufacturing are almost the same except for the production stage.

4.3.3.1 Bathroom pods manufacturing

Prefabricated bathroom pods (Timber) are mass-produced under controlled manufacturing conditions and delivered to the project site based on schedules. These are inherently beneficial in achieving tight deadlines, minimal site impact and are generally used in repetitive structures like apartments. From initial inception to the on-site installation, the manufacturing process of bathroom pods is structured and automated (depending on scale of the manufacturing organisation). The module manufacturer is accountable for these three stages. The process starts with the client's initial requirement and extends to detail design and planning, production and on-site assembly. Designing of the modular pods is a key milestone of the process and it includes taking on-site measurements, sketch designing, detailed designing and preparing shop drawings. Scheduling for material procurement, handling and delivery of the bathroom pods require greater attention to prevent delays and disruptions to the manufacturing and on-site construction processes. The production process starts from preparing the shell and continues with panels assembly, installation of appliances, and equipment and final decoration and fitment.

The prefabricated bathroom manufacturing process is shown in Figure 4.5.

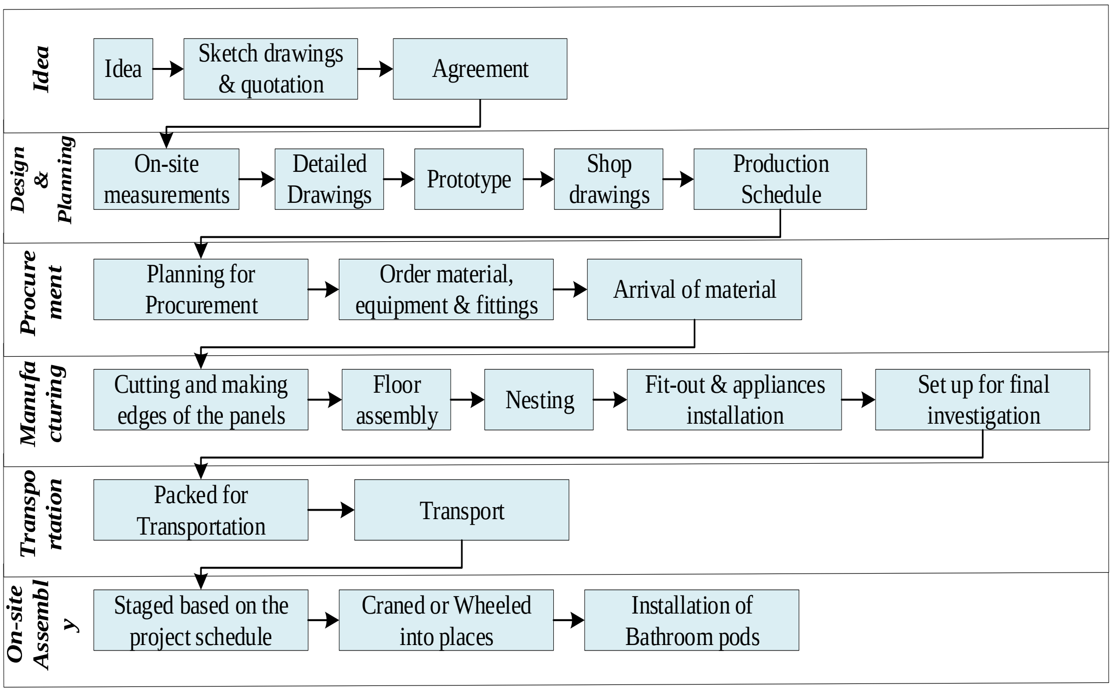

Figure 4.5: prefabricated bathroom pod manufacturing process

4.3.3.2 Prefabricated wall panel manufacturing

Prefabricated bathroom manufacturing process is complex and time consuming compared to wall panel manufacturing as it involves numerous aspects of design and construction. In New Zealand, most of the wall panel manufacturers procure timber panels from a material supplier and produce high-quality customers wall panels, such as Cross Laminated Timber (CLT) panels and closed panels. The process starts with the client's initial requirement and extends to designing, planning, procurement, production, and on-site assembly (Figure 4.6). In production, timber panels are cut according to the production drawings and then the workers apply the prime coat to prepare for subsequent edge preparation. The second coat of paint is applied only if it is especially required. In the final stage of production, openings (for doors and windows) are prepared. Finished wall panels are staged based on the installation order in the factory, to be delivered to the site.

The prefabricated wall panel manufacturing process is shown in Figure 4.6.

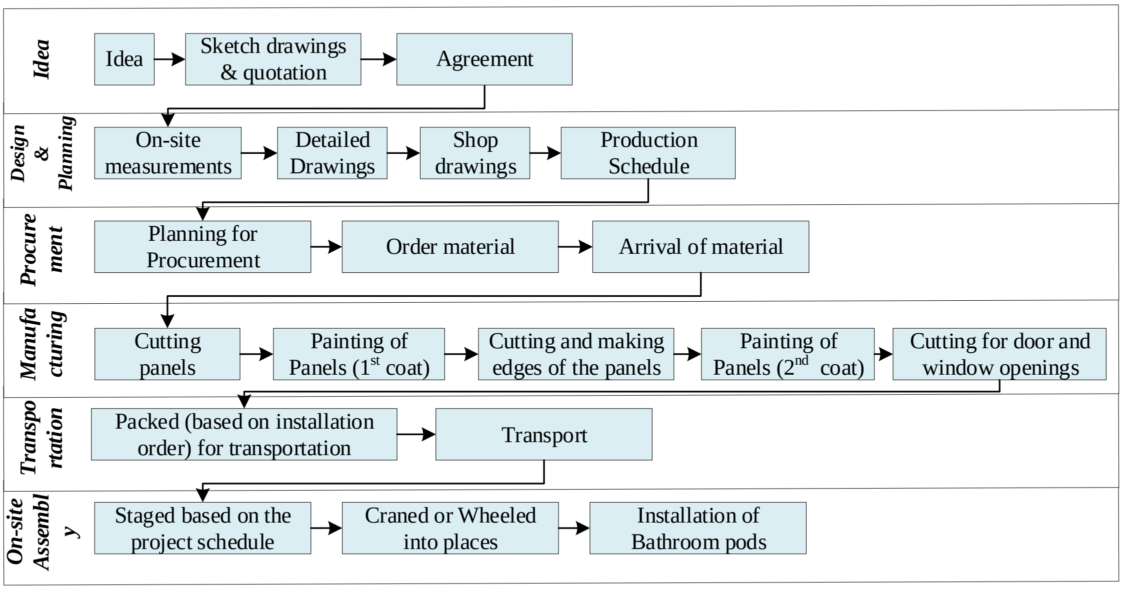

Figure 4.6: Prefab wall panel manufacturing process

As the processes of bathroom pods and wall panel manufacturing are developed, the next step is to identify the barriers associated with the manufacturing processes so as to improve the efficiency of the production. Therefore, participants were asked about their opinion on barriers in the manufacturing process of prefabricated elements/modules and mitigating these issues by using prefabrication.

4.4 Barriers for supply chain integration in module and panel manufacturing in New Zealand

The participants were asked to comment on the barriers for supply chain integration in the modules and panel manufacturing processes in order to mitigate the inefficiencies in the supply chain. They mentioned significant barriers for supply chain integration within the organisations and further indicated some barriers which impact on supply chain that are external to the organisation. The identified barriers were discussed including the participants statements from the interviews and categorised in a table based on the literature review findings.

4.4.1 Inadequate project planning and scheduling

As noted, the lack of project planning and scheduling seems to be a major internal barrier in both manufacturing processes. Compared to traditional construction, prefabrication requires a proper management system from start to end of the construction project to avoid delays and to achieve the required qual]ity and value for money. This is reflected in the following comment made by a participant.

"*So, in the beginning, it is really easy to make design decisions. But later on, when time progresses and the design progresses, it gets harder to change the design. So, we need to plan and schedule the work to minimise challenges, but the problem is that the industry is not focusing on this "* (P-02)

Jonsson (2014), Kamali and Hewage (2016), and Jaillon and Poon (2008) also highlighted the essential requirement of having a proper project planning system for prefabricated construction as manufacturing starts before the on-site construction and less flexibility in design changes. 10 out of 12 participants endorsed that, in New Zealand, most of the prefab manufacturing companies do not seem to be using advanced project planning tools for planning and scheduling. According to the participants *"we don't use any advanced project management tools to plan work ahead"* (P-10) and "*instructions for production are informed by drawings and basic production plans*" (P-11). However, participants P-08 and P-12 highlighted the use of software, such as Monday.com and Microvellum for project planning, respectively. Participant P-08 uses Monday.com software to update and provide real time information of the project schedules among the top-level management of the organization. Therefore, considering the participants' views it seems that manufacturing companies in New Zealand generally develop their production plans for the machine operators daily, or on the basis of the project considering the drawings. Therefore, delays are inevitable in case of a variation in the design.

4.4.2 Lack of technology and automation

Lack of technology use and reluctance to accept innovation is a common phenomenon in the New Zealand construction industry (Masood et al., 2016; New Zealand Productivity Commission Report, 2012). The highly automated nature of the prefabrication process requires accurate and reliable information to streamline the manufacturing process. Modern technologies facilitate effective means of handling updates and changes in the manufacturing process and indicate real-time performances. Use of extensive modern IT tools and automated machinery provide solutions for information and data exchange and performance and efficiency problems in the industry (Lessing, 2015). However, the usage of modern information and communication technologies in the New Zealand construction industry appears to be at a very low level. Furthermore, Darlow et al., (2021) argue that prefabiraction manufactuers in New Zealand are reluctant to invest in machinery rather than recruiting manpower due to the amount of capital investment required. This is further emphasized by the following statement made by one of the participants.

"*technological barriers in 3D scanning, modelling and 3d dimensioning and that sort of things are quite new in New Zealand, so it's going to take a few years to use those together*" *But there are few companies out there who use 3D scanning and BIM to design construction projects (*P-03).

This is similar to the findings of Masood et al. (2021) and Patel (2017) that emphasised the slow and reluctant response by New Zealand manufacturers to adopt technologies such as building information modelling (BIM), and enterprise resource planning (ERP) to improve the efficiency and integration in the supply chain. Even though New Zealand construction industry is reluctant to adopt new technologies (NZPC, 2012), it was noted that 2 out of 12 participants (P-06 & P-10) endorsed using BIM for their productions.

4.4.3 Lack of long-term partnerships and trust among the participants

Suppliers and clients in the supply chain of prefabricated module/panel manufacturing seem to be engaged on a project basis and are discharged when the project is completed. During the interviews, this was emphasised by a participant in stating that "*we don't have any agreements with the suppliers, we select them based on our past experience and sometimes by quotations*" (P-08). However, one of the participants had an opposite opinion on this and highlighted that they maintain a trust-based relationship with the suppliers and, therefore, lack of long-term partnerships may not be a barrier for them. This was highlighted in the following statement.

"We maintain a trust-based relationship with our suppliers and so, it is a strength to our company" (P-05).

Even though, companies maintain trust-based relationships, it is better to have an agreement with their suppliers/clients to avoid conflict of interest and to maintain transparency through the process. Lack of long-term and stable relationships creates conflicts in finding trustworthy and cooperative suppliers and clients and, therefore, organisations waste time and effort in tendering for the selection of suppliers. This hinders the opportunity for gaining trust among the stakeholders in the long run. Therefore, trust among stakeholder has become one of the major concerns in building long-term stable relationships to integrate the business functions.

4.4.4 Inconsistent goals within the organisation

Goal setting is an important component of a business to gain competitive advantage through achieving targets and improving performance. The manufactruing organisations are keen on goal-setting on a daily basis or jobs in hand rather than long-term strategic thinking. Spefically, the management system of most companies focus on completing jobs in hand based on a daily ba]sis shedule.

Other external and internal parties of the supply chain process of prefabrication have their own goals for career development rather than having common goals. Different perspectives of the participants of the process and inconsistent goals within the organisation create poor collaboration and coordination issues. Moreover, the less competitive behaviour in the market and monoploy nature has mainly affected the survival of businesses. Therfore, most of the SMEs are tackling day to day jobs rather than trying to scale up the buiness. This ultimately results in cost and time overruns and poor quality work. Two company owners interviewed had to shut down their businesses last year.

In line with that, Wilkinson (2001) highlighted unrealistic goal setting as a main problem in New Zealand construction projects. Therefore, this, coupled with lack of project planning may create delays and disruptions to the manufacturing process. Poor directions and guidance from the top-level managers are also barriers in the production process.

4.4.5 Inadequate performance measurement systems

Prefabrication is about improving efficiency in construction. However, in New Zealand, most of the manufacturing companies operate on a project basis and try to achieve a particular project within the timeframe, with less automation. Real-time performance measuring systems are not adopted in their companies. Similarly, the prefabricated manufacturing industry is not attentive in use approaches to improve their efficiency. However, one of the participants highlighted the usage of Lean Principles to minimise waste – "*we are practising lean manufacturing concept to minimise the waste of the timber parts*" (P-10).

4.4.6 Lack of information sharing

Effective and efficient means of coordination and communication is needed throughout the whole process of delivering a prefabricated building, including project planning, procurement, supply chain scheduling, assembling and construction, and delivery (Kamali & Hewage, 2016). As noted, manufacturing companies are not using any standardised information-sharing systems to share information openly. This was emphasised by one of the statements given by a participant as follows. "*We communicate information through informal ways like word of mouth or e-mails*" (P-03). Generally, e-mails, phone calls, face to face talks, and meetings are used to communicate and share information. But participant P-12 believes that communication should be reliable and accurate rather than the method used to share.

Lack of communication and coordination between the manufacturing team and on-site construction team is another problem in module and panel manufacturing supply chain which was highlighted by the participants. This is in line with the issue that Masood et al., (2021) highlighted in prefabricated house building companies which ultimately leads to quality issues in on-site installation.

4.4.7 Lack of knowledge in consumer demand

A clear idea of the market demand and its trends is necessary to ensure that the companies are getting sufficient work for survival and growth within the industry. Market investigations and surveys are needed to forecast consumer demand and demand trends in the market. However, among the interviewees, only one participant (P-12) emphasized that they are using a database for customer demand evaluation, and most of the other participants regard it as a barrier. However, surprisingly there were participants who do not even consider having a database for demand forecasting. This is reflected in the following statement made by a participant.

"We are not using any database at the moment, and it is really difficult to maintain a database as NZ construction industry is governed by SMEs" (P-07)

4.4.8 Transportation of modules

Delivery of prefabricated elements is one of the significant stages in the prefabricated housing construction. Since the modules are manufactured in a factory, delivery of these into the site should receive significant attention and manufacturing organizations need to focus on enhancing their logistic capabilities especially for two dimensional and three-dimensional products (Masood et al.,2021).

New Zealand's landscape is hilly and transportation of heavy modules across the country is quite a challenge, therefore significant cost and care is required in transportation of modules. This is emphasised by one of the participants' statements that "*in New Zealand, the land is very heavy and skinny. Therefore, transportation is difficult, and it takes a significant amount of money to transport heavy modules*" (P-03). However, 3 out of 12 participants disagreed with this view and explained that "*even though New Zealand has a skinny land we can manage transportation as there are trucks to deliver*" (P-01).

Unavailability of storage facilities on-site is another risk factor associated with the logistic of modules and has a direct impact on achieving the defined lead times (Masood et al., 2021).

4.4.9 Lack of understanding of SCM

As noted, prefab manufacturing companies are not using manufacturing concepts to improve their efficiency. Participant P-05 and P-10 are aware of Lean Principles and using it to minimise waste. However, most of the participants had a different view about supply chain as it is only focusing on supply of materials and products. Therefore, at the beginning of the interview inter]viewer had to define the term supply chain. However, some of the organisations are using the basic principles such as material management (enterprise resource planning), demand management and logistic management are practised in the organisations.

In addition to these internal barriers, few external barriers are indicated within the interviews: the scale of the New Zealand market, undercapitalised companies, anti-competitive behaviour and the lack of education about the benefits of prefabrication.

The aforementioned identified barriers in the supply chain of prefabricated elements were classified under four categories as shown in Table 4.1. These internal barriers were categorised based Awad's (2010) categorisation of SCI barriers. The external factors identified are not related to the internal supply chain of the manufacturing companies. Therefore, in this research, only the barriers that can be controlled by the manufacturing organisations (marginal barriers, relationship barriers and technical barriers) are considered.

Table 4.1: Barriers to supply chain integration

Managerial Barriers	Technical Barriers	Relationship Barriers	External barriers
• Inadequate project planning and scheduling • Inconsistent goals within the org. • Lack of clear direction and guidance • Inadequate performance measurement systems	• Lack of information sharing • Lack of technology and automation • Transportation of modules	• Lack of long-term partnerships and trust among the stakeholders	• The scale of the New Zealand market • Undercapitalised companies • Anti-competitive behaviour • Lack of education about the benefits of prefabrication

• Lack of understanding of SCM • Lack of knowledge in consumer demand			

4.5 Suggestions to improve the supply chain of module and panel manufacturing

The participants were asked to suggest solutions for the barriers in both bathroom pods and wall panel manufacturing processes in order to develop the assessment criteria in the maturity model. The following are the suggestions identified through the interviews.

Inadequate information sharing in the inception and design development stage would be a challenge to capture the clients' requirement to design the prefabricated element. To avoid this, as participants mentioned open information sharing should be encouraged through the whole supply chain, including client and supplier interfaces. This will help to avoid conflicts in on-site quality issues that can be raised as a result of poor communication and coordination between production and on-site construction (Masood et al., 2021). In the meantime, the manufacturer/respondent party of the manufacturer needs to actively participate in exchanging design criteria based on the production capacity. As noted, in prefabricated residential construction, designers encourage the early involvement of builders in the designing process to avoid changes after the design freeze and to improve buildability and avoid design changes. This is identical to the literature where of Kamali and Hewage, (2016) and Pan *et al.*, (2012) highlighted the importance of encouraging clients to participate actively in the design process to avoid unnecessary assumptions.

Throughout the whole supply chain, communication should be standardised, reliable and accurate to improve coordination and efficiency. All the participants highlighted the importance of having "*a standard platform for communication*" (P-10) to improve the coordination of the manufacturing process. Having an integrated network to share information through the whole supply chain including suppliers and clients, will be beneficial in sharing reliable and accurate information (Lessing, 2015). Organisations need to invest in modern technologies and software applications to allow a better flow of information. Modern information technology provides better sources to share information along the supply chain and avoid delays and disruptions in the process. Having access to open, reliable and accurate information is beneficial for all the stakeholders in their decision making. However, "*technical barriers in the New Zealand construction industry*" (P-01) (PrefabNZ, 2014) is a challenge in integrating the manufacturing process in the New Zealand construction industry. Furthermore, participants (6 out of 12) highlight the use of building information modelling as an information management system that can integrate the construction information flow among the project stakeholders (Kim, 2014). Masood et al., (2021) suggest using BIM to improve the seamless communication process and practical collaboration in prefabrication.

Additionally, early design freeze and less flexibility for changes in prefabrication create the requirement of a proper plan with schedules to eliminate complications (Jaillon & Poon, 2008). Production planning with adequate documentation is required to avoid delays and disruptions in the production process. According to the interview findings, participants highlighted the importance of having "*a system/software to production planning and delivering to the relevant parties*" (P-08, P-12). In the meantime, participants (P-04, P-05, P-07) endorsed the requirement of providing training to the production team on software handling and supply chain management.

In the production stage, the practice of real-time measuring is hard to find in New Zealand. It is a significant drawback in achieving deadlines and improving productivity. Since the main idea of transferring construction activities from on-site to a factory is to avoid delays from disruptions, operations in the production process should be efficient. Real-time measuring will guide top-level managers/ decision-makers to monitor the current productivity level and based on its analysis; production can be improved further. A systematic performance measurement system and a real-time analysis are required to analyse and continuously improve the production process. Real-time performance measures facilitate evaluations of the performance and thereby, it can be used for decision making and future expansions. This is reflected in the following comment made by a participant. "*Real-time performance monitoring will facilitate improvements to the continuous production line*" (P-05).

Furthermore, lack of long and stable relationships with clients and suppliers is a challenge in forecasting demands and the procurement process respectively. In the New Zealand construction industry, relationships with suppliers and clients are mostly short-term and are at arm's length. According to the findings of Ying et al., (2015) large-scale organisations in New Zealand have started moving towards collaborative relationships while small-medium enterprises which represent the majority. To rectify this, agreements and contracts were found to be a solution in the early '90s (Saad, Jones & James, 2002). However, this was superseded with the emergence of "partnering" as agreements and contracts appeared with more complications (Saad *et al*., 2002).

Another challenging problem is lack of trust among participants across the whole manufacturing process. Specifically, unskilled labourers in manufacturing are hired based on short-term contracts and this creates less dedication to their work. This could be improved through long-term relationships which can significantly affect coordination and integration in the process (Spekman *et al*., 1998; Meng et al., 2011) of organisations stills struggling with the poor contractor supplier behaviours. This is similar to the interview findings, in which they (11 out of 12 participants) highlighted the requirement of managing long-term relationships, and 2 out of 12 participants (P-03 & P-09) disclose that they have partnerships with clients and suppliers.

Logistic management is another important aspect to consider in supply chain management. Logistic management could eliminate the problems associated with the transportation of modules. Here, proper coordination in the transportation of prefabricated elements is required to avoid time wastage and storage problems. According to the participants, "*a transportation plan could help to coordinate the delivery process across New Zealand*" (P-10). In the meantime, P-06 highlight that "*we do not see transportation as a barrier for us, if we found out any problem of delivering the product to site while transporting, deliver back the products to the factory and additional cost will be covered by negotiating with the client*" Giving consideration to this, it seems that organisations are using their own strategies to have a well-organised logistic process. But the problem is the efficiency of their logistic arrangement and for that the organisations need to measure their logistic performances against goals.

4.6 A framework of barriers and enablers in module and panel supply chain

The above barriers and enablers identified from interviews were mapped into the supply chain of module/panel in New Zealand as shown in Figure 4.7. This framework is applicable only for bathroom pods and wall panel manufacturing. It was developed based on the stages of these manufacturing processes from the initial idea discussion with the client to the final installation on-site. The stages of this framework include the idea, design, planning, procurement, manufacturing, transportation, and on-site assembly. The framework will be useful for the prefab wall panel and bathroom pods manufacturing companies to identify the barriers and enablers for supply chain integration under the aforementioned stages. For the purpose of identification, barriers; managerial, technical and relationship barriers and enablers were labelled as 'M', 'T', 'R' and 'E', respectively (Figure 4.7).

4.6.1 Idea phase

The most common barriers identified in this stage are inadequate information on the demand (M.05) and lack of stable and tong-term relationships (R.01) with clients. Inadequate information sharing on the clients' requirement (T.01) is another challenge in the inception stage as it hinders the early project execution. Respondents suggested developing demand forecasts based on market surveys (E.IV) to forecast future demands (Projects). Partnering and alliancing (E.VII) was suggested by the respondents to avoid the barriers in the initial stage of manufacturing. This is similar to literature findings where Lessing (2015) suggested manufacturers improve collaborative relationships with clients to receive constant demand for projects as it facilitates the team starting projects early. Open information sharing (E.V) using an integrated system (E.VI) to share basic ideas across the supply chain is suggested to avoid the loopholes in information sharing.

4.6.2 Design phase

In the design phase, lack of clear direction and guidance from the clients (M.04), open information sharing (T.01) and lack of technology used to design (T.02) are common barriers. According to Dainty et al. (2007), information transfer and communication is the most frequent challenge in the design phase within the design team and between the design team and client. Unlike the traditional construction, in prefabrication design is unable to change after the design stage. Therefore, respondents suggested improving information sharing through an integrated system using information and communication technology (ICT) (E.V & E.VII). Tjell and Bosch-Sijtsema (2015) suggested the collaborative engagement of clients and design team to improve the mutual understanding and interest in sharing and receiving knowledge and information regarding the clients' needs and wishes.

4.6.3 Planning phase

Under the planning phase, poor project planning (M.01) and lack of goal-setting (M.02) can be identified as common issues. Lack of participation of suppliers and manufacturers in the planning stage (T.01) is another barrier in accomplishing targets of the project. This coupled with a lack of technology used to prepare schedules (T.02), creates chaos in the production process. According to the respondents, implementation of proper project planning and scheduling systems (E.II & E.VI) and establishing common goals could eliminate poor project planning, lack of technology and lack of goal-setting respectively. In line with this, Lessing (2006) recommends to achieve productivity having a systematic plan with daily basis schedules to manage the manufacturing process from start to end.

4.6.4 Procurement phase

The efficiency of the procurement stage is mainly affected by casual relationships with suppliers (R.01) and lack of demand forecasting (M.05). Respondents suggested using a real-time monitoring system (E.IV) integrated with a project planning system (E.VI) to forecast the material demand ahead of time. To avoid delays and complications due to casual relationships with suppliers, respondents suggest maintaining partnerships with regular suppliers (E.VII). Pan et al. (2008) suggested retaining long and stable relationships with suppliers to manage the risks in procurement and reduce dependence on supply. Lack of information sharing (T.01) is another barrier in this phase as it is the main success factor of procurement stage (Pan et al., 2008). In practice, less overall attention is given to this stage than it appears and it causes delays to the whole process.

4.6.5 Production phase

Lack of production planning (M.01), automation (T.02) and open information sharing (T.02) can be identified as the main barriers in the production stage. Moreover, the lack of clear directions and guidance towards the machine operators (M.04) will create defects and errors in the production (Lessing et al., 2015). Even though prefabrication is about improving efficiency, performance monitoring and improvement (M.03) seem to be little practised in the production stage. Real-time performance monitoring (E.III) is required to observe and improve the productivity of processes by analysing the records (Lessing et al., 2015). Unstable and short-term basis employment (specifically unskilled workers) (R.01) in the production process, hinders the cooperation and trustworthiness (Koskela, 2000) and thereby creates delays to the whole production process. Having a long and stable relationship (E.III) with participants of the production process saves time and effort in recruiting seasonal employees for the production (Lessing et al., 2015). Respondents suggested training and educating the participants on supply chain management (E.VIII) to avoid the barrier - lack of understanding of the concept of SCM (M.06).

4.6.6 Transportation phase

According to Ying et al., (2015) logistics apparently incur unnecessary cost and delays due to lack of automation. Further, they emphasised that the major problem in supply chain implementation in the New Zealand construction industry is related to logistics management, which is still not recognised by the industry. This is mainly caused by the lack of automation (T.02) and miscommunication between the parties (M.04 & T.01) in the delivery stage. Transportation of volumetric modules (T.03) is another challenge as the geography of New Zealand is mostly steep and hilly. Proper logistics management (E.IX) is recommended by the respondents to overcome the barriers in this stage.

4.6.7 On-site assembly stage

The stage of on-site assembly can be challenging due to overlapping schedules in the project and module production. Miscommunication (T.01) and inadequate planning (M.01) are identified as major barriers in this stage. Respondents suggested improving open information sharing (E.V & E.VI) to avoid delays and disruptions due to miscommunication. Performance monitoring of the production (E.III) and on-site construction should be encouraged in order to prevent idle time. Lack of automation (T.02) can be categorised as another challenge in this stage as it hinders quick installation of the modular units on-site.

Regarding the barriers mapped with stages of the supply chain, it could be inferred that lack of information sharing, inadequate technical system and poor planning are the major issues which reputedly impact supply chain integration in module manufacturing.

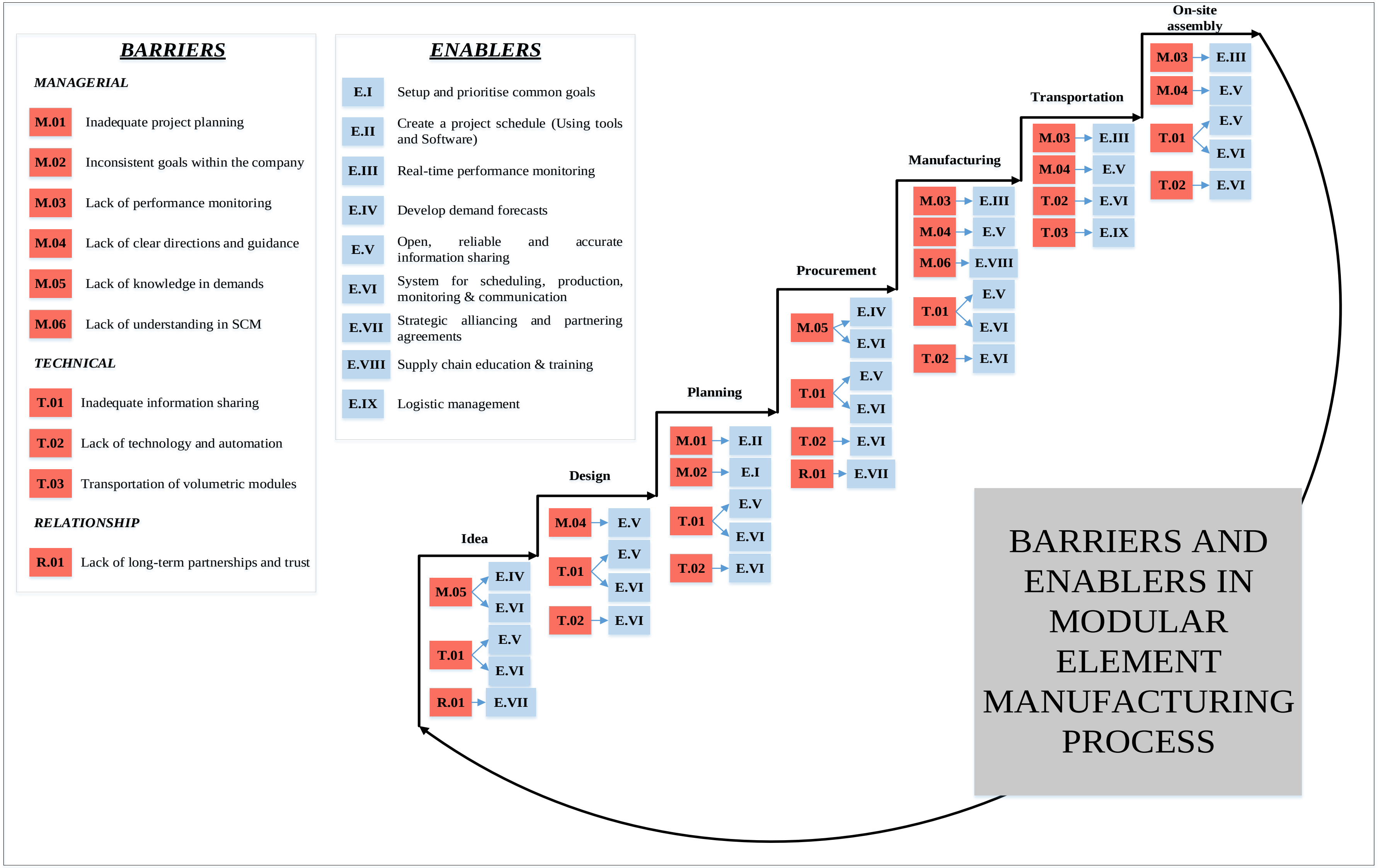

Figure 4.7: Barriers and enablers for SCI in module and panel manufacturing

4.7 Chapter summary

The chapter has presented the results of the data collection carried out with prefabrication experts in the New Zealand construction industry. According to the data collection, seven stages-idea, design, planning, procurement, manufacturing, transportation and onsite assembly were identified as main stages of both wall panel and bathroom pod manufacturing. Further, ten main barriers for supply chain integration were identified. Another four barriers were identified as external barriers which are outside of the prefabricated manufacturers but have an impact for supply chain integration. Solutions to overcome these barriers were identified as enablers. It was observed that the supply chain practices are different from one manufacturer to another. Finally identified barriers and enablers for supply chain integration were mapped into a framework to provide a guide for the wall panel and bathroom pods manufacturing companies to identify the barriers for supply chain integration and solutions to overcome barriers in each stage of their manufacturing process. Further, the identification of the stages and relationships, process mapping and identification of enablers were used in chapter 5 to develop the maturity model.

CHAPTER FIVE

SUPPLY CHAIN INTEGRATION IN RESIDENTIAL MODULE AND PANEL MANUFACTURING IN NEW ZEALAND

5.1 Overview

As specified in chapter four, participants of the semi-structured interviews suggested several solutions to overcome the lack of supply chain integration in residential module/panel manufacturing in New Zealand. According to the participants' views, reliable and accurate information sharing, planning and preparing schedules for the projects in hand, prioritising the project goals, standardising and automating the manufacturing process, performance monitoring and analysing, coordination of the project functions, maintaining long-term and trustworthy relationships, logistic management and demand forecasting were identified as the solutions/enablers. Based on these opinions and literature findings on enablers for supply chain integration (Section 2.2.5), a model was proposed. Furthermore, as manufacturing companies continuously seek to advance the efficiency of the supply chain, the maturity concept was followed to develop the proposed model. Further to that, the maturity concept has received increasing attention from different industries and academics to improve business processes.

The proposed model considered to scope, design, populate, test, deploy and maintain when developing the structure of the model. Therefore, this chapter discusses the development of the model within each stage. The structure of the maturity model consists of maturity levels, key process areas and assessment criteria. First, each of these elements are discussed considering the definitions and parameters, importance and application. Then, the key process areas are further discussed under the assessment criteria of the model.

The complete structure of the developed model is illustrated at the end of the chapter.

5.2 Model development

In the residential module manufacturing industry, supply chain practices are relatively diverse and vary from organisation to organisation and project to project as the industry is generally following a make-to-order production strategy. According to the participants of the semi-structured interviews, supply chain practices and level of integration is different from one function in one step of the supply chain and might differ from another stage. This causes an inefficient flow of information and material through the whole supply chain resulting in productivity issues. Moreover, the lack of stable and long-lasting relationships with clients and suppliers has affected the smooth production flow. Therefore, the proposed model focuses on improving the residential module and panel manufacturing supply chain, starting from the idea stage until the module and panel are assembled on-site.

The proposed model was developed following the maturity concept and adopted based on the Manufacturing Supply Chain Maturity Model established by PRTM. When developing the model, Bruin et al., (2005) development stages were considered in order to evolve the model from descriptive in nature into prescriptive and comparative in nature. According to Bruin et al. (2005), the order of the model development phases-scope, design, populate, test, deploy and maintain, are essential as the decisions made in the early stages impact the later stages of the model development. The model development framework of considering this. Figure 5.1 illustrates the phases designed to build the proposed model for this study.

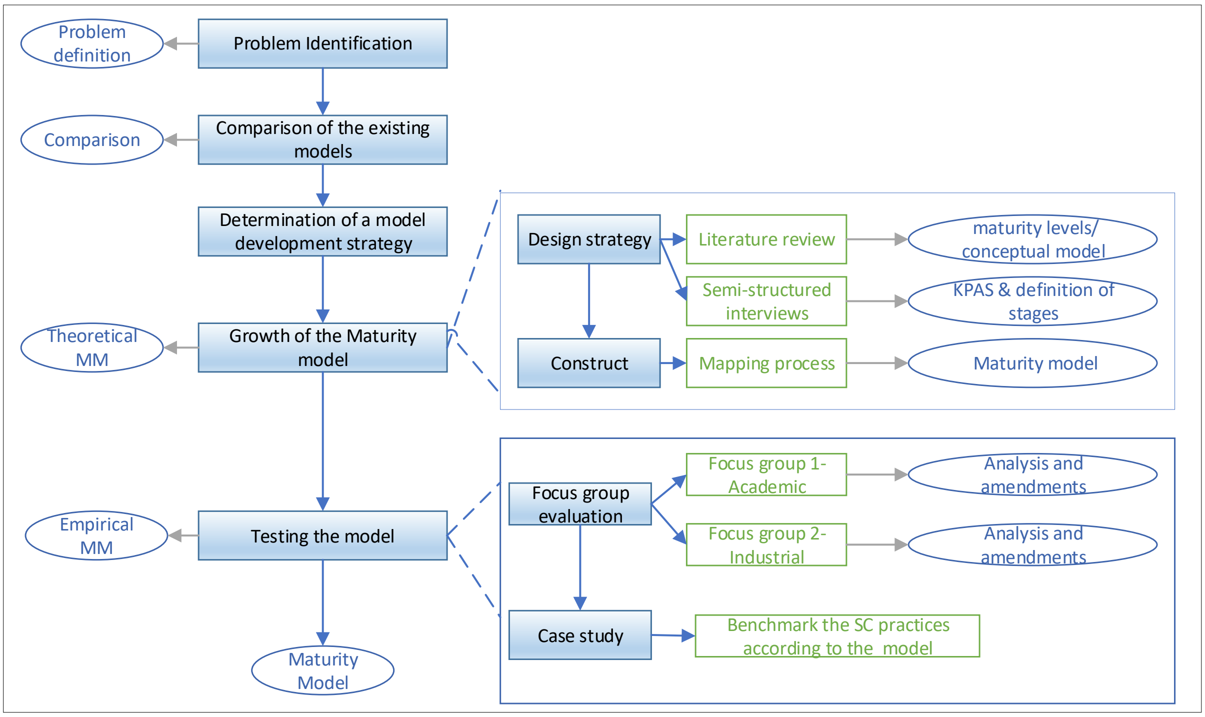

Figure 5.1: Model development phases

As the first step of the study, the research gap in residential module/panel manufacturing was identified in the literature review and then confirmed through semi-structured interviews. To surmount the gap, the maturity concept was identified in the literature as a continuous improvement strategy applied in different industries. Further, participants of the semi-structured interviews endorse the importance of an integrated arrangement to continuously improve supply chain practices in module/panel manufacturing.

Considering the research gap, boundaries of the model application and usage were identified first due to its influence on the remaining stages of the model. The focus of the proposed model was set out based on the research gap identified in the literature and semi-structured interviews. Furthermore, a review of existing maturity models in the construction industry and manufacturing sector was conducted (see section 2.2.6) to get a deep insight into the boundaries of the model. The review enabled the capturing of the gaps in the existing models so that the objectives of the proposed model were set out to fill the gaps. Integration of the module/panel manufacturing supply chains starting from the initial idea to the final installation of the modules, was the specific focus of the proposed model. To assist the development process, the main stakeholders were identified from the residential module/panel manufacturing as they are the central focus of the study.

After setting out the scope of the model, the model development strategy was determined and designed to incorporate the intended goal of integrating supply chain practices in module manufacturing. Generally, a maturity model mainly consists of maturity levels and key process areas. Maturity levels represent a logical evolution of practices to achieve predefined goals, while key process areas denote the areas/issues that need improvement. Maturity levels of the proposed model were developed through the literature review and key process areas were identified through the semi-structured interviews (discussed in detail in sections 5.2.1 and 5.2.2). The maturity model then populated defining measures for key process areas under each maturity level.

Once the model is populated, the next step is to test the model for validity, reliability and generalisability (Bruin et al., 2005). To test the model, two methods were adopted. Firstly, three case studies were conducted to benchmark the current supply chain practices against the proposed model. The details of the case study analysis are discussed at the end of this chapter. After conducting the case studies, two focus group interviews were conducted to test the validity and reliability of the model. The analysis of the focus group interviews is discussed in chapter six.

5.2.1 Maturity levels

In this study, maturity levels represent a progression of activities set out to achieve integration in module manufacturing. Figure 5.2 represents the maturity levels defined for the study. These maturity levels are adopted based on the literature review (section 2.13). In the proposed model, five maturity levels were adopted to describe the improvement sequence in integration from an unstructured and unorganised level to a coordinated and organised level (Figure 5.2). The levels are named ad-hoc, segmented, collaborative, integrated and value network. Ad-hoc and segment levels represent the immature supply chain network, while the fourth level (integrated) and fifth-level (value network) represents the mature supply chain network. The third level-coordinated stands for the transition between mature and immature supply chain practices.

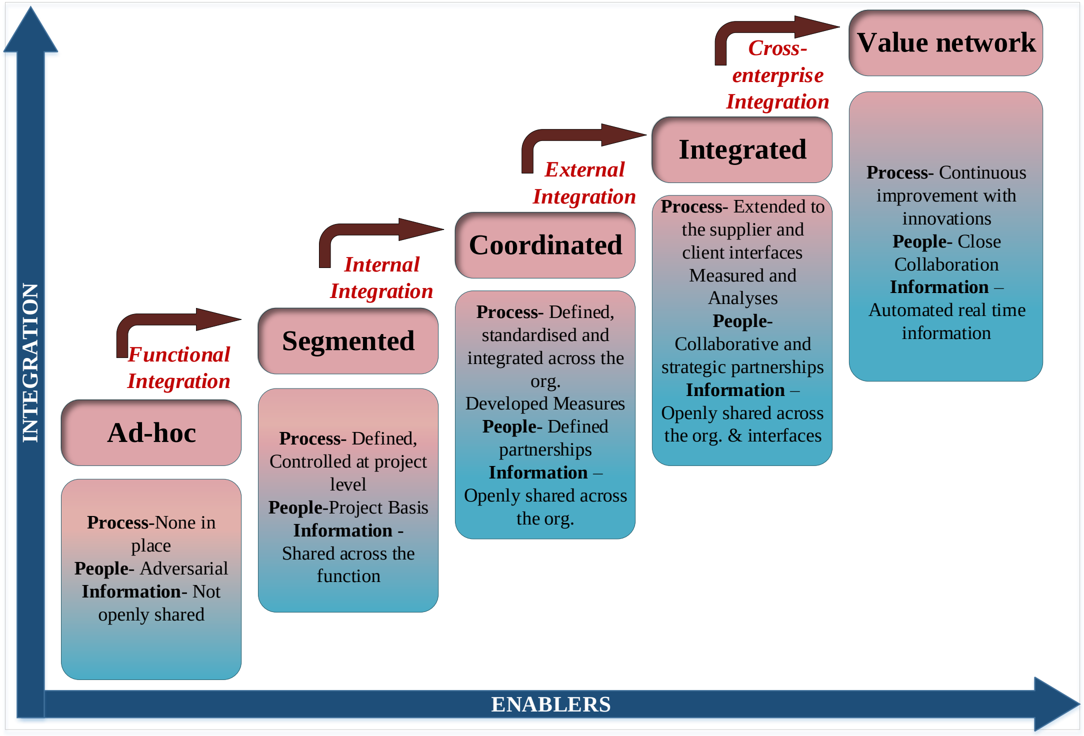

Figure 5.2: Maturity levels of the proposed model

Adapted from: (Lahit et al., 2009; PRTM Management Consultants, 2005)

Each maturity level was defined under three criteria/enablers; process, relationship and information. The three enablers were adopted based on the studies of Briscoe and Dainty (2005); Dainty et al. (2001); Handfield and Nichols Jr (1999); McDermotti and Khalfan (2012); Sabir and Irfan (2014). Furthermore, these three enablers have not been entirely considered in any maturity model developed for the construction sector. Therefore, these enablers were adopted and defined under each maturity level to progress the integration from functional integration to cross-enterprise integration of supply chains. In this research, the process is denoted as the procedures and actions taken to complete functions of the supply chain; people denoted as the working relationship with the internal and external participants and contractual relationship with the external participants of the supply chain and information is denoted as the flow of information in the supply chain. The maturity levels were defined for this study as follows.

Ad hoc - Unstructured and ill-defined processes and procedures. Organisational roles and responsibilities are not well defined. Partnerships with suppliers, clients and other skills outsourced are not formally enforced. Hire them on a project or temporary basis and discharge them after the specific work they are hired for. Data and information are not shared openly among all the participants across the supply chain.

Segmented - Processes, procedures, organisational roles and responsibilities are defined. However, processes and functions are still isolated, and there is little effort to integrate the processes within the functions (departments). Partnerships with suppliers, clients and other outsourced skills are not well defined. Data and information are shared electronically within the departments with limited access.

Coordinated - Organisation-wide processes and procedures are well defined and standardised. The processes and the activities are adequately measured. Supplier and client partnerships are well defined. Process specific information is collected and shared electronically within the organisation. Actions are taken to integrate the internal processes.

Integrated - Strategic suppliers and clients are identified, and supply chain practices are extended to both of their interfaces. Processes are measured, and performance is analysed for improvements. Information technology is used to integrate business functions, and real-time information is visible across the value chain. Information is collected and shared electronically among the participants of the value chain, including clients and suppliers.

Value network - Continuous process improvement through feedback and innovative technologies. Real-time information is effectively visible across the value chain. Information technology automates the integration of business processes across enterprises.

After defining the maturity levels, key process areas were developed. The development of the key process areas is discussed in the following section.

5.2.2 Key process areas

Key Process Areas (KPAs) is one of the main elements of a maturity model. In this maturity model key process areas are developed based on semi-structured interviews. Key process areas developed for this study include idea and design, planning, procurement, manufacturing, transportation and on-site assembly. In semi-structured interviews, participants were asked to illustrate the supply chain process in module/panel manufacturing. Based on that question, the supply chain process for module/panel manufacturing was developed (Figure 4.2, Figure 4.5 and Figure 4.6). These key process areas were identified from the developed supply chain process as they represent the main operating functions. The participants of the semi-structured interviews also confirmed these areas as crucial stages. Therefore, these areas were established as the key process areas. The definitions of these KPAs are explained as follows (Table 5.1).

Table 5.1: Key process areas of the proposed model

KPAs	Definition
Inception & design	Understanding the project scope and clients'/builders' requirements and develop/provide a design and improve the developed design into shop drawings
Planning	Make schedules assigning tasks, dates/times and resources to achieve the objectives of a project/projects
Procurement	Forecasting the material requirement, selection of suppliers and ordering the materials
Production	Production of the wall panels/bathroom pods/modular homes
Transportation	Includes loading, unloading, storing, and delivery of the finished products to the site
On-site assembly	Fixing modules on-site

5.2.3 Development of the assessment criteria

Key process areas were further characterised for each maturity level under the assessment criteria of process, relationship, and information. Each of these assessment criteria is discussed by means of the progress/maturity of the supply chain practices derived from the literature review and semi-structured interviews. The following sections explained the development of the maturity model under key process areas and maturity levels based on the supply chain.

5.2.3.1 Inception and design

Inception and design key process area covers understanding the project scope and clients' requirements and developing a design for the module and improving the developed design into shop drawings to run the manufacturing. Therefore, assessment criteria for inception and design were developed under process, relationship and information sharing. The development is illustrated below.

Process of inception and design illustrated design strategy, including the level of collaboration among the participants. According to participants of the semi-structured interviews design strategy of the modules varies from one company to another. P-01, P-09, P-10 participants are using a customised approach in designing and P-11 and P-12 are adopting standardised designing with little customisation, while P-04 participant is adopting a collaborative design strategy, where "*builders/clients are getting involved earlier in the design process in order to get rid of that inefficiency-(P-04)*". Therefore, maturity levels were defined, ranging from manual standardised designing to BIM integrated collaborative designing (Succar et al., 2012).

The contractual relationship between the client and the design team of the manufacturing company is focused in the model as it is crucial to avoid design changes in the production stage (Chiang et al., 2006; Moradibistouni et al., 2018) and to improve stakeholder coordination in the manufacturing process (Li et al., 2016). All the participants highlighted the importance of having a trustworthy and long-term relationship with their clients, and even though 60% of the participants are currently maintaining non-contractual relationships with their clients, while two of the participants have a long-term contractual relationship with their clients. Therefore, considering the maturity levels, under relationship they were defined from project-specific and adversarial relationships to consolidation of companies.

Often information sharing and response from the parties involved in the process is a critical success factor in the design (Jørgensen & Emmitt, 2009; Stroebele & Kiessling, 2017). Participants of the semi-structured interviews also suggested that the client's involvement in the designing process avoid design changes during the production (P-1, P-4 & P-12). However, identifying the difference between mere sharing information and collaborative design is very important to avoid negative implications for the supply chain process (Jørgensen & Emmitt, 2009). Therefore, the assessment criteria for information sharing were developed from the low level of information sharing to collaborative online information sharing.

5.2.3.2 Planning

To maximise the benefits of prefabrication, the manufacturing process must be well-organised and planned (Altaf et al., 2018; Stroebele & Kiessling, 2017). Therefore, planning was considered a key process area and defined as planning and scheduling the operations and resources to achieve the objectives of a project. Accordingly, assessment criteria for planning were developed under process, information sharing and relationship of the participants.

Process of planning focused on planning strategy including scheduling- assigning tasks, dates/times and resources to achieve the objectives of a project. In the maturity model, the planning process was defined for the ad-hoc level to value network level, considering the semi-structured interviews and literature review. According to the participants, planning was identified as one of the crucial stages as "*it requires a lot of planning in the early stages because the design cannot be changed at the end* (P-09)". However, according to the participants, manufacturers are using different types of planning methods and systems. One participant (P-08) highlighted that they are planning their work daily and communicating it daily to the production team. On the other hand, some manufacturers are using different planning systems-Last Planner System™ and Monday.com. Even though there are sophisticated planning systems, there is still a lack of integration between planning and other functions- design, production and assembly (P-03, P-04, P-10, P-12). Therefore, the planning process was defined for the model from daily basis project planning to continuous planning integrated with real-time monitoring.

The working relationship with planning team members was considered when developing the assessment criteria for planning key process area. However, in practice, the relationship at one function may be adversarial and other functions may be collaborative (Meng et al., 2011). Therefore, it is impossible to find a supply chain in which the relationship is precisely the same. Therefore, to continuously improve the collaborative working relationship, the planning key process area was defined from adversarial arms-length relationship to adaptive relationship.

In order to avoid mistakes during production, planning of activities with the resource requirement is essential. For this, an integrated information system is required to pick up or transfer real-time information related to production, design, procurement and assembly (Lessing, 2015; Viana, 2015). According to the semi-structured interviews, most of the participants (10 out of 12 participants) agreed that they were not using any standardised and integrated system to share information as they "*communicate information through informal ways like word of mouth or e-mails*" (P-03). Therefore, assessment criteria for information sharing in planning were developed from separate information sharing channels to real-time open information sharing through integrated systems such as BIM.

5.2.3.3 Procurement

In this proposed maturity model, procurement was considered a forecasting of material requirement, selection of suppliers and ordering the materials. Accordingly, assessment criteria for procurement were developed under process, information sharing and relationship of the participants.

Procurement was identified as one of the main stages in the manufacturing process as it could cause delays to the production process. Therefore, the process of procurement considered forecasting materials and ordering materials. According to interview participants, they are using different systems and methods to forecast the material requirement such as enterprise resource planning (ERP), building information modelling (BIM), Monday.com and excel. To improve the integration of the procurement key process areas (KPA), assessment criteria of process in procurement was defined from ad-hoc ordering processes to integrated procurement process with production for accurate and reliable ordering of materials.

Lack of long and stable relationships with clients and suppliers is a challenge in forecasting demands and the procurement process, respectively. In the New Zealand construction industry, relationships with suppliers and clients are primarily short-term and are at arm's length. According to the findings of Ying et al. (2015), large scale organisations in New Zealand has started moving towards collaborative relationships while small-medium enterprises represent the majority. To rectify this, agreements and contracts were found to be a solution in the early '90s (Saad et al., 2002). However, this was superseded with the emergence of "partnering" as agreements and contracts appeared with more complications (Saad et al., 2002). Therefore, considering that, assessment criteria for contractual relationship in procurement was defined from arms-length relationship to collaborative while working relationship was defined from project-specific to consolidation of companies.

Sharing information on material requirements and delivery schedules between the suppliers; communicating information required for material forecasting; and on material deliveries across the internal supply chain was considered in procurement KPA. According to the P-11 participant, material requirements are analysed based on the production requirement and inventory levels and make orders considering the storage capacity. As the New Zealand construction industry is comparatively less automated (Masood et al., 2016), efficiency in the procurement process is relatively low. Therefore, assessment criteria for information sharing were developed from delayed information sharing to real-time information sharing across the whole supply chain, including interfaces.

5.2.3.4 Production

For production of the modules, panels are considered under this key process area, and assessment criteria were developed for the process, relationship and information sharing.

Process of production focused on operations of the production function, including planning and manufacturing, and real-time performance monitoring. Most of the manufacturing processes in New Zealand are semi-automated and require skilled and unskilled manpower to work in the manufacturing facilities. Semi-structured interview findings suggest that real-time performance monitoring and analysing is seldom practised in module manufacturing companies (10 out of 12 participants). Even though there are systems available for performance monitoring, companies hesitate to invest money and time on this as most companies are SMEs. Therefore, considering this assessment criteria for process improvement in production were defined.

The working relationship between the production team participants was considered under the relationship in production KPA. Therefore, assessment criteria were developed from adversarial relationship to adaptive relationship.

Information sharing in production focused on sharing production information schedules, design changes, performance monitoring, analysis and feedbacks across the supply chain process. All the participants highlighted the importance of having "*a standard platform for communication"* (P-10) to improve the coordination of the manufacturing process. In addition, having an integrated network to share information through the whole supply chain, including suppliers and clients, will be beneficial in sharing reliable and accurate information (Lessing, 2015). Assessment criteria for information sharing, therefore, developed from little information sharing to real-time information sharing.

5.2.3.5 Transportation

Transportation in this proposed maturity level was defined as loading, unloading, storing, and delivery of the manufactured products to the site. Assessment criteria for the transportation key process area were developed under process, relationship and information sharing as described below.

The process of transportation of manufactured modules is transporting using different methods due to the geography of New Zealand. Established manufacturers use their own trucks, machinery and manpower to deliver the completed modules to the site. Outsourcing the delivery of products is another of the methods currently used in New Zealand (P-05), specifically, when they deliver products from North Island to South Island or vice versa. Therefore, considering this, the process in transportation was developed from an undefined process to a defined and integrated process with the manufacturing supply chain.

The working relationship between the transportation team with the main supply chain was considered under the relationship in transportation KPA. Therefore, assessment criteria were developed from adversarial relationship to adaptive relationship.

Information sharing between the transportation team with the main supply chain were considered under the relationship in transportation KPA. Therefore, assessment criteria were developed from seldom exchange information sharing to real-time information sharing.

5.2.3.6 On-site assembly

Assembly of the manufactured modules or panels on site was considered. Assessment criteria for the on-site assembly key process area was developed under process, relationship and information sharing as described below.

Process of on-site assembly key process area is another vital stage as the environment is entirely different. According to the interviews, the supply chain in the manufacturing plant is not integrated with the main building supply chain on-site (Meng, 2020). Therefore, delays and disruptions are inevitable in most situations. Furthermore, there could be problem fixing due to dimension errors. Therefore, assessment criteria for process in on-site assembly was developed from an undefined process of installation to a defined process and integrated SCs.

Working relationships between the on-site assembly team with the leading supply chain were considered under the relationship in on-site assembly KPA. Therefore, assessment criteria were developed from adversarial relationship to adaptive relationship.

Information sharing between the on-site assembly team with the main supply chain was considered under the relationship in on-site assembly KPA. Therefore, assessment criteria were developed from hardly exchange information sharing to real-time information sharing.

5.2.4 Proposed Maturity Model

The proposed maturity model is presented in a matrix format. In the following, supply chain practices established to assess each key process area are discussed. This is for each maturity level based on the enablers for supply chain integration identified and suggested in the literature review and semi-structured interviews.

5.2.4.1 Idea and design

At the ad-hoc level, the initial design development process is not collaborative. Little information is exchanged openly or in a timely manner. The manufacturer withholds or manipulates the information on pre-designed models. Therefore, the relationship build-up with the client will be a project-specific arms-length relationship.

Limited cooperation between the client and the manufacturer can be seen at the segmented level with much information sharing. Based on the design information and the client's requirements, the design is developed as two-dimensional computer aid designing (2D CAD) drawings. So, at this level, technology is used to develop the design.

At the coordinated level, some degree of collaboration happens between the client and the manufacturer. Part of the supply chain is integrated to achieve the mutual objectives of the project. A short-term agreement is formed to have a trustworthy and transparent relationship with clients for future work. Real-time information is shared across the company. However, client interfaces are not included in the supply chain network.

The designing step proceeds with getting ideas from the client and advice from the supplier. The manufacturer extends the relationship with the most frequent clients into long-term fixed agreements. Design specific information is openly shared across the whole supply chain, including interfaces. Revit, ArchiCAD and Navisworks are a few BIM supported software used at this level to integrate design and information sharing.

At the value network level, manufacturing organisations move into innovative designing. Frequent clients are approached and decide to merge or acquire businesses. BIM integrated designing with real-time information sharing across the supply chain.

Table 5.2: Inception and design KPA

KPA	Assessment criteria	Ad-hoc	Segmented	Coordinated	Integrated	Value Network
Inception & Design (Kwak & Ibbs, 2002; Jørgensen & Emmitt, 2009; Meng et al., 2011; Vaidyanathan & Howell, 2007; Arif et al., 2017)	Process	Manual and standardised designing	Consider clients requirements 2D CAD drawings printed in papers	Collaborative designing with the client,3D CAD/BIM drawings printed in papers	Collaborative designing with the client and involved suppliers for more ideas, 3D BIM modelling streamed on mobile devices	BIM integrated designing
	Relationship with clients	Project-specific and relationships	Limited cooperation of the client in designing	Short-term agreements with clients	Long-term and fixed agreements with client	Mergers or acquisitions with clients
	Information Sharing	Little information sharing on design requirements	Design information is shared between the client and designer/draftsman	Some information is shared across the org.	Open information sharing across the org. and interfaces	Real-time information sharing

5.2.3.2 Planning

Planning at the ad-hoc level of a company is ill-defined and unstructured. Schedules are prepared daily to complete the jobs at hand, creating more chances of missing deadlines. The relationship between the parties is confrontational, and therefore leads to less functional cooperation. Prepared schedules are not openly shared even across the planning division.

At the segmented level, plans and schedules are prepared based on projects. Targets are defined but still missed more often than not. A limited degree of cooperation appears between the parties within the planning division. Schedules are openly shared across the division.

Planning is more structured, and schedules prepared for the projects at hand. Schedules are openly and accurately shared across the organisation. At this level, the planning division makes an effort to communicate schedule changes instantaneously among the relevant parties. Parties collaboratively work to achieve a common goal in the project, and if things go wrong, collaborative effort will be taken to find a cost-effective solution.

Synchronisation of planning and scheduling at the integrated level is extended to the client and supplier interfaces. Therefore, the organisation consider schedules and plans of the external interfaces when preparing schedules. The planning function is integrated across the whole organisation, including external interfaces to share real-time information on existing schedules and changes for existing schedules. Parties, including clients and suppliers, closely work together to achieve a common goal for the manufacturing organisation.

The planning function is synchronised with other functions at the value network level to facilitate a smooth supply chain flow. Real-time analysis on planning functions is used to make improvements in terms of process, people and technology. Information is shared accurately and on time using integrated systems like BIM, synchrono and Monday.com.

Table 5.3: Planning KPA

KPA	Assessment criteria	Ad-hoc	Segmented	Coordinated	Integrated	Value Network

Planning (Jia et al., 2011; Kwak & Ibbs, 2002; Meng et al., 2011; Arif et al., 2017)	Process	Daily basis planning and scheduling	Project basis planning and scheduling	Production planning and scheduling for the jobs in-hand	Integrated planning and scheduling	Continuous improvement through real time analysis
	Relationship	Confrontation/ arm's length	Limited Cooperation	Collaborative	Close Collaboration	Adoptive collaboration
	Information Sharing	Schedules are not openly shared across the org.	Information is shared across the planning division	Some information is shared across the org.	Open information sharing across the org. and interfaces	Real-time information sharing

5.2.3.3 Procurement

At the ad-hoc level, the manufacturing organisation has not defined their procurement process. Materials are obtained from different suppliers at different times. The relationship between supplier and manufacturer is on a project basis or one time only. Material requirements are informed when the requirement arises, and inventory information is not openly shared across the organisation.

Material requirements are identified on a project basis as the organisation maintains a database for inventory management (Microsoft Excel). Inventory and material requirements are openly shared across the functional division. Supplier is informed on material requirements openly and accurately.

Procurement at the coordinated level is well organised. Material requirements based on the project at hand are considered and process procurement based on materials at the manufacturing premises and the availability of storage facility. Supplier and manufacturer maintain a good relationship and form short-term agreements.

At the integrated level, supplier interfaces are integrated with the organisations' supply chain process. The relationship with suppliers extended and formed into long-term fixed agreements in order to have a continuous flow of materials. Information on inventory requirements and available materials is openly shared across the supply chain, including supplier interfaces. Systems and software are used to monitor material usage and to order material without delays and disruptions to manufacturing.

Manufacturing organisations expand merging or acquiring supplier organisations at the value network level. Procurement and manufacturing are integrated and automated, connecting supplier interfaces. In addition, real-time information sharing is facilitated by integrating inventory management tools/software.

Table 5.4: Procurement KPA

KPA	Assessment criteria	Ad-hoc	Segmented	Coordinated	Integrated	Value Network
Procurement (Kwak & Ibbs, 2002; Meng et al., 2011; Khalfan & McDermott, 2006; Arif et al., 2017)	Process	Chaotic processes and ad-hoc ordering	Project specific procurement (Kwak & Ibbs, 2002)	Plan and order for the projects in hand (Kwak & Ibbs, 2002)	Integrated with the supplier interfaces for automated ordering (Kwak & Ibbs, 2002)	Integrated with the production for automated ordering (Kwak & Ibbs, 2002)
	Relationship	Project specific	Limited cooperation with the suppliers	Short-term agreements with the suppliers	Long-term and fixed agreements with suppliers	Mergers or acquisitions
	Information Sharing	Material requirements are informed on ad-hoc basis	Functional level information sharing on inventory requirements	Material requirements are shared based on the production	Inventory requirements are openly shared across the org. and interfaces	Real-time information sharing

5.2.3.4 Production

At the ad-hoc level, production processes and procedures are vague and unstructured. Process measures are not in place. Production performance is low and uncertain, and because of this, project deadlines are repeatedly unaccomplished. The chaotic nature of the relationship between participants of the production team often interferes with the alignments of the procedures in the production function. Production information is not openly visible across the functional division.

At the segmented level, procedures and processes are defined and documented at the functional level. The production process is monitored, and hence the flow is more foreseeable. Participants relationship is trustworthy and limited cooperation of the parties is there. Production information is openly shared across the division.

Processes and procedures are well-defined and measured formally and regularly. Process performance, therefore becomes more predictable and cooperation between intra-organisation participants forms a collaborative environment that structures the production function to achieve the targets. Continuous improvement efforts take shape focused on root cause elimination and performance improvements. At the coordinated level, production information is openly and accurately shared across the organisation.

At the integrated level, SCM measures and management systems for production are deeply embedded in the organisation. Process performance becomes very predictable using formal and regular measures that are analysed for future improvements. Therefore, the goals of the organisation are reliably achieved. Information related to production is openly shared across the organisation, including its supplier and client interfaces.

Production is automated and synthesised into an integrated system operated using an information communication system at the value network level. Real-time performance analysis predicts future production and creates innovation in continuity in the production. The supply chain participants, including external interfaces, build a solid and resilient relationship based on trust, self-awareness, and reliable decision making. This strong relationship generates capability in flexible and innovative decision-making to adapt to change.

Table 5.5: Production KPA

KPA	Assessment criteria	Ad-hoc	Segmented	Coordinated	Integrated	Value Network

Production (Kwak & Ibbs, 2002; Vaidyanathan & Howell, 2007; Meng et al., 2011; Jørgensen & Emmitt, 2009; Arif et al., 2017)	Process	Discrete processes, No performance measures	Processes are documented and monitored at a functional level	Defined processes. Regular and formal measures for monitoring the production process	Regular and formal measures, Feedbacks and analysis for future work	Innovation based on real-time performance analysis
	Relationship	Confrontation/ arm's length	Limited cooperation	Collaborative	Close Collaboration	Adaptive collaboration
	Information Sharing	Little information is exchanged	Production information is shared across the production division	Production information is shared across the org.	Open information sharing across the org. and interfaces	Real time information sharing

5.2.3.5 Transportation

At the ad-hoc level, the transportation process and procedures for loading, unloading, storing and delivery are not defined. Decisions on the mode of delivery and delivery schedules are constantly changing, and therefore, delays and cost overruns are inevitable. The relationship between the delivery team participants and the connection between the delivery team and the in-house supply chain is adversarial and distinct. Delivery is most often outsourced. Therefore, information about the delivery phase is seldom available to the in-house supply chain.

Project-specific delivery procedures are defined and documented at the segmented level. A limited degree of cooperation appears between the delivery team participants and the connection between the delivery team and the in-house supply chain. Delivery schedules are shared between the delivery team. Delivery targets are set to achieve.

At the coordinated level, defined and documented delivery processes are put in place and followed. Delivery team participants work closely to achieve delivery targets. Delivery information is often shared in the in-house supply chain.

Manufacturers prepare delivery procedures, processes including schedules, together with the client. Therefore, the client's project schedules are shared and acknowledged at the integrated level. Relationships are collaborative and continue to grow. Delivery schedules and real-time delivery performances are openly shared across the organisation and to the client interfaces.

The delivery process is integrated with the whole supply chain via ITC systems to achieve targets at the value network level. Based on the performance analysis, the delivery function is continuously improved. Real-time information is shared across the whole supply chain. Adaptive collaboration is practised to adapt to changing cultures.

Table 5.6: Transportation KPA

KPA	Assessment criteria	Ad-hoc	Segmented	Coordinated	Integrated	Value Network
Transportation (Tetik et al., 2022; Handfield & Straight, 2004; Meng et al., 201; Arif et al., 2017)	Process	Processes and procedures for loading, unloading, storing and model of delivery are not defined	Documented processes and procedures	Defined processes and procedures	Delivery schedules are made with close collaboration of the two parties	Integrated process with business process across the enterprises
	Relationship	Adversarial	Limited cooperation	Collaborative	Close Collaboration	Adaptive collaboration
	Information Sharing	Information on delivery and schedules are seldom	Project-specific delivery schedules are exchanged	Open information sharing on delivery schedules	Logistics information is openly shared across the org. and interfaces	Real-time information sharing

		exchange d				

5.2.3.6 On-site assembly

At the ad-hoc level, on-site assembly is carried out manually. Most of the processes in on-site assembly are unstructured and ill-defined. Relationships between participants are adversarial, and therefore, problems are inevitable during the on-site installation. Installation information is not openly shared.

On-site installation process is defined and structured. However, the defined processes are not frequently followed. A limited corporation is visible at the segmented level to achieve the targets. Installation information is openly shared among the installation team but not communicated to the in-house supply chain.

At the coordinated level, defined and the team members follow documented processes to achieve targets. Installation information, including delays and defects, are promptly informed and shared across the supply chain. The installation team work collaboratively.

The installation process is fully automated, and performance is monitored using real-time performance indicators at the integrated level. On-site assembly information is openly and accurately shared across the whole supply chain, including client interfaces. Clients' projects schedules are shared and incorporated in the manufacturers' on-site installation schedule. Supply chain participants work close collaboratively.

The on-site assembly process is integrated with the whole supply chain via ICT systems to achieve targets at the value network level. Based on the performance analysis, the module installation function is continuously improved. Real-time information is shared across the whole supply chain. Adaptive collaboration is practised to adapt to changing cultures.

Table 5.7: On-site assembly KPA

KPA	**Assessment criteria**	**Ad-hoc**	**Segmented**	**Coordinated**	**Integrated**	**Value Network**

On-site assembly (Meng et al., 2011; Kwak & Ibbs, 2002; Vaidyanathan & Howell, 2007; Arif et al., 2017)	Process	Un defined and less automated	Documented processes and procedures, less automated	Defined processes and procedures	Automated processes with real-time performance monitoring	Integrated process with business process across the enterprises
	Relationship with clients	No Collaboration	Limited cooperation	Collaborative	Close Collaboration	Adaptive collaboration
	Information Sharing	Little information is exchanged on on-site installation	Installation schedules and procedures are shared with the client	On-site assembly information is shared openly	On-site assembly information is shared openly	Real-time information sharing

5.3 Maturity model for residential module and panel manufacturing

After categorising the supply chain practices to improve the integration, the following model was developed. Based on the following model current performance level of the module manufacturing companies can be benchmarked and based on their benchmark goals, can be proposed to improve the supply chain integration.

Table 5.8: Proposed maturity model to improve supply chain integration in module and panel manufacturing

Process	Assessment criteria	I-Ad-hoc	II-Segmented	III-Coordinated	IV-Integrated	V-Value Network
K_1 -Inception & Design	**A_1 -Process**	**K_1A_1I-** Standardised designing	**K_1A_1II-** Consider clients requirements	**K_1A_1III-** Collaborative designing with the client	**K_1A_1IV-** Collaborative designing with the client and suppliers	**K_1A_1V-** Innovative designing
	A_2 - Relationship	**K_1A_2I-** Project specific relationships	**K_1A_2II-** Limited cooperation of the client in designing	**K_1A_2III-** Short-term agreements with clients	**K_1A_2IV-** Long-term and fixed agreements with client	**K_1A_2V-** Mergers or acquisitions with clients

	A_3 - Information	**K_1A_3I-** Little information sharing on design requirements	**K_1A_3II-** Design information is shared between the client and designer/draftsman	**K_1A_3III-** Some information is shared across the org.	**K_1A_3IV-** Open information sharing across the org. and interfaces	**K_1A_3V-** Real-time information sharing
K_2 -Planning	**A_1 -Process**	**K_2A_1I-** Daily basis planning and scheduling	**K_2A_1II-**Project basis planning and scheduling	**K_2A_1III-** Production planning and scheduling for the jobs in-hand	**K_2A_1IV-** Integrated planning and scheduling	**K_2A_1V-** Continuous improvement through real time analysis
	A_2 - Relationship	**K_2A_2I-** Confrontation/ arm's length	**K_2A_2II-** Limited Cooperation	**K_2A_2III-** Collaborative	**K_2A_2IV-** Close Collaboration	**K_2A_2V-** Adoptive collaboration
	A_3 - Information	**K_2A_3I-** Schedules are not openly shared across the org.	**K_2A_3II-** Information is shared across the planning division	**K_2A_3III-** Some information is shared across the org.	**K_2A_3IV-** Open information sharing across the org. and interfaces	**K_2A_3V-** Real-time information sharing
K2 - Procurement	**A_1 -Process**	**K_3A_1I-** chaotic processes	**K_3A_1II-** Project specific procurement	**K_3A_1III-**order for the projects in hand	**K_3A_1IV-** integrated with the supplier interfaces for automated ordering	**K_3A_1V-** integrated with the production for automated ordering
	A_2 - Relationship	**K_3A_2I-** Project specific	**K_3A_2II-** Limited cooperation with the suppliers	**K_3A_2III-** Short-term agreements with the suppliers	**K_3A_2IV-** Long-term and fixed agreements with supplier	**K_3A_2V-** Mergers or acquisitions

	A_3 - Information	**K_3A_3I-** Material requirements are informed on ad-hoc basis	**K_3A_3II-** Functional level information sharing on inventory requirements	**K_3A_3III-** Material requirements are shared based on the production	**K_3A_3IV-** Inventory requirements are openly shared across the org. and interfaces	**K_3A_3V-** Real-time information sharing
K_4- Manufacturing	**A_1 -Process**	**K_4A_1I-** Discrete processes, No performance measures	**K_4A_1II-** Processes are documented and monitored at functional level	**K_4A_1III-** Defined processes. Regular and formal measures for monitoring the production process	**K_4A_1IV-** Regular and formal measures, Feedbacks and analysis for future work	**K_4A_1V-** Innovation based on real time performance analysis
	A_2 - Relationship	**K_4A_2I-** Confrontation/arm's length	**K_4A_2II-** Limited cooperation	**K_4A_2III-** Collaborative	**K_4A_2IV-** Close Collaboration	**K_4A_2V-** Adaptive collaboration
	A_3 - Information	**K_4A_3I-** Little information is exchanged	**K_4A_3II-** Production information is shared across the production division	**K_4A_3III-** Production information is shared across the org.	**K_4A_3IV-** Open information sharing across the org. and interfaces	**K_4A_3V-** Real time information sharing
K_5 - Transportation	**A_1 -Process**	**K_5A_1I-** Processes and procedures for loading, unloading, storing and model of delivery are not defined	**K_5A_1II-** Documented processes and procedures	**K_5A_1III-** Defined processes and procedures	**K_5A_1IV-** Delivery schedules are made with close collaboration of the two parties	**K_5A_1V-** Integrated process with business process across the enterprises
	A_2 - Relationship	**K_5A_2I-** Project specific	**K_5A_2II-** Limited cooperation	**K_5A_2III-** Collaborative	**K_5A_2IV-** Close Collaboration	**K_5A_2V-** Adaptive collaboration

	A_3 - Information	**K_5A_3I-** Information on delivery and schedules are hardly exchanged	**K_5A_3II-** Project specific delivery schedules are exchanged	**K_5A_3III-** Open information sharing on delivery schedules	**K_5A_3IV-** Logistics information is openly shared across the org. and interfaces	**K_5A_3V-** Real time information sharing
K_6- on-site assembly	**A_1 -Process**	**K_6A_1I-**Cranes and movers for lifting and installation, most of the work done manually	**K_6A_1II-** Documented processes and procedures	**K_6A_1III3-** Defined processes and procedures	**K_6A_1IV-** Automated processes with real-time performance monitoring	**K_6A_1V-** Integrated process with business process across the enterprises
	A_2 - Relationship	**K_6A_2I-**No Collaboration	**K_6A_2II-** Limited cooperation	**K_6A_2III-** Collaborative	**K_6A_2IV-** Close Collaboration	**K_6A_2V-** Adaptive collaboration
	A_3 - Information	**K_6A_3I-** Little information is exchanged on on-site installation	**K_6A_3II-** Installation schedules and procedures are shared with the client	**K_6A_3III-** Onsite-assembly information is shared openly	**K_6A_3IV-** Onsite-assembly information is shared openly	**K_6A_3V-** Real-time information sharing

5.4 Scope and limitations of the model

The research scope is limited to bathroom pods and wall pannel manufacturing used in New Zealand residential construction. The main aim of the study is to develop a model to benchmark and improve the supply chain in prefabricated residentail manufacturing. The supply chain of bathroom pods and wall pannel manufacturing is considered from initial inception and design stage to assembly on-site, including the stages' planning, manufacturing, transportation and assembling.

Prefabrication construction is classified into five types: component-based prefabrication, panelised prefabrication, modular prefabrication, whole building prefabrication, and hybrid prefabrication. Of these, panelised prefabrication is one of the most well-established and most common types of prefabrication in New Zealand (PrefabNZ, 2013, Burgess et al., 2013, Bell, 2009), while hybrid prefabrication is suitable for housing sector developments the same as for the other types of building construction (Langdon & Everest, 2004). This research has particularly explored the supply chains of panelised and module prefab manufacturing, specifically bathroom pods, module houses and wall-panel manufacturing.

The developed model focused only on internal SCs and therefore, external barriers like scale of the market, competition, regulations and market conditions are disregarded. The stages of the manufacturing process is a benchmark based on the sub-criteria; process, people and information sharing and technological platforms.

5.5 Summary

A maturity model was developed to benchmark current supply chain practices and achieve integration of the module manufacturing supply chain. The model was developed based on the principles of PRTM manufacturing maturity model. The proposed model consists of five maturity levels, six key process areas and three sub-criteria. Further, assessment criteria were developed for each key process area under the maturity levels to assess the current practice and improve integration. The proposed model is developed in order to identify the manufacturers' current maturity level of their supply chain and thereby improve the integration followed by criteria proposed in the subsequent maturity levels.

Once the model is developed, the next step is to test the maturity model. The developed maturity model was validated and tested through focus group interviews and three case studies. The process of validation and testing of the model is discussed in the next chapter.

CHAPTER SIX

BENCHMARKING SUPPLY CHAIN PRACTICES OF MODULE/PANEL MANUFACTURING IN NEW ZEALAND

6.1 Overview

The development of the maturity model was discussed in the previous chapter. Once the model is developed, it requires testing for validity. Therefore, to test the developed model, two focus group interviews and case studies were conducted. This chapter is an illustration of the testing process. In the first part of the chapter, the validation process through focus group interviews are discussed. Based on the analysis of the focus group interviews, amendments were made and presented in the chapter.

Three case studies were conducted to validate the construct of the model, then based on the findings, their current supply chain practices were benchmarked against the proposed model. The analysis of the case study findings is presented using radar chart diagrams at the end of the chapter, followed by a conclusion.

6.2 Testing of the model

Once the maturity model is developed, testing the validity of the model is required before real-life application (Bruin et al., 2005; Schumacher et al., 2016). According to Bruin et al. (2005), it is important to test both the construct of the model and the validity of the assessment instrument. Construct validity refers to ensuring the proposed model is theoretically sound and accurate. To achieve that, two focus group interviews were conducted. Analysis of the focus group interviews were discussed in the next section.

Testing the assessment instrument is important for assessing the validity of the measurement and the reliability of the results. Therefore, to test the validity and reliability of the assessment instrument, three case studies were conducted. Details of the case studies and analysis of the data collected from the case studies are discussed at the end of the section.

The following figure illustrates the steps of the testing phase (Figure 6.1).

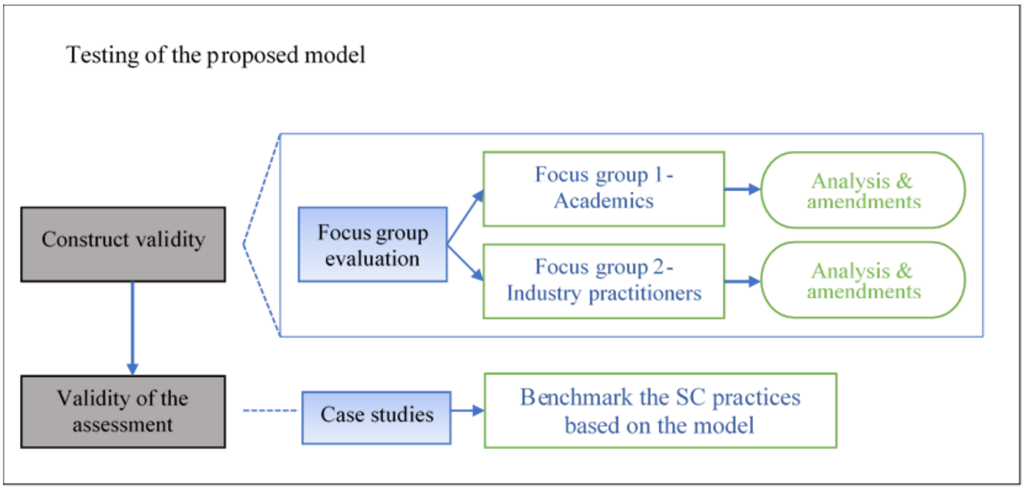

Figure 6.1: Testing process of the proposed model

6.3 Validation process of the model

As mentioned in the previous section, the developed maturity model was validated using focus group interviews. Two focus group interviews were used to validate the assessment instrument of the model. These two focus group interviews were conducted among academics and industry practitioners. The first focus group interview was conducted as a pilot interview among academics. The second focus group was conducted among industry practitioners and researchers. The following section discusses the details of the focus group interviews, including analysis of the data gathered and amendments made to the model accordingly.

6.3.1 Focus group 1

The first focus group interview was conducted among academic practitioners in the School of Built Environment at Massey University. Invitations for the interview were sent to all the lecturers in the school. However, only four lecturers participated due to a Covid 19 lockdown. The focus group interview was conducted via zoom platform.

During the focus group interview, a presentation on the model was delivered first. After the presentation, a discussion was conducted, and a questionnaire was shared to test the validity, reliability and generalisability of the proposed model. The questionnaire was developed using google forms and shared with participants before the focus group interview. The questions of were focused on the following themes, and it contained both open-ended questions and Likert scale questions.

- Structure of the model
- The complexity of the model
- Applicability of the model
- Implementation of the model
- Language and the clarity of the model

6.3.1.1 Profile of the participants

The demographic information of the pilot focus group interview participants is illustrated in Table 6.1 in terms of the position and years of experience in the academic field. All four participants have sound knowledge and experience in research and are actively engaging with the construction industry.

Table 6.1: Demographic data -focus group 1

Participant ID	Position	Years of experience
F1P1	Post-doctoral research fellow at Massey University	10 years
F1P2	Lecturer at Massey University	27 years
F1P3	Lecturer at Massey University	30 years
F1P4	Lecturer at Massey University	16 years

6.3.1.2 Findings from the focus group 1

The findings from focus group interview one is discussed under the aforementioned criteria. The opinions on the proposed model and amendments they suggested are presented as quotes where appropriate.

Structure of the model

To test the validity and reliability of the assessment instrument of proposed maturity model, a question on the comprehensibility of the maturity model was examined. According to the opinions of the participants, all agreed with the clarity of the model as a whole, (Figure 6.2). Furthermore, during the discussion, F1P4 participant suggested to "elaborate the meaning of supply chain in this research" to enable easy comprehension of the concept, even by a layperson.

The clarity of the content was questioned to seek the comprehensiveness of the terms and assessment criteria defined for the model. All participants agreed with the clarity of the content. Participants' opinions on the model's clarity and content are presented in Figure 6.2.

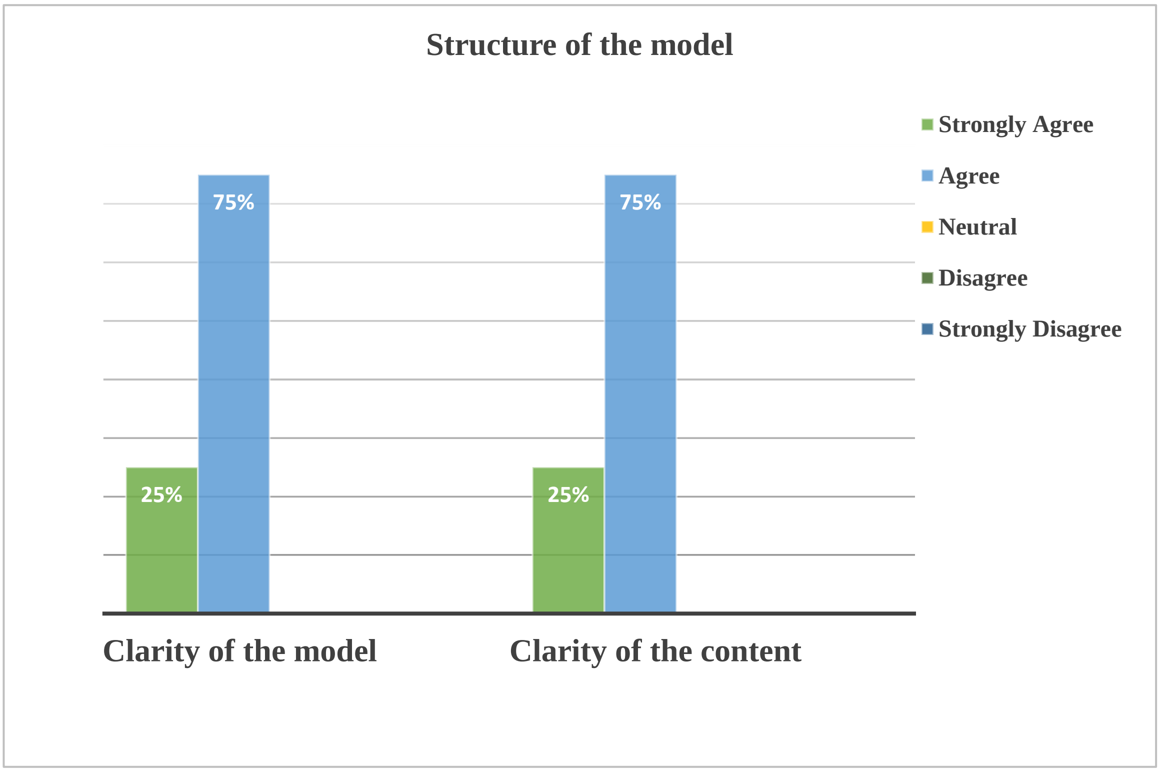

Figure 6.2: Participants' opinion on the structure of the model

The complexity of the model attributes

Participants were asked to scale the appropriateness and adequacy of the maturity levels developed for the model. According to the participants' opinions, all agreed with the adequacy of the maturity levels developed. Next, participants were questioned whether the model captures all the attributes of the assessment criteria. This question was asked to seek the comprehensiveness of the assessment criteria developed for the model. Two out of four participants agreed with this, while the rest scaled their opinion as neutral. Furthermore, one of the neutral participants highlighted to "widen the model to include other criteria like risk, and quality" (F1P1). Participants opinions on the adequacy of the maturity levels and comprehensiveness of the assessment criteria are presented in following figure 6.3.

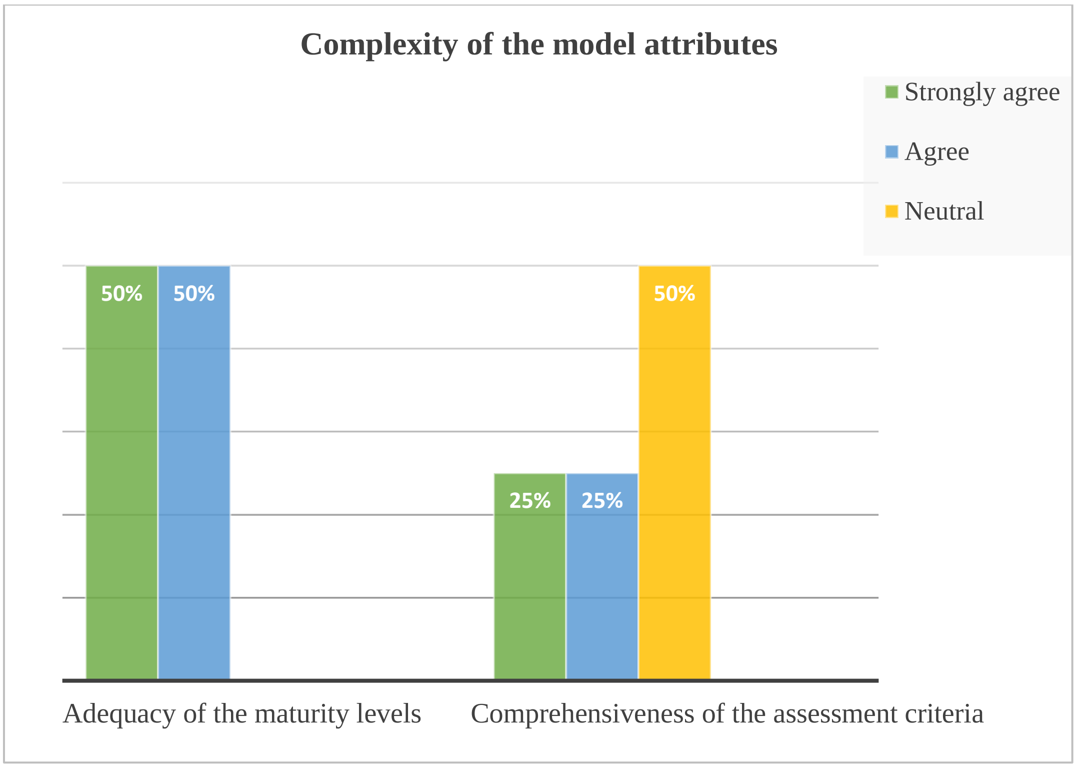

Figure 6.3: Participants opinions on the complexity of the model attributes

Implementation of the model

To investigate the applicability of the model in the industry, participants were asked to scale the user-friendliness of the model. All the participants agreed that the model is user-friendly. Moreover, chances of implementation of the model in the industry were questioned, and two participants were neutral with their opinion. The rest of the participants agreed with the model's applicability in the industry. Figure, 6.4 illustrates the opinions of the participants on the implementation of the model.

Further to their opinions, F1P3 participants commented that "validation through actual case studies will help to check the applicability of the model further". Even though the New Zealand productivity commission recommended focusing on improving the supply chains in construction (New Zealand Productivity Commission, 2016), there may be implementation issues as the New Zealand construction industry is resistant to changing its traditional ways (BRANZ, 2018).

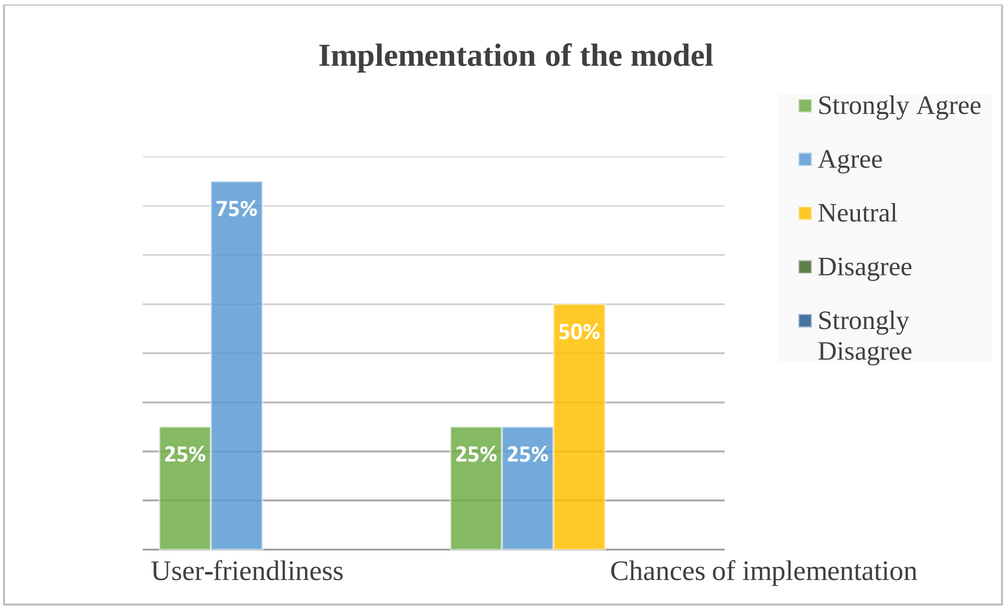

Figure 6.4: Participants' opinion on the implementation of the model

Improvements to the model

Participants were asked to suggest any improvements to the model. This question was developed as an open-ended question. All the participants have provided valuable responses to further develop the model. Based on their responses, most participants highlighted that it would be better to look into other prefabrication elements to apply this model (F1P1, F1P2 and F1P4). One of the participants further mentioned that applying the model, in reality, would make the model more reliable and accurate (F1P3). Furthermore, F1P2 participant recommended, "modifications that could be made to the model in other prefab contexts".

One participant made another suggestion for the assessment system to develop the model. F1P2 participant commented to "develop a scoring system apart from the radar chart". In this research, supply chain practices are proposed to benchmark and map using radar charts. Further, F1P2 suggested stating the limitations of the model.

F1P3 participant suggested "widen the model to include other criteria so that it can be more useful and more practically applicable in the New Zealand construction industry" and the amendments made based on this comment are discussed in the next section. Moreover, F1P1 commented -"show the problems in the supply chain and demonstrate the way model can solve these".

Responses and amendments made based on the participants' comments are listed in the following section.

6.3.1.3 Responses for the feedback received from focus group 1

The responses for the suggestions proposed by the participants of the focus group interview is presented as a table below.

Table 6.2: Responses for the suggestions/feedback received from focus group 1

Theme	Participant's suggestions	Response
Improvements to the model	Looking into other prefab elements to apply the model (F1P1, F1P2 & F1P4)	This is outside the scope of the research and further discussed in Chapter 7- Discussion
	State the application process (F1P4)	Three case studies were selected including a wall-panel manufacturer, wall-panel, bathroom pod manufacturer and a modular-houses manufacturer. So, with the time limitation, these three case studies provide a good evaluation of the model.
	Develop a scoring system apart from the radar chart (F1P2)	In this research, supply chain practices are proposed to benchmark and map using radar charts as it visually represents the current practice level based on the model so that any layperson can understand. Further, (Facchini, Oleśków-Szłapka, Ranieri, & Urbinati, 2020); Lessing (2015); (Netland & Alfnes, 2011) have used radar charts to represent the output of the maturity scores as it is an easy-to-read output.

	State the limitations of the model (F1P2)	Limitations of the model were discussed in Chapter 5 (See section 5.5)
	Illustrate the problems in the supply chain and demonstrate the way the model can solve these (F1P4)	Agreed and discussed under Chapter 7- Discussion
	Widen the model to include other criteria so that it can be more practical and more practically applicable in the New Zealand construction industry (F1P3)	This can be a future study

The feedback and suggestions received from the focus group participants are illustrated in the above table with the responses and actions made. Limitations of the model were highlighted in chapter five under scope and limitations of the model. This maturity model was developed based on wall panel manufacturing and bathroom pods manufacturing and can be adjusted to other prefabrication types with adjustments and it could be a further research. Relationship, information sharing, and process are the main criteria considered under the KPAs of the manufacturing process. The content of the model was not changed or amended after the focus group as all the suggestions received were regarding the implementation of the model and scope of the model.

The first focus group was conducted as a pilot discussion with the academics who are experts in the prefabrication and supply chain. The second focus group was initiated with the industry practitioners to gain their opinion on the model.

6.3.2 Focus group 2

The second focus group interview was conducted among prefabrication experts in New Zealand. Invitations for the interview were sent to all the members of OffsiteNZ, and only four members confirmed their participation due to Covid 19 lockdown in 2020. Focus group interview was conducted via zoom platform.

During the focus group interview, a presentation on the model was delivered first. After the presentation, a discussion continued based on the questions prepared to test the validity, reliability and generalisability of the proposed model. Questions were developed to test the validity of the model and shared with the participants before the focus group interview. Developed questions focused on the following themes.

- Structure of the model
- The complexity of the model
- Applicability of the model
- Implementation of the model
- Language and the clarity of the model

6.3.2.1 Profile of the participants

The demographic information of the participants of the second focus group interview is illustrated in Table 6.3 in terms of the position and years of experience in the construction industry. All four participants have sound knowledge as well as experience in research and are actively engaged with the construction industry research in New Zealand.

Table 6.3: Demographic data - focus group 2

Participant ID	Position	Years of experience in the industry
F2P1	Innovation consultant and an executive member of PrefabNZ	20 years
F2P2	An executive member of PrefabNZ	More than 10 years in NZ
F2P3	Researcher and a member of PrefabNZ	12 years
F2P4	Researcher and a member of PrefabNZ	10 years

6.3.2.2 Findings from the focus group 2

The responses made for the suggestions proposed by the participants of the focus group interview 2 is presented as a table below.

Table 6.4: Responses for the suggestions/feedback received from focus group 2

Theme	Participant's comments/suggestions	Response
1. Structure of the model	Illustration of the meaning of relationship and the diversification of relationship across the maturity stages (P-01)	Accepted and amended. In this maturity model, both the contractual relationship and working relationship are considered in the inception and design and procurement stages/KPAs and for the rest of the stages/KPAs, a working relationship is considered. The diversification of the relationship across the maturity levels are defined as follows. The terms Arm's length, Limited cooperation, Collaborative, Close collaboration and Adaptive collaboration is amended as 'Adversarial relationships' try to put on blame on others, no effort to joint problem solving, Limited Cooperation between the

		parties, and parties concentrate on defending their own work, Some degree of collaboration between the parties, joint effort is taken for problem solving, parties supporting each other, Maintain close collaboration over series of jobs, working together to achieve the long-term mutual goals, and Adaptive collaboration of the SC participants in dynamic and uncertain environment to deliver customer value respectively. Contractual relationship (only in the design and procurement stages) is diversified across the maturity stages as Project/job specific, Informal and trust based, Short-term agreements, Long-term and fixed agreements and Mergers or acquisitions between clients/suppliers. (See K_1A_2 K_2A_2, K_3A_2, K_4A_2 & K_5A_2 in Table 6.5)

	Early contractor involvement in the designing process. (P-03)	Yes, Early Contractor Involvement (ECI) was considered in defining the process criteria in the design KPA. In the inception and design stage clients' involvement and collaboration is considered as the builders' contribution in the designing. (See K_IA_1 in Table 6.5)
	Consideration of the type of project where restrictions apply for information sharing (P-03)	This model was developed considering the general SC of module manufacturing. Therefore, there can be a future research on the applicability of this model into different types of projects.
	Combining transportation and on-site assembly stages. (P-02)	Agreed and amended. Transportation and on-site assembly stages are combined and considered as a one key process area. (See K_5 in Table 6.5)

2. The complexity of the model	How does the framework compensate for regulations and the regulatory environment? (P-02)	This model is developed considering the internal SC of manufacturing companies. Each external factor are disregarded due to time constraints. Generally, in NZ, manufacturing companies are required to get their products before starting the business and therefore, a builder is responsible for getting the approvals from the authorities before starting the project. When a manufacturer gets a particular job, the regulations are already approved for the project.
	Consideration of risk in outsourcing for transportation of modules (P-04)	There would be the risk of outsourcing transportation. According to the case studies we conducted, one of them using their company-own transportation system while the other two companies are relying on outsourcing based on the relationship they continue. However, the risk is not considered as it is within the scope of this study.

	Addressing connectivity issues in the installation of the modules (P-04)	Generally, companies take on-site measurements before design the final drawings. But if the manufacturers come across any installation issues due to the measurement changes, they rectify them under their cost. But rectification of issues was not considered in this model.
3. Applicability of the model	Evaluating the framework by real case studies. (P-01)	As the next step of this study, three companies are selected to conduct case studies including a wall-panel manufacturer, wall-panel, bathroom pod manufacturer and a modular-houses manufacturer. So, with the time limitation, these three case studies will provide a good evaluation of the model.
	Limited applicability due to the scale of the industry (P-02)	This model was developed considering the general SC of module manufacturing. Therefore, there can be future research on the applicability of this model to different types of projects.
4. Implementation of the model	Validation and testing through actual case studies (P-03), (P-01)	As the next step of this study, three companies are selected to conduct case

		studies including a wall-panel manufacturer, wall-panel, bathroom pod manufacturer and a modular-houses manufacturer
5. Language and clarity of the model	Repetitive and similar words. (P-03)	Accepted and Amended the wordings of the model and the following section highlights those amendments.

6.3.2.3 Amendments made after focus group 2

Alterations were made to the proposed model based on the suggestions and modifications proposed by the participants. The following is the altered model. As the participants suggested the clarity of the words was addressed by defining the words and repetitions of the words specifically, the term relationship was addressed by diversifying the maturity of the relationship level by level. Each individual maturity level criteria were rephrased to elaborate the meaning and purpose. Furthermore, terminology was developed to define the terms used in the maturity model (Table 6.6).

Table 6.5: Proposed model after validation

Process	Assessment criteria	I-Ad-hoc	II-Segmented	III-Coordinated	IV-Integrated	V-Value Network
K_1 -Inception & Design	**A_1 -Process**	**K_1A_1I-** Choose from standardised designs Drawings on paper	**K_1A_1II-**Develop design considering client's requirements 2D CAD drawings printed on paper	**K_1A_1III-** Collective designing between client/builder and designer 3D CAD/BIM drawings printed on paper	**K_1A_1IV-** Collective designing with the interfaces through an integrated platform 3D BIM modelling streamed on mobile devices	**K_1A_1V-** Innovative designing integrated with BIM
	A_2 -People	**K_1A_2I-** Project/job specific and adversarial	**K_1A_2II-** Informal and trust based and develop design with a limited cooperation between the parties	**K_1A_2III-** Short-term agreements, and Client and the manufacturer share their ideas openly and in a timely manner and develop the design	**K_1A_2IV-** Long-term and fixed agreements with the clients, maintain close collaboration over series of jobs, working together to achieve the long-term mutual goals	**K_1A_2V-** Mergers or acquisitions between client companies, Adaptive collaboration between client and manufacturer in designing

	A_3 -Information	**K_1A_3I-** Client's requirement is disclosed to a responsible party and design information is not available across the function/division, only accessible to the designer	**K_1A_3II-** Design information is available across the function/division	**K_1A_3III-** Collaboratively, design information is shared across the org.	**K_1A_3IV-** Real time design information is shared across the whole supply chain connecting the client, supplier interfaces	**K_1A_3V-** Common platform for information sharing along the supply chain to develop the design.
K_2 -Planning	**A_1 -Process**	**K_2A_1I-** Plans and schedules are made on daily basis manually	**K_2A_1II-** Plans and schedules are made on project basis Use of excel sheets for production scheduling	**K_2A_1III-** Production planning and scheduling for the jobs in-hand Use of software for production scheduling such as Ms project /ERP for production scheduling	**K_2A_1IV-** Use an integrated system for production scheduling and real time measuring Use of a common software for production scheduling and performance monitoring	**K_2A_1V-** Integrated system for production scheduling and information sharing and Continuous improvement through real time analysis
	A_2 -People	**K_2A_2I-** Adversarial relationships try to put on blame for	**K_2A_2II-** Limited Cooperation between the parties, and	**K_2A_2III-** Some degree of collaboration between the	**K_2A_2IV-** Maintain close collaboration over series of jobs,	**K_2A_2V-** Adaptive collaboration of the SC participants in

		others, no effort at joint problem solving	parties concentrate on defending their own work	parties, joint effort is taken for problem solving, parties supporting each other	working together to achieve the long-term mutual goals	dynamic and uncertain environment to deliver customer value
	A_3 -Information	**K_2A_3I-** Production schedules are not openly exchanged, relevant parties are informed, relevant information within the function	**K_2A_3II-** Production schedules are openly shared among the production team	**K_2A_3III-** Production schedules are openly shared across the internal supply chain, changes to the schedules only informed to the relevant parties	**K_2A_3IV-** Production schedules are openly shared across the whole supply chain, changes are informed openly	**K_2A_3V-** Real time information sharing of the production schedules through the value chain
K2 - Procurement	**A_1 -Process**	**K_3A_1I-** No inventory management systems, orders made on ad-hoc basis Manual inventory planning	**K_3A_1II-** Project specific inventory management systems A database for inventory management through excel files	**K_3A_1III-** A proper and advanced inventory management system Resources planning tools are used within the company (like ERP, industry 4.0)	**K_3A_1IV-** Use an integrated system linked with the performance to forecast the material requirement Resources planning tools are used together with the supply chain planning	**K_3A_1V-** Continuous improvement on inventory management based on the performance and integrated with production and planning

	A_2 -People	**K_3A_2I-** Project specific relationship and adversarial	**K_3A_2II-** Informal basis, suppliers are selected based on experience and trust, Limited cooperation between the parties	**K_3A_2III-** Short-term agreements with suppliers, some degree of collaboration between the parties, joint effort is taken for problem solving, parties supporting each other	**K_3A_2IV-** Long-term and fixed agreements, maintain close collaboration over series of jobs, working together to achieve the long-term mutual goals	**K_3A_2V-** Mergers or acquisitions, Adaptive collaboration of the SC participants in dynamic and uncertain environment to deliver customer value
	A_3 -Information	**K_3A_3I-** Material requirements are informed on ad-hoc basis	**K_3A_3II-** Material requirements are informed based on project basis	**K_3A_3III-** Material requirements are shared based on the projects in hand	**K_3A_3IV-** Production performance and inventory requirements are openly shared among the suppliers	**K_3A_3V-** Real time information sharing for continuous supply forecast
K_4- Manufacturing	**A_1 -Process**	**K_4A_1I-** Discrete processes. Production is not carried according to the schedules. Performance is not measured production is carried out based	**K_4A_1II-** Processes are documented production is carried according to the schedules, but the schedules are project	**K_4A_1III-** Defined processes, Continuous production process according to the schedules. Regular and	**K_4A_1IV-** Continuous production process according to the schedules. Regular and formal measures, Feedback and	**K_4A_1V-** Continuous improvement based on real time performance analysis Fully automated system integrated

		on the instructions from the management Limited number of machines are used with the manpower	specific. Performance is measured but not formally and regularly Somewhat automated and workers are used for minor works and to operate machinery	formal measures and feedbacks Automated and limited number of workers to operate the machinery	analysis for future work Fully Automated and integrated with the performance measurement	with the whole supply chain
	A_2 -People	**K_4A_2I-** Adversarial relationships try to put blame on others, no effort at joint problem solving	**K_4A_2II-** Limited Cooperation between the parties, and parties concentrate on defending their own work	**K_4A_2III-** Some degree of collaboration between the parties, joint effort is taken for problem solving, parties supporting each other	**K_4A_2IV-** Maintain close collaboration over series of jobs, working together to achieve the long-term mutual goals	**K_4A_2V-** Adaptive collaboration of the production team to deliver customer value
	A_3 -Information	**K_4A_3I-** Schedules are not openly exchanged, relevant parties are informed, relevant information within the division	**K_4A_3II-** Production schedules are openly shared among the production team	**K_4A_3III-** Production schedules are openly shared across the internal supply chain, changes to the schedules only	**K_4A_3IV-** Production schedules are openly shared across the whole supply chain, changes are informed openly	**K_4A_3V-** Real time information sharing of the production schedules

				informed to the relevant parties		
K_5 - Transportation & on-site assembly	**A_1 -Process**	**K_5A_1I-** Processes and procedures for loading, unloading, storing, and of delivery are not defined. Delivery is outsourced and builder (client) is responsible for installation Cranes and movers for lifting and installation, most of the work done manually	**K_5A_1II-** Documented processes and procedures Automated for lifting and moving, installation is manual	**K_5A_1III-** Defined processes and procedures Partially automated, lifting and installation done separately	**K_5A_1IV-** Delivery schedules are made with close collaboration of the two parties Fully automated system for lifting and installation	**K_5A_1V-** Integrated process with business process across the enterprises Fully automated installation and linked with whole supply chain
	A_2 -People	**K_5A_2I-** Project specific/outsourcing	**K_5A_2II-** Limited Cooperation between the parties, and parties concentrate on defending their own work	**K_5A_2III-** Some degree of collaboration between the parties, joint effort is taken for problem solving, parties supporting each other	**K_5A_2IV-** Maintain close collaboration over series of jobs, working together to achieve the long-term mutual goals	**K_5A_2V-** Adaptive collaboration of the production team to deliver customer value

	A_3 -Information	**K_5A_3I-** Information is not openly exchanged, relevant parties are informed, relevant information within the division	**K_5A_3II-** Information is openly shared among the production team	**K_5A_3III-** Information is openly shared across the internal supply chain, changes to the schedules only informed to the relevant parties	**K_5A_3IV-** Information is openly shared across the whole supply chain, changes are informed openly	**K_5A_3V-** Real time information sharing on transportation and installation

Table 6.6: Terminology

Terminology	
Inception & design	Understanding the project scope and clients'/builders' requirements and develop/provide a design and improve the developed design into shop drawings
Planning	Make schedules assigning tasks, dates/times and resources to achieve the objectives of a project/projects
Procurement	Forecasting the material requirement, selection of suppliers and ordering the materials
Manufacturing	Production of the wall panels/bathroom pods/modular homes
Transportation & on-site assembly	Includes loading, unloading, storing, and of delivery of the finished products to the site and installation
Ad hoc	Unstructured and ill-defined processes and procedures. Organisational roles and responsibilities are not well defined. Partnerships with suppliers, clients and other skills outsourced are not formally enforced
Segmented	Processes, procedures, organisational roles and responsibilities are defined. However, processes and functions are still isolated, and there is little effort to integrate the processes within the functions (departments). Partnerships with suppliers, clients and other skills outsourced are not well defined. Data and information is shared electronically within the departments with limited access
Coordinated	Organisation-wide processes and procedures are well defined and standardised. The processes and the activities are adequately measured. Supplier and client partnerships are well defined. Process specific information is collected and shared electronically within the organisation. The actions are taken to integrate the internal processes.
Integrated	Strategic suppliers and clients are identified, supply chain practices are extended to both of their interfaces. Processes are measured, and performance is analysed for improvements. Information technology is used to integrate business functions, and real-time information is visible across the value chain. Information is collected and shared electronically among the

	participants of the value chain, including clients and suppliers.
Value network	Continuous process improvement through feedback and innovative technologies. Real-time information is effectively visible across the value chain. Information technology automates the integration of business processes across enterprises.
Process	Procedure and actions taken to complete the stage/step
People	Working relationship with the participants of the Supply chain. If any external party is involved working relationship and contractual relationship are considered
Information	Sharing information, the participants of the supply chain and information channels
Adaptive collaboration	Capability of team work in the changing environment/situation

6.4 Benchmarking current SC practices

After validating the assessment instrument of the proposed model, three case studies were conducted to test the construct validity. Data was collected through semi-structured interviews and based on the collected data and current supply chain practices of the companies were benchmarked against the proposed model. The analysis of the case studies is discussed in the next section, comparing the companies' current positions on the model.

6.4.1 Benchmarking the current supply chain practices

Three case studies were conducted to benchmark the supply chain practices based on the developed model. A background description of the selected cases is discussed below.

6.4.1.1 Case A

This company was established more than 25 years ago, then in 2017 the company was restructured with new ownership. In total, the company consists of 25 employees, including 10 permanent and 10-15 casual workers (Figure 6.5).

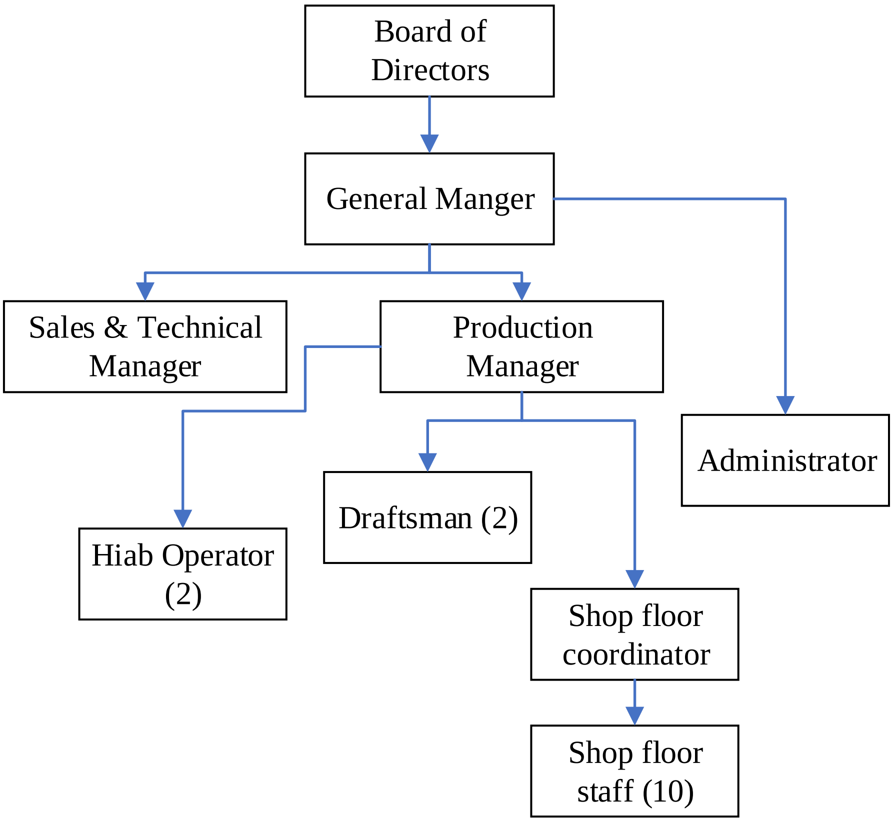

Figure 6.5: Organisational structure of Case A

The company's business is the production of re-manufactured walls and ceiling panels for large and small projects, including houses, schools, retirement villages and medical facilities. Case A contributes to achieving productivity and efficiency in the construction industry with the benefits of faster construction, increased floor space, and durability. Using this system, the company can produce on average a 180 m^2 single storey house in four to six weeks. Generally, the company completes about 300 houses per year, most applying a make-to-order production strategy.

Client companies/developers, builders and prefab house building manufacturers are the business's customers, and the company has no obligations to the tenants or to do with any maintenance work after the installation. To achieve customer satisfaction, they complete each job following the vision of "IFOTIS- In Full On Time In Spec". The company is not process-oriented in any formal way, but projects follow a predefined path involving multiple activities. Most activities remain in-house except the transportation and on-site assembly. The company aims to expand the business by improving the client base to include new builders and new developers. They believe that their supply chain plays a vital role in increasing their capacity in terms of technology and relationships. The company finds it challenging to forecast the demand as it constantly changes due to the unpredictable nature of project approvals. However, they avoid delays during the production quite well. During unavoidable circumstances, the company minimise the effect on the client by maintaining a healthy relationship.

6.4.1.2 Case B

Case B was established six years ago in 2015 and owned by one of the leading construction companies in New Zealand. The company operates under a comprehensive ISO9001 Quality Assurance Program and is a recognised off-site manufacturer by most Councils throughout New Zealand. Currently, the company handles a workforce of 45 direct and 15 indirect employees.

To increase productivity and sophistication, the company incorporates the most innovative techniques and worldwide case studies. The company operates mainly in the residential housing market and the commercial housing market in New Zealand, providing prefabricated panels, roof and floor cassettes, and bathroom pods. In addition to that, the company delivers façade panels, trusses and volumetric units in timber and steel. Apart from production, the company offers value engineering, design, and structural expertise advice and guidance to their clients.

Using Laminated Veneer Lumber (LVL), Case B can manufacture panels for a standard 190 m2 residential house within a day. Installation of insulation, rap board, building paper, cavity battens and cladding, will take another two to three days. The company uses 90x45 mm size LVL timber to produce core framing timber for building construction. They deliver customised and project-specific bathroom pods and can complete a bathroom pod within 13 days.

The company maintains a design-led strategy to provide value for money for their clients. They believe this approach enhances efficiency and streamlines the production process to deliver dynamic and innovative buildings with improved economies of scale. The company's main problem is the limited supply of their primary lumber material. As one of the leading manufacturers in New Zealand, they may have to ramp up their capacity to supply the demand. However, supply constraints in timber delay their production flow. According to Case B, lack of understanding of the actual cost of quality is another supply chain issue they face while installing fittings and equipment in bathroom pods. Poor quality and lack of standards in fittings and equipment slows down the assembly process. To overcome this, Case B tends to import most of its fittings and equipment. Transportation of volumetric bathroom pods around New Zealand is another challenge they are experiencing currently. They have not defined and standardised their logistic process yet as they consider out other methods such as sea and rail freight to transport modules around New Zealand.

6.4.1.3 Case C

Case C company was founded 20 years ago in 2002 by the owner to solve the gap in organisations and individuals in the prefabricated market in New Zealand. The company mainly focuses on bathroom pods manufacturing for residential and commercial buildings. Even though Case C is established in the Auckland region, projects are carried out around New Zealand, including Wellington, Northland, and Napier.

To cater to clients' requirements, seventeen direct employees are currently working in the company. The company structure includes a general manager, operational manager, two production managers, and one sales manager as displayed in Figure 6.6. The company maintains a long-term stable partnership with their leading supplier of timber panels. Generally, 6 to 8 weeks are taken for the company to complete a bathroom, and the duration depends upon the materials used.

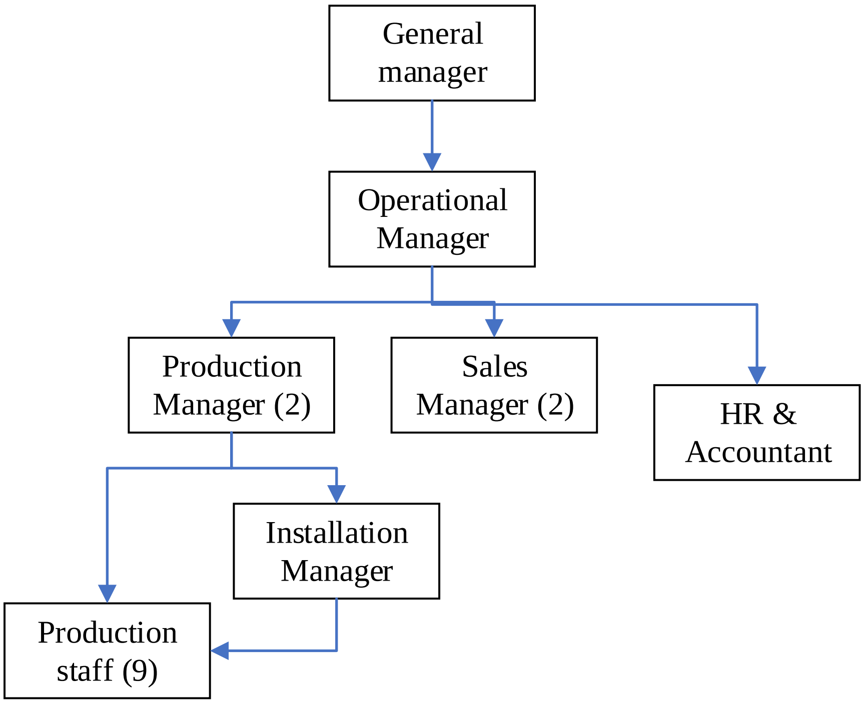

Figure 6.6: Organisation structure of Case C

As a manufacturing company, Case C is continuously trying to improve customer satisfaction and to achieve this, they frequently have meetings with their clients to ensure value for money. In addition to this, a higher degree of customisation in designing has created issues to the smooth flow of the supply chain.

6.4.2 Benchmark of supply chain practices against the maturity model

The current performance level of the case studies according to the proposed maturity model was benchmarked into radar charts as follows.

6.4.2.1 Inception and Design KPA

All three companies are applying a make-to-order production strategy. Current practices during inception and design stage of the companies were recorded as Figure 6.7. Case A and Case B have a predefined path to process the inception and design stages while Case B is performing at the ad-hoc level as the company is forming their "capacity agreements". Case A is currently maintaining a stable relationship with 50-80 clients based on trust. However, the company does not continue any contracts with their clients. This is similar to Case B and Case C, where these companies are maintaining quite cooperative non-contractual relationships with their clients. On the other hand, Case B and Case A are owned by construction companies and the mother companies, and their subsidiary companies are working under written contracts to supply the finished products for house building projects.

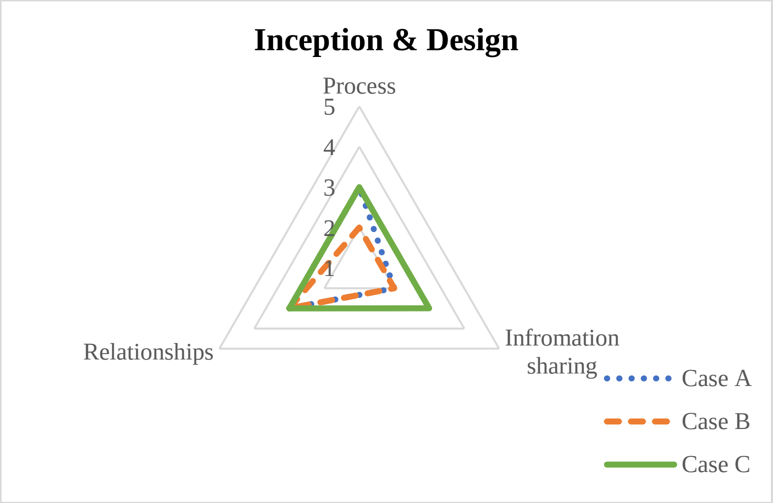

Figure 6.7: Inception and Design KPA

Case C openly shares design specific information with their clients as they believe "communication is the best way to achieve customer satisfaction". According to Case A, generally, the client is involved mainly in the inception stage to provide the design requirements, and panel-designing is not usually shared among the clients. However, clients' main project schedule is considered in the whole production process. The designer of the company initiates the designing of the panels after the initial agreement with clients. Case C uses Microvellum and PRO100 software to design the production drawings, while Case A and Case B use ARCHICAD and CADworks, respectively, for details. Most interestingly, Case A is maintaining two designers, both in-house and external. According to the company policy, the completed panel designs are usually cross-checked by the other designer to avoid errors and design changes in the later stages. In the meantime, Case B is maintaining eight in-house design teams to cater for the demand. However, neither of the designing processes of the three companies are synchronised with other primary functions such as production and planning.

6.4.2.2 Planning KPA

All three companies try to maintain good control over the manufacturing process, logistics operations, and on-site installation. Moreover, all three companies have already systemised and documented the policies, processes, procedures and authorisations to conduct the functions in the companies. However, process documentation is not practised in Case A and Case B. Their current performance during planning stage is benchmarked as following figure 6.8.

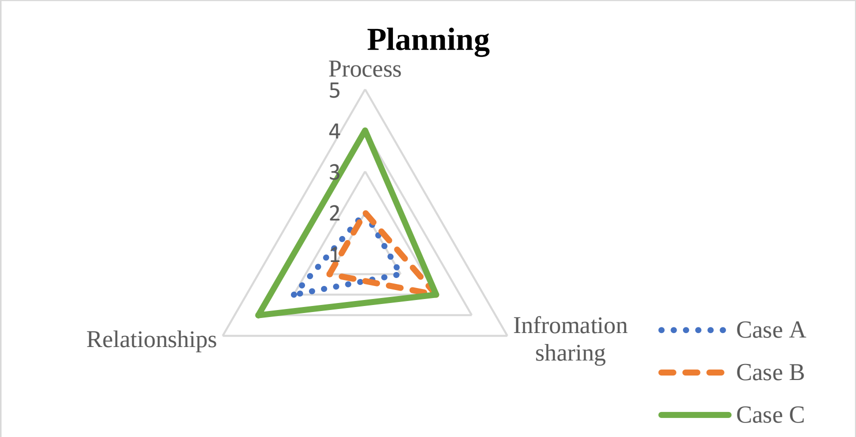

Figure 6.8: Planning KPA

Case A uses an automated system- "Monday.com" for production planning, production monitoring and customer relationship management. The production planning of Case A is developed by the management level members based on the projects in hand. The shop floor schedule is continuously cross-checked with the overall project schedule and the client's schedule. Further to this, "the company has a capacity of producing two jobs at a time. Still, the storage capacity of the factory is not sufficient, and therefore, generally, the project is planned to complete the day before it is required on-site. Therefore, the company is currently planning to increse the capacity". Case C uses "two software, Smartsheet and Empower for project planning and each participant of the internal supply chain get their own schedule including the tasks to complete". On the other hand, Case B is using Microsoft project as their main production planning system, and Microsoft Excel is maintained to share production schedules. Therefore, they think "the company's planning process needs to improve to integrate processes using more systems and tools from the clients' initiative to designing to planning to procurement to manufacturing to installation. We do have issues in the supply chain". However, these three companies are not sharing their production schedules with their respective clients.

Case C openly shares their planning information throughout their internal supply chains through their planning systems and emails. Case A and Case B use their production planning systems to share information with its management level members.

Therefore, relevant and timely production information is informed to the shop floor members through regular daily meetings. In addition, both companies are maintaining weekly meetings to review their production process.

6.4.2.3 Procurement KPA

The procurement process of these three companies has accurately developed and informed all the members, including the job roles. However, Case B believes that "there are some gaps in their documented procurement process in terms of management of transactions of materials. Even though we use ERP system for procurement handling, most of the transactions and management of materials handled manually". All the companies select their suppliers considering the quality, relationship, price and time. Case B and Case C evaluate their supplier performance prioritising delivery time and quality of the product. However, Case A does not use a systematic performance measurement system to evaluate the suppliers.

All three case study companies maintain close collaborative relationships with their primary suppliers and maintain long-term fixed agreements to keep the continuous supply. Case A and the suppliers have quite a distinct relationship in terms of sharing each other's schedules. However, for research and development the company seeks advice and knowledge of the suppliers to improve their product varieties. Case B highlighted that they "also maintain short-term agreements and transactional relationships with their suppliers". However, non of the companies are sharing their procurement schedules with the suppliers and vice versa. Both Case B and Case C emphasised that they share delivery dates with the suppliers. Furthermore, according to Case B, they have supplier side employees to maintain a continuous supply of materials. However, that strategy "failed as it was complicated and had issues in communication". This is benchmarked as illustrated in figure 6.9.

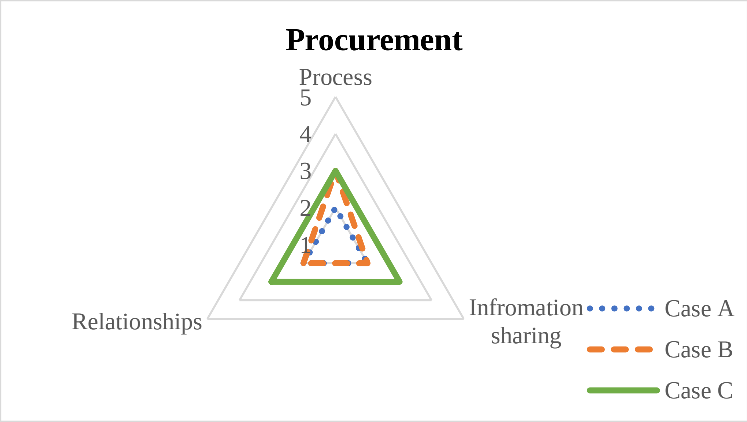

Figure 6.9: Procurement KPA

5.4.2.4 Production KPA

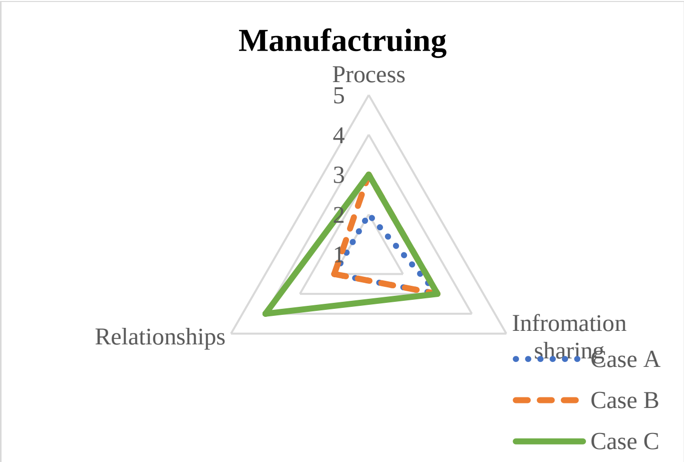

Figure 6.10: Production KPA

The production process of all the companies have reasonable control over the process and is operated with automated machinery (as represented in Figure 6.10). However, there is some degree of integration with the other main functions. The production process of Case A and Case C is fully automatic, while Case B has a semi-automated production process. In Case A, "the whole production process is automated with computer numerical control (CNC) machines and operated via Moday.com. Even though their production process is streamlined with the application - "Moday.com", the performance is not evaluated against the schedule". Case B's production process is streamlined via Empower and the company’s own-built system and measures real-time performance. Product quality and efficiency are improved based on the real-time performance monitoring reports and feedback from clients and installation team members. The production process of Case A is not measured using any tools or systems. The production is only reviewed weekly and an open-door policy is adhered to by all the members to gain their feedback and opinions regarding the production line. Case B is quite similar to Case A. They maintain Excel sheets to update their production process. However, Case B has reviewed different production strategies and implemented lean manufacturing concepts. They believe they need to focus on integrating their production process. Case A also uses lean manufacturing strategies to reduce material waste.

Case A tries to minimise the changes and errors through proper design. However, if they encounter any design changes, the production team and design team collaboratively work to produce the clients' requirements with less wastage. Case B and Case C adhere to the same strategy. Case C further highlighted, "if the impact of the change is under the tolerance level, the company itself bears the cost and if not, they negotiate it with the particular client".

In Case A and Case B, information is shared among the participants, mostly verbally and by email. Production information (panel design) and plans are shared among the shop floor member through daily and weekly meetings. Case C uses Smartsheet to update production specific information among the internal supply chain. All three companies maintain a collaborative relationship with their production team members and Case B highlighted that they "have an open culture environment in the production".

6.4.2.5 Transportation and on-site assembly KPA

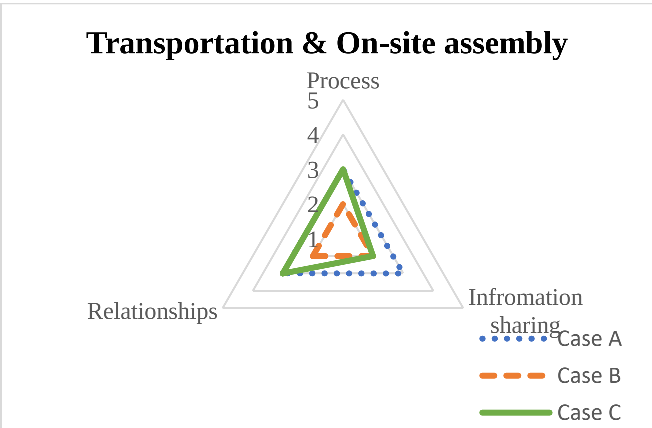

Figure 6.11: Transportation and on-site assembly KPA

Case A and C have a systematic product delivery process where the company uses their own trucks and employees to handle transportation. The benchmark of the company performances is illustrated in figure 6.11. Case A said that they "own a 420kg crane truck for loading and unloading the panels as hiring for transportation is expensive and it requires expertise". These two companies (Case A and C) are responsible for installing their products and coordinating the builder's participants. For ease of installation, panels are staked and loaded based on the order of installation. On the other hand, Case B manages their delivery products and outsources transportation to companies to handle deliveries. Therefore, installation of the products is either handled by the company itself or allows the builder to install using their fixing manuals.

All the companies closely monitor the delivery and installation process and inform the relevant parties of any delays and disruptions. Semi-automated loading and unloading processes can be seen in the companies and their installation processes are manual.

Even though the schedules are shared with the client/on-site construction team, their schedules are not fully integrated with any of the companies schedules. Some systematic use of performance measurement is carried out by Case A and B.

Usually, three employees, including one licenced building practitioner, can handle the installation of the panels. The client is responsible for the disruptions and on-site delays. If the company is unable to install the product on the scheduled date, the panels are transported back to the manufacturing plant and the cost is shared based on the responsibility. The company can complete a particular job within a day.

Delivery schedules are integrated with the client's main project schedule the responsible party shares delays in the delivery for the disruption. Tracking and performance measurement system for transportation is not considered.

6.4.2.6 Overall maturity of the case studies

Figure 6.12 illustrates the overall maturity of the supply chain practices at each key process area. It is evident that the case studies are functioning at different maturity levels. All cases are operating inception and design at the coordinated level where some degree of collaboration and collective designing can be seen. In planning, Case C is performing at the coordinated level while Case A and Case B are functioning their supply chain practices at a segmented level.

The procurement function of the companies is functioning at different levels. Case B and Case C are performing at the coordinated level and Case A is performing at the segmented due to distinct relationships and non-standardised processes in procurement. In manufacturing, Case C's supply chain practices are at a higher maturity level than Case A and B. This is because Case A and Case B run semi-automated production processes without performance monitoring.

Case A and C perform transportation and on-site assembly at the coordinated level where systematic logistic and installation processes are established and coordinated with on-site work. Case B is performing their transportation and on-site activities at the segmented level.

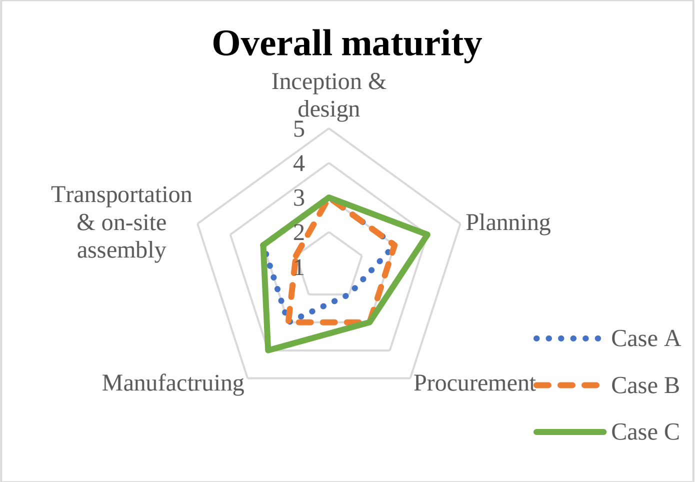

Figure 6.12: Overall maturity

6.6 Summary

Supply chain practices in New Zealand module manufacturing seem to be performing at a low level. However, the performance level of SC integration is different from one company to another company. Inadequate usage of technology and automation, lack of long and stable relationships, less standardisation, lack of performance monitoring and less coordination are the main reasons for this situation. The proposed model provides sound guidelines to eliminate these challenges and to improve integration in module manufacturing. In line with this, this model was acknowledged as a valuable tool to be applied in the industry to improve supply chain integration. Therefore, further widening the application in different prefabrication contexts will be helpful in the industry.

CHAPTER SEVEN

DISCUSSION

7.1 Overview

This chapter provides a discussion based on the study's results, including the findings of the interviews, focus group discussions and case studies, and the literature review findings. This study set out to guide prefabrication manufacturing companies that supply modules and panels to build houses to improve the efficiency of their supply chain process. The first section of this chapter describes the overall process of prefabricated house building and residential module manufacturing. The subsequent sections describe barriers and enablers for supply chain integration, comparing the literature findings with semi-structured interview findings. The final sections provide an overview of the maturity model proposed to overcome the barriers identified in semi-structured interviews.

7.2 Prefabricated residential construction supply chain

It is clear that the prefabrication supply chain process is complex and unique, depending on the type of prefabrication used. The developed supply chain process for prefabricated house building (Figure 4.5-Chapter 4) is aligned with Vrijhoef and Koskela (2000) roles of supply chain management in construction. The developed process seems to be consistent with other studies (Mostafa et al., 2014; Vrijhoef & Koskela, 2000). However, the proposed process in the study was developed horizontally considering only 2 supplier-side tiers.

In this study, the prefabricated residential construction supply chain is a novel finding for the New Zealand construction industry. MBIE report (2012) has represented a housing input chain for New Zealand and it only outlines the material, labour and finance inputs that are required for house building. Further Masood et al.'s (2022) conceptualization of prefabricated house building through the supply chain lenses is a demonstration of the structure of prefabricated house building supply chains. On the other hand, the developed supply chain process in this study, encompasses mainly pre-assembly and onsite construction with information and material flows.

In line with findings in the literature (Lessing, 2015; Stroebele & Kiessling, 2017), it was confirmed, that the design and planning stages are key milestones of the prefabricated housing construction as they involves design freezes, cost planning, methods of procurement and project planning and scheduling. Therefore, designers/architects need to develop a thorough understanding of the basic requirements and parameters of design and detailing of prefabricated houses to subsequent approvals and minimise the complications in the construction stage. Specifically in New Zealand, acquiring the building consent was identified as another crucial step as it is time-consuming. Furthermore, participants confirmed the current attention of the industry towards prefabrication to overcome the inefficiencies in house building as emphasised in the previous studies (Bakhtiarizadeh et al., 2021; Masood et al., 2016; PrefabNZ, 2014)

As the research narrowed down into module element manufacturing, the supply chain for bathroom and wall panel manufacturing was established (See Chapter 4). The developed supply chain processes could be recognised as novel findings. Both processes include six main stages- idea, design and planning, procurement, manufacturing, transportation and onsite assembly. Establishing these process will be helpful for the industry to standardise the supply chain processes and to recognise the concurrent and dependent stages, will ultimately be useful for improving the efficiency of the whole process.

7.3 Barrier and enablers for supply chain integration in module/panel manufacturing

Even though the prefabricated construction industry lags behind in applying supply chain practices, many authors have explored improving prefabricated housing supply chain (Doran & Giannakis, 2011; London & Kenley, 2001; Naim & Barlow, 2003;

Stroebele & Kiessling, 2017), prefabrication and lean manufacturing (Arbulu & Ballard, 2004), and lately, the integration of supply chain strategies to prefabrication (Lessing et al., 2015; Mostafa, Chileshe, et al., 2014). However, there has been little research considering the nature and the constraints in the prefabricated housing supply chain specifically for module manufacturing. On the other hand, the New Zealand construction industry is also left behind in applying supply chain practices (Masood et al., 2016; Ying et al., 2015). Therefore, this research attempted to identify barriers and enablers for supply chain integration in module manufacturing. The identified barriers were categorised into internal and external barriers (Table 7.1). Internal barriers were further categorised into managerial, technical and relationship as these three aspects are considered basics/principles of supply chain integration (Alfalla-Luque, Medina-Lopez, & Dey, 2013; Fabbe-Costes & Jahre, 2008).

Table 7.1: Barrier to SCI

Internal Barriers			**External barriers**
Managerial Barriers	**Technical Barriers**	**Relationship Barriers**	
• Inadequate project planning and scheduling • Inconsistent goals within the org. • Lack of clear direction and guidance • Inadequate performance measurement systems • Lack of understanding of SCM • Lack of knowledge in consumer demand	• Lack of information sharing • Lack of technology and automation • Transportation of modules	• Lack of long-term partnerships and trust among the stakeholders	• The scale of the New Zealand market • Undercapitalised companies • Anti-competitive and reluctant to change behaviour • Lack of education about the benefits of prefabrication

In line with the interview findings, Behera et al. (2015) have investigated problems at the different interfaces of a construction supply chain. According to their findings, conflicts due to participants own goals, delays in information sharing, the accuracy of the shared information, adversarial relationships, lack of planning and design changes were identified as the issues. Akintoye et al. (2000) also highlighted that top management commitment, followed by the poor understanding of the concept, an inappropriate organisation structure to cope with the concept, low commitment from partners and lack of appropriate information technology as main barriers for collaborative practice.

In the New Zealand context, lack of information sharing was identified as an issue prevailing in the supply chain of prefabricated house building (Bakhtiarizadeh et al., 2021; Masood et al., 2016). On the other hand, Nesarnobari et. al (2022) highlights disruptions to prefabricated supply chains due availability of imported raw materials and lack of storage capacity. Further, Masood et al., (2016) and PrefabNZ (2014) highlighted that the industry is reluctant to invest in technology. Therefore, the categorisation of the barriers for supply chain integration exemplify the challenges that the industry needs to overcome to achieve efficiency. Therefore, the findings related to barriers reinforce the existing knowledge and provide solid background to investigate enablers to overcome.

To conquer the identified issues, the literature specifies number of enablers for supply chain integration (See chapter 2). However, the literature fails to propose a holistic way to achieve supply chain integration in residential module manufacturing even though it was confirmed through preliminary interviews that there are inefficiencies in the supply chain of prefabricated residential construction. Semi-structured interview findings suggested enablers for supply chain integration.

Barlow and Ozaki (2005); Roy et al. (2005) have identified several areas of the house-building process, such as logistics and supply chain partnering, long-term relations with suppliers, and support by integrated information sharing systems, in order to achieve an integrated production system. In line with this, Briscoe and Dainty (2005) identified managing communication and information flow, establishing long-term relationships, alignment of supply chain systems, securing project objectives for supply chain integration through case studies investigations. Moreover, a study done by Behera et al. (2015) explored the construction of a coal-based thermal power project and listed out suggestive measures for managing a typical CSCM system for the power plant construction. Their research includes similar findings to the literature and semi-structured interviews. In line with the above mentioned studies, Lessing (2015) identified eight characteristic areas that need to be continuously improved in order to achieve supply chain integration in industrialised house building.

Similarly, respondents of the semi-structured interviews agreed that, real-time information sharing, setting up common goals, establishing long-term and trustworthy relationships, proper planning and scheduling, supply chain training and education, developing a demand forecast, real-time performance monitoring and logistics management are enablers of supply chain integration. Usage of integrated systems like BIM was one of the highlighted suggestions to improve integration as it facilitates real-time information sharing. Some contrasting views were recognised during the focus group interviews regarding information sharing. A participant of the focus group interview pointed out that the real time verbal communication is visible in the industry to share information. However, efficiency of information sharing, accuracy of the shared information and availability for the participants of the supply chain is questionable. Findings from the case studies further emphasised the requirement of formal communication channels to share accurate and timely information across the whole supply chain.

Case study findings further confirm the demand for contractual relationships with clients and suppliers, a system to schedule the work and monitor the production process to overcome the uncertainties in their supply chain process. Therefore, in summary, the findings of this study incline towards the necessity of integrating supply chain practices.

7.4 Improving SCI in residential module and Panel manufacturing

In this research, the maturity of supply chain integration is suggested to overcome the existing barriers in the supply chains and to improve integration. The model is developed to benchmark the current supply chain practices and as a guide to enhance practices so as to achieve an efficient production process. The proposed model was developed based on the principles of the Manufacturing Supply Chain Maturity Model established by PRTM.

The progression of integration was described through five maturity levels in line with the capability maturity model. The developed key process areas are unique to this proposed model. On the other hand, Lessing's (2015) maturity model developed for industrialised housing contains only four maturity levels and eight characteristic areas, including use of information and communication, planning and control of the processes and long-term relationships. In the proposed model of this study these areas were considered within the key process areas. Relationship sub-criteria in the proposed model was developed considering Meng et al.'s (2011) maturity model. Therefore, the developed model is unique and confirms the previous literature.

The following section discusses the barriers identified from the semi-structured interviews and how the model helps to overcome the barriers.

7.4.1 Inception and design

Participants of the semi-structured interviews highlighted that information sharing, lack of technology, lack of long-term stable relationships with clients and poor demand forecasting are problems related to the inception and design stage. Case study findings reveal information sharing as one of the main problems in the design stage. Moreover, case study results further disclose the need of an integrated system for designing and information sharing and a long-term collaborative relationship with clients.

These problems can be overcome adopting improvements stated as assessment criteria in the proposed maturity model. The Table 7.2 illustrates how the identified barriers can be overcome with the proposed maturity model. In this table coordinated, integrated and value network levels are included as these three represent mature practices. Demand forecasting can be achieved with long-term trustworthy clientele.

Table 7.2: Inception and design

Barriers	Maturity Levels		
	Coordinated	Integrated	Value Network
Lack of clear direction and guidance Lack of technology	Collaborative designing with the client,3D CAD/BIM drawings printed on paper	Collaborative designing with the client and involved suppliers for more ideas, 3D BIM modelling streamed on mobile devices	BIM integrated designing

Lack of trustworthy and long-term relationship with clients	Short-term agreements with clients	Long-term and fixed agreements with clients	Mergers or acquisitions with clients
Lack of information sharing Lack of clear direction and guidance	Some information is shared across the org.	Open information sharing across the org. and interfaces	Real-time information sharing using BIM

7.4.2 Planning

In the planning stage, inadequate project planning, inconsistent project goals, lack of collaboration, inadequate information sharing, and lack of technology and automation were identified as the main problems. In line with this, Masood et al. (2016) highlighted the resistance to adopting new technologies, lack of collaboration within SC participants, and inadequate information sharing as issues in the New Zealand house building industry. This is similar to the residential module/panel manufacturing sector, where; the case study companies' supply chain practices are scaled at segmented and coordinated levels. Table 7.3 illustrates the barriers identified and how these barriers can be overcome with the maturity model.

Table 7.3: Planning

Barriers	**Maturity Levels**		
	Coordinated	**Integrated**	**Value Network**
Inadequate project planning lack of technology and automation	Production planning and scheduling for the jobs in-hand	Integrated planning and scheduling	Continuous improvement through real time analysis
Lack of collaboration Inconsistent project goals	Collaborative	Close Collaboration	Adoptive collaboration
Lack of information sharing	Some information is shared across the org.	Open information sharing across the org. and interfaces	Real-time information sharing

7.4.3 Procurement

Participants of the semi-structured interviews endorsed that lack of knowledge in demand, inadequate information sharing, lack of technology and automation, lack of long-term trustworthy relationships with suppliers and lack of planning are problems in the procurement stage. Case study interviews revealed that New Zealand module manufacturing companies are not integrated in their procurement function with production. Therefore, the proposed model guides the companies to improve their practices as illustrated in Table 7.4.

Table 7.4: Procurement

Barriers	**Maturity Levels**		
	Coordinated	**Integrated**	**Value Network**
Lack of knowledge in demand Lack of technology and automation	Plan and order for the projects in hand	Integrated with the supplier interfaces for automated ordering	Integrated with the production for automated ordering
Lack of long and stable relationships	Short-term agreements with the suppliers	Long-term and fixed agreements with supplier	Mergers or acquisitions
Inadequate information sharing	Material requirements are shared based on the production	Inventory requirements are openly shared across the org. and interfaces	Real-time information sharing

7.4.4 Manufacturing

In the manufacturing stage, the identified problems include; lack of clear directions and guidance, lack of performance monitoring, inadequate information sharing, and lack of collaboration and inadequate technology and automation. According to the case study findings, two of the case studies revealed that they are not using any real-time performance monitoring to measure the manufacturing performance. Further, production function is not integrated with other main functions such as procurement, designing. This reflected the inadequate information sharing and lack of clear directions and guidance in the manufacturing stage. To improve the efficiency of the production process, the following maturity guidelines are helpful (Table 7.5).

Table 7.5: Manufacturing

Barriers	Maturity levels		
	Coordinated	**Integrated**	**Value Network**
Lack of performance monitoring Lack of clear directions and guidance	Defined processes. Regular and formal measures for monitoring the production process	Regular and formal measures Feedback and analysis for future work	Innovation based on real-time performance analysis
Lack of collaboration	Collaborative	Close Collaboration	Adaptive collaboration
Inadequate information sharing	Production information is shared across the org.	Open information sharing across the org. and interfaces	Real time information sharing

7.4.5 Transportation and on-site assembly

Lack of directions and guidance, inadequate information sharing, low level of collaboration, lack of technology and automation, delivery of volumetric modules were identified as main barriers in transportation and on-site assembly stage. In line with this, case study findings also accepted the fact that, transportation and on-site assembly involves discrete operations due to less coordination of the process and in-between people being engaged. Participants of the focus group also, endorsed the risk of transportation and on-site assembly. Topography of New Zealand has particularly impact negatively impacted transportation. Table 7.6 illustrates the proposed model's guidelines to overcome the aforementioned barriers.

Table 7.6: Transportation and on-site assembly

Barriers	Maturity levels		
	Coordinated	**Integrated**	**Value Network**
Process	Defined processes and procedures	Delivery schedules are made with close collaboration of the two parties Automated installation processes with real-time performance monitoring	Integrated and automated process with business process across the enterprises
Relationship	Collaborative	Close Collaboration	Adaptive collaboration
Information Sharing	Openly share information related to delivery schedules and installation internal	Logistics and installation information is openly shared across the org. and interfaces	Integrated real-time information sharing

The above tables illustrate how the maturity model overcome the barriers for supply chain integration strategically. Several studies have been conducted to identify barriers and enablers in the prefabricated housing industry in New Zealand, however, it appears that only a few are being considered in the practical context. This emphasises the demand within the industry for a systematic and realistic model to measure and improve the supply chain practices.

In this model, achieving a value network level implies the fully automated and integrated network across the business enterprises. Improvements to the prefabrication supply chain can acquire the cost, quality and time benefits compared to traditional construction (Construction, 2011; PrefabNZ, 2014; Shahzad et al., 2015). Furthermore, supply chain integration could reduce the wastage, enhance profit, competitiveness and flexibility for change (Alfalla-Luque et al., 2013; Awad, 2010; Power, 2005). The proposed model also focuses on improving inventory management and logistics management. Therefore, this model aims to achieve the efficiency of the prefabricated residential construction process and ultimately improve the productivity in the process.

The case study analysis confirms that the current supply chain practices are at a tactical level. This confirms previous findings on prefabrication and supply chain management in New Zealand (Masood et al., 2016). The developed model will guide the prefabricated manufacturers to achieve strategic level from tactical level project management (Cleland & King, 1988).

7.5 Summary

This chapter provided implications based on the findings from data collection and the literature review. The main aim of this research is to guide residential module manufacturers to overcome barriers in their supply chains and to improve integration in terms of people, process and information sharing. The proposed model provides a sound assessment tool for module manufacturers to benchmark their practices and thereby improve the performance based on the guidelines. Based on the implications of this chapter, chapter 8 discusses the conclusions and recommendations of the study.

CHAPTER EIGHT

8.1 Overview

Heretofore, this thesis has discussed the gaps identified in the prefabricated residential construction supply chain, the methodology designed to achieve the aim and the findings from the interviews. Considering the results, this chapter presents a set of conclusions in relation to the research objectives. Applications of these conclusions are discussed as recommendations in the subsequent section of the chapter, including contributions to knowledge, suggestions for future research and limitations encountered.

8.2 Summary of Key Findings

The study was designed to determine a mechanism to guide module manufacturers to improve integration and efficiency in their supply chains. The following sections provide a summary of key findings related to the objectives of the study.

8.2.1 Objective 1- Nature of the processes and supply chain relationships of module and panel manufacturing in New Zealand

Objective 1 of the study tried to fill the gaps in prefabricated residential construction by identifying the nature of the SC processes and its relationships. Further, the study established three SC process diagrams for prefabricated residential construction, bathroom pods manufacturing and wall panel manufacturing (Figure 4.2, Figure 4.5 and Figure 4.6 in Chapter 4).

Six main stages of module and panel manufacturing were identified. Both bathroom pods and wall panel manufacturing processes are shown to be ad-hoc and complex and vary from project to project and company to company. Therefore, establishing a standardised supply chain network will benefit prefabrication manufacturers, construction companies, and the construction industry so as to realise and manage the nature of the process and its relationships. Furthermore, these supply chain networks including relationships, material and information flows, will become a base for future research on prefabricated residential construction.

Construction as a small-medium enterprise dominated industry in New Zealand, Low-level productivity and inefficiency are inevitable. The developed supply chain network diagrams could be utilised to define the scope of the functions/stages and propose initiatives to improve the efficiency of the supply chain. Additionally, identifying the nature of the relationships along the supply chain will benefit from improving the collaboration. Increasing efficiency through standardisation of the manufacturing process will prevent manufacturing companies from becoming bankrupt, which is a pervasive situation in the New Zealand construction industry.

8.2.2 Objective 2- Barriers to SCI in module and panel manufacturing in the New Zealand residential sector

The second objective was to identify the barriers to supply chain integration in module and panel manufacturing in the New Zealand residential sector. The study found thirteen main barriers to SCI. The identified barriers were categorised under internal and external barriers, and internal barriers were further classified into managerial barriers, relationship barriers and technical barriers (Table 7.1). The internal barriers include inadequate project planning and scheduling, inconsistent goals within the organisation, lack of clear direction and guidance, inadequate performance measurement systems, lack of understanding of SCM and lack of knowledge of consumer demand. The study further found relationship barriers due to a lack of information sharing, lack of technology and automation and transportation of modules as technical barriers and lack of long-term partnerships and trust among the stakeholders as relationship barriers.

The external barriers-the scale of the New Zealand market, undercapitalised companies, anti-competitive and reluctant to change behaviour and lack of education about the benefits of prefabrication, were disregarded as they were uncontrollable by the manufacturing companies.

8.2.3 Objective 3- Enablers for SCI in module and panel manufacturing in New Zealand residential construction

The third objective was to identify the enablers for supply chain integration of modular manufacturing in the New Zealand housing sector. The literature review and semi-structured interview contributed to fulfilling this third objective. Accordingly, the study found nine enablers that can inhibit the barriers to supply chain integration. Further, a framework was developed mapping the barriers and enablers in the stages of the supply chain (idea and design, planning, procurement, manufacturing, transportation and assembly) (Figure 4.7). The framework is an illustration of the barriers and enablers for SCI in the module/panel elements manufacturing and will provide a guide for the wall panel and bathroom pod manufacturing companies for improving integration across the whole manufacturing process. This framework could be beneficial for the house building industry to improve the relationships and collaboration with the prefabrication manufacturers to increase the construction process's efficiency.

8.2.4 Objective 4- A model to measure and improve supply chain integration in module and panel manufacturing in the New Zealand residential construction

The fourth objective of the study was to develop and validate a framework to assess the current supply chain practices in module and panel manufacturing companies and improve supply chain integration. The framework was developed as a maturity model based on the enablers identified. The proposed maturity model has five maturity levels (ad-hoc, segmented, collaborative, integrated and value network) and five key process areas (idea and design, planning, procurement, manufacturing and transportation and assembly). The model provides the assessment criteria for each KPA under three subcategories-process, relationship and information sharing. The model was validated through case studies and focus group interviews. Based on the validation suggestions received to widen the scope of the model to apply for different types of prefabrication.

The developed model can be used as an assessment tool to measure the supply chain performance of manufacturing companies and can be used to evaluate the improvements in performance over a period. Further, the model can be used as a guide to improve supply chain performance based on the maturity levels proposed in the model.

8.3 Contribution of the research to the theory and practice

There are several vital contributions which outcomes of this research are listed as follows.

- The study provides empirically established prefabricated residential construction supply chains, including relationships, information, material and finance flows. Moreover, bathroom pod and wall panel manufacturing processes are established based on the established residential construction supply chains. The study further provides useful information on prefabrication and its applicability in the construction industry, focusing on New Zealand's residential sector.
- The study provides new knowledge of barriers to supply chain integration in prefabricated residential construction, and these barriers were categorised into internal and external barriers. The categorisation of internal barriers is a piece of new knowledge to the construction sector. To overcome these barriers, nine enablers were identified. The framework established based on the empirical understanding of the barriers and enablers leads to an improved understanding of the problems in the stages of the manufacturing process and provides direction for actions.
- The maturity model provides a useful tool for assessing SCI and identifying key criteria for further improvement.

8.5 Recommendations

The recommendations arising from the study are presented as follows. Firstly, the recommendations are given to the key stakeholder and then the recommendations are drafted generally to the construction industry and academics.

8.5.1 Recommendations to the module and wall panel manufacturers

The following is an outline of recommendations to the module/wall panel manufacturers.

- Prefabricated module and panel manufacturers could use the developed model as tool to benchmarks their supply chain practices or else they could utilise the model to continuously improve supply chain integration in their production process. And further, the model can be used to realise the impact of COVID 19 on the performances of the supply chain practices and to improve the SC practices based on that benchmark.

- Prefabricated module and panel manufacturers should understand the importance of maintaining a standardised supply chain process in order to improve the efficiency of the manufacturing process. Furthermore, they should focus on improving on establishing long-term and committed relationships with their suppliers and clients.
- The study identified ten barriers associated with SCI in the manufacturing process. Therefore, manufacturers first need to focus on identifying the barriers associated with their processes in order to take actions based on proposed enablers.
- The main result of the study is the maturity model and the model can be used as a tool to assess the current level of SCI and to improve based on the key criteria developed. Therefore, module and panel manufacturers can use this model to benchmark their supply chain practices. Based on their current performance level, manufacturers can improve SCI in their business network by adopting the key criteria developed in the model.

8.5.2 Recommendations to the construction industry and government

The following is an outline of recommendations to the construction industry, including responsible organisations that could assist the prefabrication.

- Residential construction industry can identify the barriers associated with prefabricated module and panel manufacturing SCs. Based on that industry can develop innovative approaches in order to mitigate external barriers. The industry could initiate financial arrangements that can support prefab manufacturers.
- Kianga Ora, as an government organisation responsible for housing supply in New Zealand could identify the barriers based on the study and focus on mitigating these barriers based on the proposed enablers. Further, they could improve the usage of prefabrication in their projects and provide more long-term collaborative relationships with prefabricated module/panel

manufacturers. As Kianga Ora has started to work in collaborative relationships with some module and panel suppliers, they could use the maturity model to assess the maturity level of their relationships.

- Industry and government can educate the general public on the benefits of prefabrication and the different options prefabrication can offer in terms of building a house.
- As New Zealand supply chain is geographically spread out, transporting modules is a challenge. Transportation between North and South islands is a major cost for everyone associated with the construction industry. Therefore, the study emphasises the need for better transport infrastructure in New Zealand to improve the logistics aspect of the supply chain.
- Industry and government could conduct research on prefabrication and supply chain. Currently, there is little research conducted on both prefabrication and supply chain in New Zealand. Therefore, there is a wide scope to conduct more research to support various aspects of the supply chain.

8.5.3 Recommendations for future studies

The study recommends further studies in the following areas to expand the current research findings.

- The study mainly focused on barriers and enablers for SCI in module/panel manufacturing. Further research could conduct on types of prefabrication used in residential construction.
- The study developed a maturity model focusing on process, people and information sharing. Therefore, further studies are required to extend the current research finding considering other factors such as risk.
- In this study, the developed model is used only to benchmark three case studies. Therefore, further studies are required to implement the model in actual case studies to validate the model further. After implementing the model in actual case studies, benefits gained from maturing the SCI will be benefitted.
- The scope of the current studies lies within the boundary of module/panel manufacturing for the residential sector in New Zealand. Further research can

be implemented to check the validity of the model in other types of prefabrication, such as whole building and hybrid. Also, applicability for different types of building construction could be another research.

- Testing the model if it supports to mitigate the SC issues arise mainly due to Covid 19 can be a future research. Further, the model can be developed to mitigate the barriers raised due to Covid 19 as a global pandemic.

8.5 Limitations of the research

The research scope is limited to the manufacturing process of prefabricated elements used in housing construction in New Zealand. The study's main aim is to develop a framework to measure and improve the supply chain practices in the prefabricated elements manufacturing process. The manufacturing process of modular elements is considered from initial inception to project completion, including the stages of design, planning, manufacturing, transportation and assembling.

Prefabrication construction is classified into five types: component-based prefabrication, panelised prefabrication, modular prefabrication, whole-building prefabrication, and hybrid prefabrication. Of these, panelised prefabrication is one of the most well-established and most common types of prefabrication in New Zealand (PrefabNZ, 2013; Burgess et al., 2013; Bell, 2009) while bathroom pods are becoming a trend in residential apartment buildings. Therefore, in this research, the manufacturing processes of modular bathrooms and wall panels are considered.

As the research is based on multi-tier qualitative methods, the validity of the research findings is based on the accuracy of the opinions provided by the participants. The semi-structured interviews were limited to twelve participants due data saturation after conducting twelve interviews. The interview participants included manufacturers, builders, developers and architects engaged in housing construction in New Zealand.

According to the study, the development and implementation of an SCI maturity model in prefabricated residential construction can achieve higher prospects, and further research on this area is essential at the moment.

REFERENCES

Adams, A., & Cox, A. L. (2008). *Questionnaires, in-depth interviews and focus groups* (pp. 17-34). Cambridge University Press.

Ahmed, M., Thaheem, M. J., & Maqsoom, A. (2020). Barriers and opportunities to greening the construction supply chain management: cause-driven implementation strategies for developing countries. *Benchmarking: An International Journal*.

Akintoye, A., McIntosh, G., & Fitzgerald, E. (2000). A survey of supply chain collaboration and management in the UK construction industry. *European journal of purchasing & supply management, 6*(3), 159-168.

Akkermans, H., Bogerd, P., & Vos, B. (1999). Virtuous and vicious cycles on the road towards international supply chain management. *International Journal of Operations & Production Management*. 19(5/6), pp. 565-582. https://doi.org/10.1108/01443579910260883

Albaloushi, H., & Skitmore, M. (2008). Supply chain management in the UAE construction industry. *International Journal of Construction Management, 8*(1), 53-71.

Alfalla-Luque, R., Medina-Lopez, C., & Dey, P. K. (2013). Supply chain integration framework using literature review. *Production Planning & Control, 24*(8-9), 800-817.

Alshenqeeti, H. (2014). Interviewing as a data collection method: A critical review. *English linguistics research, 3*(1), 39-45.

Altaf, M. S., Bouferguene, A., Liu, H., Al-Hussein, M., & Yu, H. (2018). Integrated production planning and control system for a panelized home prefabrication facility using simulation and RFID. *Automation in construction*, 85, 369-383.

Amaratunga, D., Baldry, D., Sarshar, M., & Newton, R. (2002). Quantitative and qualitative research in the built environment: application of “mixed” research approach. *Work study*.

Arbulu, R., & Ballard, G. (2004). *Lean supply systems in construction*. International Group for Lean Construction. Conpenhague, Dinamarca

Arif, M., Al Zubi, M., Gupta, A. D., Egbu, C., Walton, R. O., & Islam, R. (2017). Knowledge sharing maturity model for Jordanian construction sector. *Engineering, Construction and Architectural Management*.

Awad, D. (2010). A broader view of the supply chain integration challenges. *Int. J. Business Performance and Supply Chain Modelling, 2*(3)

Badir, Y. F., Kadir, M. A., & Hashim, A. H. (2002). Industrialized building systems construction in Malaysia. *Journal of Architectural Engineering, 8*(1), 19-23.

Bakhtiarizadeh, E., Shahzad, W. M., Poshdar, M., Khalfan, M., & Rotimi, J. O. B. (2021). Blockchain and Information Integration: Applications in New Zealand's Prefabrication Supply Chain. *Buildings, 11*(12), 608.

Barker, K. (2003). *Review of Housing Supply: Securing Our Future Housing Needs*: Interim Report: Analysis: HM Stationery Office.

Barlow, J., & Ozaki, R. (2005). Building mass customised housing through innovation in the production system: lessons from Japan. *Environment and Planning A, 37*(1), 9-20.

Barlow, J., & Ozaki, R. (2005). Building mass customised housing through innovation in the production system: lessons from Japan. Environment and Planning A, 37(1), 9-20.

Barratt, M. (2004), ―Understanding the meaning of collaboration in the supply chain‖, Supply Chain Management: An International Journal, Vol. 9, No. 1, 2004, pp. 30 – 42

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. Supply chain management: an international journal, 9(1), 30-42.

Basnet, C., Corner, J., Wisner, J., & Tan, K. C. (2003). Benchmarking supply chain management practice in New Zealand. Supply Chain Management: An International Journal, 8(1), 57-64.

Bassett, M., & Malpass, L. (2013). Different Places, Different Means: Why some countries build more than others.

Beamon, B. M. (1998). Supply chain design and analysis: Models and methods. *International journal of production economics, 55*(3), 281-294.

Behera, P., Mohanty, R., & Prakash, A. (2015). Understanding construction supply chain management. *Production Planning & Control*, *26*(16), 1332-1350.

Bell, P. (2009). *Kiwi prefab: Prefabricated housing in New Zealand.,* Victoria University of Wellington.

Bell, P. and Southcombe, M. (2012). *KiwiPrefab - cottage to cutting edge*. Wellington, New Zealand, Balasoglou Books.

Bertram, N., Fuchs, S., Mischke, J., Palter, R., Strube, G., & Woetzel, J. (2019). Modular construction: From projects to products. *McKinsey & Company: Capital Projects & Infrastructure*, 1-34.

BIFNZ. (2013). Residential Construction Sector Market Study: Submission on Issues Paper. Wellington, New Zealand Building Industry Federation.

Bildsten, L. (2011). Exploring the opportunities and barriers of using prefabricated house components. In *19th Conference of the International Group of Lean Construction (IGLC), July 13-15, Lima, Peru*.

Boyd, N., Khalfan, M. M., & Maqsood, T. (2012). Off-site construction of apartment buildings. *Journal of Architectural Engineering*, *19*(1), 51-57.

BRANZ (2013). *BRANZ response to Ministry of Business, Innovation and Employment: Residential construction sector market study*. Wellington, New Zealand, Building Research Association of New Zealand.

BRANZ. (2010). *Construction productivity the lowest in 20 years*. Retrieved from http://www.branz.co.nz/cms_show_download.php?id=db0ab6091f9fb125f8fe853534bba2c888af5cd7

Bridgefield Group. (2006). Bridgefield group erp/Supply Chain (SC) glossary. [Online] Available: http://bridgefieldgroup.com/bridgefieldgroup/glos7.htm#P (March 3, 2020).

Briscoe, G., & Dainty, A. (2005). Construction supply chain integration: an elusive goal? Supply chain management: *An International journal*, *10*(4), 319-326.

Briscoe, G., Dainty, A. R., & Millett, S. (2001). Construction supply chain partnerships: skills, knowledge and attitudinal requirements. *European journal of purchasing & supply management, 7*(4), 243-255.

Bryman, A. and Bell, E. (2011). *Business Research Methods*. 3rd ed. Oxford et al.: Oxford University Press.

Burgess, J. C., Bucket, N. R. and Page, I. (2013). *Prefabrication impacts in the New Zealand construction industry*. Building Research Association of New Zealand (BRANZ).

Burrell, W.G., and Morgan, G. (1979). *Sociological paradigms and organizational analysis* . London: Heinemann.

Burwood, S., & Jess, P. (2005, October). Modern methods of construction evolution or revolution. In A BURA Steering and Development forum report.

Burwood, S., & Jess, P. (2005). *Modern methods of construction evolution or revolution.* In A BURA Steering and Development forum report.

Bygballe, L. E., Jahre, M., & Swärd, A. (2010). Partnering relationships in construction: A literature review. *Journal of purchasing and supply management*, *16*(4), 239-253. https://doi.org/10.1016/j.pursup.2010.08.002

Bygballe, L. E., Jahre, M., & Swärd, A. (2010). Partnering relationships in construction: A literature review. *Journal of purchasing and supply management*, *16*(4), 239-253.

Cervero, R., & Duncan, M. (2002). Benefits of proximity to rail on housing markets: Experiences in Santa Clara County. *Journal of Public Transportation*, *5*(1), 1-18

Chaston, D. (2021). Residential building consents jump in November, partly as COVID catchup, partly encouraged by very strong demand for housing where supply is very constrained. From interest.co.nz https://www.interest.co.nz/property/108602/residential-building-consents-jumpnovember-partly-covid-catchup-partly-encouraged

Chiang, Y.-H., Chan, E. H.-W., & Lok, L. K.-L. (2006). Prefabrication and barriers to entry—a case study of public housing and institutional buildings in Hong Kong. *Habitat International, 30(*3), 482-499.

CHRANZ. (2011). Discussion Paper: Why have Residential Construction Costs Increased more than Costs in other Sectors of the New Zealand Economy? Wellington, New Zealand: The Centre for Housing Research, Aotearoa New Zealand.

Cicmil, S. (2006). Understanding project management practice through interpretative and critical research perspectives. *Project management journal*, *37*(2), 27-37. https://doi.org/10.1177/875697280603700204

Cleland, D. I., & King, W. R. (1988). *Project management handbook.* New York: Van.

Collis J, Hussey R (2009). Business Research: A Practical Guide for Undergraduate & Postgraduate Students. New York: Palgrave MacMillan

Colorado State University. (2006). *Conducting Content Analysis*.

Construction, M. H. (2011). *Prefabrication and modularization: increasing productivity in the construction industry*. Smart Market Report

Cooper, M. C., & Ellram, L. M. (1993). Characteristics of supply chain management and the implications for purchasing and logistics strategy. *The international journal of logistics management*.4(2),13-24

Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply chain management: more than a new name for logistics. *The international journal of logistics management*, *8*(1), 1-14.

Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply chain management: more than a new name for logistics. *The international journal of logistics management*, *8*(1), 1-14.

Curtis, M.D. (2011). BRANZ Study Report 270: New House Owners Satisfaction Survey 2011. Wellington, New Zealand: Building Research Association of New Zealand.

Cushman, M., Venters, W., Cornford, T., & Mitev, N. N. (2002). *Understanding sustainability as knowledge practice*.

Dainty, A. R., Millett, S. J., & Briscoe, G. H. (2001). New perspectives on construction supply chain integration. Supply chain management: *An International journal*, *6*(4), 163-173.

Dainty, A., Moore, D., & Murray, M. (2007). *Communication in construction: Theory and practice*. Routledge.

Darlow, G., Rotimi, J. O., & Shahzad, W. M. (2021). *Automation in New Zealand's offsite construction (OSC): a status update*. Built Environment Project and Asset Management

David, M., & Sutton, C. D. (2011). *Social research: An introduction*. Sage.

Dawson, C 2009, *Introduction to research methods: a practical guide for anyone undertaking a research project*, 4th edn, How To Books, Oxford.

DBHNZ (2012). *Productivity roadmap*, Department of Building and Housing Wellington, New Zealand.

De Bruin, T., Rosemann, M., Freeze, R., & Kaulkarni, U. (2005). Understanding the main phases of developing a maturity assessment model. In *Australasian Conference on Information Systems (ACIS)* (pp. 8-19). Australasian Chapter of the Association for Information Systems.

Denny-Smith, G., Sunindijo, R. Y., Loosemore, M., Williams, M., & Piggott, L. (2021). How construction employment can create social value and assist recovery from COVID-19. Sustainability, 13(2), 988.

Deshmukh, A. J., & Vasudevan, H. (2014). Emerging supplier selection criterion in the context of traditional vs green supply chain management. *International Journal of Managing Value and Supply Chains*, *5*(1), 19.

Doran, D., & Giannakis, M. (2011). An examination of a modular supply chain: a construction sector perspective. Supply chain management: *An International journal*, *16*(4), 260-270.

Doran, D., & Giannakis, M. (2011). An examination of a modular supply chain: a construction sector perspective. Supply Chain Management: An International Journal, 16(4), 260-270.

Dubois, A., & Gadde, L. E. (2000). Supply strategy and network effects—purchasing behaviour in the construction industry. *European journal of purchasing & supply management, 6*(3-4), 207-215.

Easterby-Smith, M., Thorpe, R., & Jackson, P. R. (2012). *Management research*: Sage.

Ebner, N., & Iacovidou, E. (2021). The challenges of Covid-19 pandemic on improving plastic waste recycling rates. *Sustainable Production and Consumption*, *28*, 726-735.

Elnaas, E. (2014). *The decision to use Off-Site Manufacturing (OSM) systems for house building projects in the UK*. University of Brighton,

Fabbe-Costes, N., & Jahre, M. (2008). Supply chain integration and performance: a review of the evidence. *The international journal of logistics management*

Facchini, F., Oleśków-Szłapka, J., Ranieri, L., & Urbinati, A. (2020). A maturity model for logistics 4.0: An empirical analysis and a roadmap for future research. *Sustainability*, *12*(1), 86.

Farley, G. A. (1997). Discovering supply chain management: a roundtable discussion. APICS-the performance advantage, 7(1), 38-39.

Farmer, M. (2016). Modernise or Die: The Farmer Review of the UK Construction Labour Model. *Construction Leadership Council*, 36.

Fearne, A., & Fowler, N. (2006). Efficiency versus effectiveness in construction supply chains: the dangers of "lean" thinking in isolation. Supply chain management: *An international journal, 11*(4), 283-287.

Fellows, R., & Liu, A. (2008, December). Impact of participants' values on construction sustainability. In *Proceedings of the Institution of Civil*

Engineers-Engineering Sustainability (Vol. 161, No. 4, pp. 219-227). Thomas Telford Ltd.

Forum, H. (2002). Homing in on excellence: A commentary on the use of offsite fabrication methods for the UK housebuilding industry.

Franklin, C., & Ballan, M. (2001). Reliability and validity in qualitative research. The handbook of social work research methods, 4(273-292).

Gaze, C., Ross, K., Nolan, E., Novakovic, O., & Cartwright, P. (2007). Modern methods of construction (MMC) in housing: Drivers and barriers to their use. BRE INFORMATION PAPER IP, 3

Georgiadou, M. C. (2019). An overview of benefits and challenges of building information modelling (BIM) adoption in UK residential projects. *Construction Innovation*.

Georgiadou, M. C. (2019). An overview of benefits and challenges of building information modelling (BIM) adoption in UK residential projects. Construction Innovation.

Gibb, A. G. (1999). *Off-site fabrication*: prefabrication, pre-assembly and modularisation: John Wiley & Sons.

Gibb, A. G., & Isack, F. (2001). Client drivers for construction projects: implications for standardization. *Engineering Construction and Architectural Management*, *8*(1), 46-58.

Gibb, A., & Pendlebury, M. (2006). Glossary of terms. Buildoffsite: Promoting Construction Offsite, London, 39.

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The qualitative report*, *8*(4), 597-607.

Goodier, & Gibb, A. (2007). Future opportunities for offsite in the UK. *Construction Management and Economics*, *25*(6), 585-595.

Goodier, & Pan, W. (2012). Briefing: Future trends in UK housebuilding.

Gorgolewski, M. T. (2004). Housing in the natural city: The role of prefabrication. *Ekistics*, 113-117.

Gosling, J., & Naim, M. M. (2009). Engineer-to-order supply chain management: A literature review and research agenda. *International journal of production economics*, *122*(2), 741-754.

Gosling, J., Jia, F., Gong, Y., & Brown, S. (2016). The role of supply chain leadership in the learning of sustainable practice: toward an integrated framework. *Journal of Cleaner Production*, 137, 1458-1469.

Gray, J., Skates, H,, & Osterhaus, W. (2001). *Innovative, affordable, and sustainable housing, in CIB World Building Congress*, Wellington: New Zealand, pp. 1-8

Greene, J. C., & Caracelli, V. J. (1997). Defining and describing the paradigm issue in mixed-method evaluation. *New directions for evaluation*, *74*, 5-17.

Grix, J. (2002). Introducing students to the generic terminology of social research. *Politics, 22*(3), 175-186.

Haas, C. T., & Fagerlund, W. R. (2002). *Preliminary research on prefabrication, pre-assembly, modularization and off-site fabrication in construction*: Construction Industry Institute.

Hampson, K.; Brandon, P. Construction 2020: A Vision for Australia's Property and Construction Industry; CRC Construction Innovation: Boca Raton, FL, USA, 2004.

Handfield, R., & Nichols Jr, E. (1999). Introduction to. Supply Chain Management, Prentice Hall, Englewood Cliffs, NJ

Harris, C. (2021). Government lets factories return to unplug building supplies bottleneck [Press release]. Retrieved from Government lets factories return to unplug building supplies bottleneck

Hart, SJ 1991, 'A first-time user's guide to the collection of interview data from senior managers', in NC Smith & P Dainty (eds), *The management research handbook*, Routledge, New York, pp. 190-203.

Heron, J. (1996). *Co-operative inquiry: Research into the human condition*. Sage.

Housing Forum, (2002). *Homing in on excellence: A commentary on the use of offsite fabrication methods for the UK housebuilding industry*

Hu, W. (2008, December). Improving construction collaboration performance through supply chain control and management. In *2008 International Conference on Information Management, Innovation Management and Industrial Engineering*.1, 58-61. IEEE.

Iacovidou, E., Purnell, P., Tsavdaridis, K. D., & Poologanathan, K. (2021). Digitally enabled modular construction for promoting modular components reuse: A UK view. *Journal of Building Engineering*, *42*, 102820.

Jaillon, L., & Poon, C.-S. (2008). Sustainable construction aspects of using prefabrication in dense urban environment: a Hong Kong case study. *Construction Management and Economics, 26*(9), 953-966.

Jeong, J. G., Hastak, M., & Syal, M. (2006). Supply chain simulation modeling for the manufactured housing industry. *Journal of urban planning and development*, *132*(4), 217-225. 10.1061/(ASCE)0733-9488(2006)132:4(217)

Jia, G., Chen, Y., Xue, X., Chen, J., Cao, J., & Tang, K. (2011). Program management organization maturity integrated model for mega construction programs in China. *International Journal of Project Management, 29*(7), 834-845.

Jonsson, H., & Rudberg, M. (2014). Classification of production systems for industrialized building: a production strategy perspective. *Construction Management and Economics, 32*(1-2), 53-69.

Jørgensen, B., & Emmitt, S. (2009). Investigating the integration of design and construction from a “lean” perspective. *Construction Innovation, 9*(2), 225-240.

Kamali, M., & Hewage, K. (2016). Life cycle performance of modular buildings: A critical review. Renewable and Sustainable Energy Reviews, 62, 1171-1183.

Kanji, G. K., & Wong, A. (1998). Quality culture in the construction industry. *Total quality management*, *9*(4-5), 133-140. https://doi.org/10.1080/0954412988758

Kaufman, A., Wood, C. H., & Theyel, G. (2000). Collaboration and technology linkages: a strategic supplier typology. *Strategic Management Journal*, *21*(6), 649-663. https://doi.org/10.1002/(SICI)1097-0266(200006)21:6<649::AID-SMJ108>3.0.CO;2-U

Kawecki, L. R. (2010). *Environmental performance of modular fabrication*: Calculating the carbon footprint of energy used in the construction of a modular home: Arizona State University.

Kim, S. W., Park, M. K., Lee, P. H., & Lee, K. H. (2014, December). Sustainable design and construction of a prefab housing system with high performance. In *the proceedings of the 30th International PLEA conference, CEPT University, Ahmedabad* (pp. 16-18).

Kohlegger, M., Maier, R., & Thalmann, S. (2009*). Understanding maturity models*. Results of a structured content analysis: na.

Koskela, L. (2000). We need a theory of construction. In *Berkeley-Stanford Construction Engineering and Management Workshop: Defining a Research Agenda for AEC Process/Product Development in*.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction*. VTT Technical Research Centre of Finland.

Kumar, R 2005, *Research methodology: a step-by-step guide for beginners*, Sage, London.

Kwak, Y. H., & Ibbs, C. W. (2002). Project management process maturity (PM) 2 model. *Journal of Management in Engineering*, *18*(3), 150-155.

Lahti, M., Shamsuzzoha, A. H. M., & Helo, P. (2009). Developing a maturity model for Supply Chain Management. *International Journal of Logistics Systems and Management*, *5*(6), 654-678.

Langdon, D. (2004). Everest (2004) Off-site manufacturer–Cost model. Building, October (42), 67-72.

Langdon, D. (2004). Everest. *Stairway Communications Ltd.: London, UK.*

Latham, S. M. (1994). Constructing the team.

Lawson, R., & Ogden, R. (2010). *Sustainability and process benefits of modular construction*. Paper presented at the Proceedings of the 18th CIB World Building Congress, TG57-Special Track, Salford, UK.

Lee, H. L., & Billington, C. (1992). Managing supply chain inventory: pitfalls and opportunities. MIT Sloan Management Review.

Lessing, J. (2006). Industrialised house-building. Concept and Processes

Lessing, J. (2015). Industrialised house-building – development and conceptual orientation of the field. *Construction Innovation, 15*(3), 378-399. 10.1108/CI-06-2014-0032

Lessing, J., Stehn, L., & Ekholm, A. (2015). Industrialised house-building–development and conceptual orientation of the field. *Construction Innovation, 15*(3), 378-399.

Li, C. Z., Hong, J., Xue, F., Shen, G. Q., Xu, X., & Mok, M. K. (2016). Schedule risks in prefabrication housing production in Hong Kong: a social network analysis. *Journal of Cleaner Production*, 134, 482-494.

Lockamy, A., & McCormack, K. (2004). Linking SCOR planning practices to supply chain performance: An exploratory study. *International journal of operations & production management*. 24(12),1192-1218. https://doi.org/10.1108/01443570410569010

London, K. A., & Kenley, R. (2001). An industrial organization economic supply chain approach for the construction industry: a review. *Construction Management & Economics, 19*(8), 777-788.

Love, P. E., Irani, Z., & Edwards, D. J. (2004). A seamless supply chain management model for construction. *Supply chain management: an international journal*.9(1), 43-56

Lu, N. (2007). Investigation of the designers' and general contractors' perceptions of offsite construction techniques in the United States construction industry. Clemson University,

Lu, N. (2009). The current use of offsite construction techniques in the United States construction industry. Paper presented at the Construction Research Congress 2009: Building a Sustainable Future.

Lu, N., & Korman, T. (2010). Implementation of building information modeling (BIM) in modular construction: Benefits and challenges. Paper presented at the Construction Research Congress 2010: Innovation for Reshaping Construction Practice.

Lu, N., & Liska, R. W. (2008). Designers' and general contractors' perceptions of offsite construction techniques in the United State construction industry. *International journal of construction education and research,* 4(3), 177-188.

Mah, D. (2011). Framework for rating the sustainability of the residential construction practice.

Manley, K., & Widén, K. (2019). Prefabricated housing firms in Japan and Sweden: Learning from leading countries. In *Offsite Production and Manufacturing for Innovative Construction* (pp. 399-418). Routledge

Martinez, S., Jardon, A., Navarro, J. M., & Gonzalez, P. (2008). Building industrialization: robotized assembly of modular products. *Assembly Automation*.

Mason, G. (2013). New Zealand Productivity Commission.

Masood, R., Lim, J. B., & González, V. A. (2021). Performance of the supply chains for New Zealand prefabricated house-building. *Sustainable Cities and Society*, *64*, 102537.

Masood, R., Lim, J. B., González, V. A., Roy, K., & Khan, K. I. A. (2022). A systematic review on supply chain management in prefabricated house-building research. *Buildings*, *12*(1), 40.

Masood, R., Lim, J., & Gonzalez, V. A. (2016). A Taxonomy of Construction Supply Chain for Affordable Housing in New Zealand.

Mathers, N., Howe, A., & Hunn, A. (2018). Ethical considerations in research. In Developing Research in Primary Care (pp. 51-70). CRC Press.

Mayer, C. J., & Somerville, C. T. (2000). Residential construction: Using the urban growth model to estimate housing supply. *Journal of urban economics*, *48*(1), 85-109.

MBI (2010). *Improving construction efficiency & productivity with modular construction Charlottesville*, VA, USA, Modular Building Institute

MBIE (2013). Construction, Ministry of Business, *Innovation and Employment*, New Zealand 2013.

McCormack, K., Ladeira, M. B., & de Oliveira, M. P. V. (2008). Supply chain maturity and performance in Brazil. Supply chain management: *An International journal*

McDermotti, P., & Khalfan, M. (2012). Achieving supply chain integration within construction industry. *Construction Economics and Building*, *6*(2), 44-54.

McDonald, P., & Temple, J. (2013). Projections of housing demand in Australia, 2011–2041. Canberra: National Housing Supply Council.

Meiling, J., Backlund, F., & Johnsson, H. (2012). Managing for continuous improvement in off-site construction: Evaluation of lean management principles. *Engineering, Construction and Architectural Management*.

Meiling, J., Backlund, F., & Johnsson, H. (2012). Managing for continuous improvement in off-site construction: Evaluation of lean management principles. Engineering, Construction and Architectural Management.

Meng, X. (2010). Assessment framework for construction supply chain relationships: Development and evaluation. *International journal of project management*, *28*(7), 695-707.

Meng, X. (2020). Proactive management in the context of construction supply chains. *Production Planning & Control, 31*(7), 527-539.

Meng, X., Sun, M., & Jones, M. (2011). Maturity model for supply chain relationships in construction. *Journal of Management in Engineering, 27*(2), 97-105.

Meng, X., Sun, M., & Jones, M. (2011). Maturity model for supply chain relationships in construction. *Journal of management in engineering*, *27*(2), 97-105.

Mentzer, J., Witt, W. D., Keebler, J., Min, S., Nix, N., Smith, D., & Zacharia, Z. (2001). Defining Supply Chain (SC) management. *Journal of Business Logistics, 22*(2). https://doi.org/10.1002/j.2158-1592.2001.tb00001.x

Mohajan, H. (2017). Two criteria for good measurements in research: Validity and reliability. *Annals of Spiru Haret University Economics Series*, (4).

Mokhtar, S. N., & Mahmood, N. Z. (2008). Approach in construction industry: A study on prefabrication method as a tool for waste minimization. Paper presented at the International Conference on Environmental Research and Technology (ICERT.

Moradibistouni, M., & Gjerde, M. (2017). Potential for prefabrication to enhance the New Zealand construction industry. *Proceedings of the Back to the Future: The Next*, *50*, 427-435.

Moradibistouni, M., Vale, B., & Isaacs, N. (2018). Prefabrication: New Zealand manufacturers of prefabricated buildings and components 2017. Paper presented at the International Conference of the Architectural Science Association.

Morledge, R., Knight, A., & Grada, M. (2009). The concept and development of supply chain management in the UK construction industry. *Construction supply chain management: Concepts and case studies*, 23-41.

Mostafa, S., Chileshe, N., & Zuo, J. (2014). Enhancing Australian Housing Affordabillity: Off-site Manufacturing Supply Chain Strategies. Akademika forlag,

Mostafa, S., Dumrak, J., Chileshe, N., & Zuo, J. (2014). *Offsite manufacturing in developing countries: current situation and opportunities.* Paper presented at the 5th International Conference on Engineering, Project, and Production Management.

Mostafa, S., Dumrak, J., Chileshe, N., & Zuo, J. (2014, November). Offsite manufacturing in developing countries: current situation and opportunities. In *The 5th International Conference on Engineering, Project, and Production Management*.

Mullens, M. A., & Kelley III, M. E. (2004). Lean homebuilding using modular technology. *Housing and Society*, *31*(1), 41-54.

Murray, M. (2008). Rethinking construction: the egan report (1998*). Construction reports 1944*, 98, 178-195.

Muya, M., Price, A. D. F., & Thorpe, A. (1999, September). Contractor's supplier management. In *Proceedings of CIB W55165 Joint Triennial Symposium, Customer Satisfaction: A Focus for Research and Practice in Construction* (pp. 5-10).

Nadim, W., & Goulding, J. S. (2010). Offsite production in the UK: the way forward? A UK construction industry perspective. *Construction Innovation, 10*(2), 181-202.

Naim, M., & Barlow, J. (2003). An innovative supply chain strategy for customized housing. *Construction Management and Economics*, *21*(6), 593-602.

Navaratnam, S., Ngo, T., Gunawardena, T., & Henderson, D. (2019). Performance review of prefabricated building systems and future research in Australia. *Buildings*, *9*(2), 38.

Navaratnam, S., Ngo, T., Gunawardena, T., & Henderson, D. (2019). Performance review of prefabricated building systems and future research in Australia. *Buildings*, *9*(2), 38.

Nesarnobari, S., Shahzad, W., & Jelodar, M. B. (2022, November). The Status Quo of Prefabricated Housing: An investigation into New Zealand Construction Sector. In IOP Conference Series: Earth and Environmental Science (Vol. 1101, No. 4, p. 042014). IOP Publishing.

Netland, T. H., & Alfnes, E. (2011). Proposing a quick best practice maturity test for supply chain operations. Measuring Business Excellence

NZPC (2012). *Housing affordability inquiry*. New Zealand Productivity Commission Wellington: New Zealand.

O'Connor, J. T., O'Brien, W. J., & Choi, J. O. (2014). Critical success factors and enablers for optimum and maximum industrial modularization. Journal of Construction Engineering and Management, 140(6), 04014012.

Olaniyan, A., Bosede, A., & Olusola, O. (2015). Supply chain management practices in construction procurement: perceptions of professional quantity surveyors in Ondo State, Nigeria. *PM World Journal*, *4*(4), 1-12.

Oliver, R. K., & Webber, M. D. (1992). Supply Chain Management: Logistic Catches up with Strategy. Outbook, Booz Alen & Hamilton Inc., 1982. Logistic: The Strategic Issues. Ed. M. Christopher. Champan & Heath, London.

Page, I. (2012). *Prefab set to grow: Cost effective and convenient Wellington*, New Zealand, Building Research Association of New Zealand (BRANZ).

Page, I. and Norman, D. (2014). *Prefabrication and standardisation potential in buildings*. Wellington, New Zealand, Building Research Association of New Zealand.

Pan, W., & Goodier, C. (2012). House-building business models and off-site construction take-up. *Journal of architectural engineering, 18*(2), 84-93.

Pan, W., & Sidwell, R. (2011). Demystifying the cost barriers to offsite construction in the UK. *Construction Management and Economics*, *29*(11), 1081-1099.

Pan, W., Gibb, A. G., & Dainty, A. R. (2007). Perspectives of UK housebuilders on the use of offsite modern methods of construction. *Construction Management and Economics*, *25*(2), 183-194.

Pan, W., Gibb, A. G., & Dainty, A. R. (2008). Leading UK housebuilders' utilization of offsite construction methods. *Building Research & Information, 36*(1), 56-67.

Pan, W., Gibb, A. G., & Dainty, A. R. (2012). Strategies for integrating the use of off-site production technologies in house building. *Journal of Construction Engineering and Management, 138*(11), 1331-1340.

Parker, C., Scott, S., & Geddes, A. (2019). Snowball sampling. SAGE research methods foundations

Pasquire, C. L., & Gibb, A. G. (2002). Considerations for assessing the benefits of standardisation and pre-assembly in construction.

Patel, Y. (2017). File to factory: a case study of automated prefabrication house-building methods for small-to-medium enterprises.

Pedrini, C. N., & Frederico, G. F. (2018). Information Technology Maturity Evaluation in a Large Brazilian Cosmetics Industry. *International Journal of Business Administration, 9*(4), 15-24.

Pero, M., Stößlein, M., & Cigolini, R. (2015). Linking product modularity to supply chain integration in the construction and shipbuilding industries. International Journal of Production Economics, 170, 602-615.

Poshdar, M., Gonzalez, V. A., Antunes, R., Ghodrati, N., Katebi, M., Valasiuk, S., ... & Talebi, S. (2019). Diffusion of lean construction in small to medium-sized enterprises of housing sector. In Proceedings of the 27th Annual Conference of the International Group for Lean Construction (IGLC), Dublin, Ireland (pp. 3-5).

Power, D. (2005). Supply chain management integration and implementation: a literature review. Supply chain management: *An International journal, 10*(4), 252-263.

Power, D. (2005). Supply chain management integration and implementation: a literature review. *Supply chain management: An International journal*.

PrefabNZ (2014). *Value case for Prefab: How offsite construction can deliver better cost-effective housing to more New Zealanders*. Wellington, New Zealand, PrefabNZ.

PrefabNZ (2018). *Levers for PREFAB: How offsite construction can deliver better cost-effective housing to more New Zealanders*. Wellington, New Zealand, PrefabNZ.

PrefabNZ. (2013). Prefab roadmap: A way forward for prefabrication in New Zealand (2013–2018). Wellington, New Zealand: PrefabNZ. Retrieved from http://www.buildingabetternewzealand.co.nz/cms_show_download.php?id=10

Proverbs, D. G., & Holt, G. D. (2000). Reducing construction costs: European best practice supply chain implications. *European Journal of Purchasing & Supply Management*, *6*(3-4), 149-158. https://doi.org/10.1016/S0969-7012(00)00011-3

PRTM Management Consultants (2005) *Supply Chain Management Maturity Model: Understand the Transformation Required to Move from a Functionally Focused Supply Chain to Cross-enterprise Collaboration*, http://www.prtm.com/services/supply_chain_maturity_

Rahim, A. R. A., & Baksh, M. S. N. (2003). The need for a new product development framework for engineer-to-order products. European Journal of Innovation Management, 6(3), 182-196.

Rider Levett Bucknells. (2021). Forecast Report 99.

Ross, K. (2002). Non-traditional housing in the UK: a brief review. Council of Mortgage Lenders.

Rotimi, F. E., Almughrabi, F. M., Samarasinghe, D. A. S., & Silva, C. (2022). Specific skill requirements within prefabricated residential construction: stakeholders' perspectives. Buildings, 12(1), 43.

Roy, R., Low, M., & Waller, J. (2005). Documentation, standardization and improvement of the construction process in house building. *Construction Management and Economics, 23*(1), 57-67.

Saad, M., Jones, M., & James, P. (2002). A review of the progress towards the adoption of supply chain management (SCM) relationships in construction. *European Journal of Purchasing & Supply Management*, *8*(3), 173-183.

Saad, M., Jones, M., & James, P. (2002). A review of the progress towards the adoption of supply chain management (SCM) relationships in construction. *European Journal of Purchasing & Supply Management*, *8*(3), 173-183.

Saad, M., Jones, M., & James, P. (2002). A review of the progress towards the adoption of supply chain management (SCM) relationships in construction. *European Journal of Purchasing & Supply Management*, *8*(3), 173-183. https://doi.org/10.1016/S0969-7012(02)00007-2

Sabir, R., & Irfan, M. (2014). Levels & barriers to supply chain integration: a conceptual model of supply chain performance. International Journal of Management Science and Business Administration, 1(1), 52-59.

Salami, E., Aydinli, S., & Oral, E. L. (2013). Barriers to the Implementation of Supply Chain Management-Case of Small to Medium Sized Contractors in Turkey. *International Journal of Science and Research*, *5*(9), 516-520.

Samarasinghe, A., Tookey, J., & Rotimi, J. (2013). *Supply chain collaboration in New Zealand house construction.*

Samarasinghe, D. A. S. (2014). Building materials supply chains: an evaluative study of the New Zealand residential construction. Auckland University of Technology

Sarshar, M., Haigh, R., Finnemore, M., Aouad, G., Barrett, P., Baldry, D., & Sexton, M. (2000). SPICE: a business process diagnostics tool for construction projects. *Engineering, construction and Architectural management*

Saunders, M. N., & Townsend, K. (2016). Reporting and justifying the number of interview participants in organization and workplace research. *British Journal of Management*, *27*(4), 836-852.

Saunders, M., Lewis, P., & Thornhill, A. (2009). Research Methods for Business Students (5th edn). In: Pearson Education.

Schmidt, G., & Wilhelm, W. E. (2000). Strategic, tactical and operational decisions in multi-national logistics networks: a review and discussion of modelling issues. International Journal of Production Research, 38(7), 1501-1523.

Schumacher, A., Erol, S., & Sihn, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. *Procedia Cirp, 52*(1), 161-166.

Schumacher, A., Erol, S., & Sihn, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. *Procedia Cirp*, *52*, 161-166. https://doi.org/10.1016/j.procir.2016.07.040

Seidman, I. (2013). Interviewing as qualitative research: A guide for researchers in education and the social sciences. Thousand Oaks, CA: Sage

Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill building approach*. john wiley & sons.

Serpell, A., & Heredia, B. (2004). Supply chain management in construction: Diagnosis and application issues. *Globalisation and Construction*, *455*.

Serpell, A., & Heredia, B. (2004). Supply chain management in construction: Diagnosis and application issues. *Globalisation and Construction*, *455*.

Shahzad, W. M. (2016). *Comparative analysis of the productivity levels achieved through the use of panelised prefabrication technology with those of traditional building system: a thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy (PhD) in Construction, School of Engineering & Advanced Technology, Massey University, Albany, New Zealand* (Doctoral dissertation, Massey University).

Shahzad, W., Mbachu, J., & Domingo, N. (2015). Marginal productivity gained through prefabrication: Case studies of building projects in Auckland. Buildings, 5(1), 196-208.

Shingo, S. (1988). Non-stock production: the Shingo system of continuous improvement. CRC Press.

Shooshtarian, S., Maqsood, T., Wong, P. S., Khalfan, M., & Yang, R. J. (2021). Extended producer responsibility in the Australian construction industry. Sustainability, 13(2), 620.

Smits, W., van Buiten, M., & Hartmann, T. (2017). Yield-to-BIM: impacts of BIM maturity on project performance. *Building Research & Information*, *45*(3), 336-346.

Sparksman, G., Groak, S., Gibb, A., & Neale, R. (1999). *Standardisation and pre-assembly: Adding value to construction projects*. CIRIA Report, 176

Spekman, R. E., Kamauff, J. W., & Myhr, N. (1998). An empirical investigation into supply chain management: a perspective on partnerships. *Supply Chain Management: An International Journal*.

Spekman, R. E., Kamauff, J., & Spear, J. (1999). Towards more effective sourcing and supplier management. *European Journal of Purchasing & Supply Management*, *5*(2), 103-116.

Statistics New Zealand. (2021). https://www.stats.govt.nz.

Steinhardt, D. A., & Manley, K. (2016). Adoption of prefabricated housing–the role of country context. *Sustainable cities and society*, *22*, 126-135.

Steinhardt, D., Manley, K., Bildsten, L. and Widen, K. (2019). The structure of emergent prefabricated housing industries: A comparative case study of Australia and Sweden. *Construction management and Economics*, 1-19.

Storey, J., Emberson, C., Godsell, J., & Harrison, A. (2006). Supply chain management: theory, practice and future challenges. *International Journal of Operations & Production Management*. 26(7),754-774

Straight, S. L.(n.d.) *How Mature Is your Supply Chain*? The SCRD Capability Maturity Model© Robert B. Handfield, Ph. D. Bank of America University Distinguished Professor of SCM Director, Supply Chain Resource Consortium.

Stroebele, B. S., & Kiessling, A. J. (2017). Impact Analysis of Complexity Drivers in the Supply Chain of Prefabricated Houses. *Journal of Management and Strategy*, *8*(1), 1.

Succar, B., Sher, W., & Williams, A. (2012). Measuring BIM performance: Five metrics. *Architectural Engineering and Design Management*, *8*(2), 120-142.

Swartz, E., Money, A., Williams, B., & Remenyi, D. (1998). Doing research in business and management: an introduction to process and method. *Doing Research in Business and Management*, 1-320.\

Tam, C. M. (2002). *Impact on structure of labour market resulting from large-scale implementation of prefabrication*. Paper presented at the Advances in Building Technology: Proceedings of the International Conference on Advances in Building Technology, 4-6 December, 2002, Hong Kong, China.

Tam, C., Tam, V. W., Chan, J. K., & Ng, W. C. (2005). Use of prefabrication to minimize construction waste-a case study approach. *International Journal of Construction Management, 5*(1), 91-101.

Tashakkori, A., & Creswell, J. W. (2008). Editorial: Mixed methodology across disciplines. *Journal of Mixed Methods Research*, *2*(1), 3-6.

Taylor, M. D. (2010). A definition and valuation of the UK offsite construction sector. *Construction Management and Economics, 28*(8), 885-896.

Tetik, M., Peltokorpi, A., Seppänen, O., & Holmström, J. (2022). Defining the Maturity Levels for Implementing Industrial Logistics Practices in Construction. *Frontiers in Built Environment*, *7*, 190.

Thanasegaran, G. (2009). Reliability and Validity Issues in Research. *Integration & Dissemination*, *4*.

Tjell, J., & Bosch-Sijtsema, P. M. (2015). Client's presence during design. A study on roles, practice and visual management. Management, 733, 742.

Tongco, M. D. C. (2007). Purposive sampling as a tool for informant selection.

Trevett, C. (2018, June 24). Housing Mnister Phil Twyford looks overseas for KiwiBuild prefab house builders. Retrieved from NZ Herald: https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12076991 (accessed 27 June 2018)

Trevett, C. (2018, June 24). Housing Mnister Phil Twyford looks overseas for KiwiBuild prefab house builders. Retrieved from NZ Herald: https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12076991 (accessed 04 February 2023)

Tushman, M., & Moore, W. L. (1988). *Readings in the Management of Innovation*: Ballinger.

Twycross, A., & Shields, L. (2004). Validity and reliability-What's it all about? Part 2 Reliability in quantitative studies. *Paediatric Nursing, 16*(10), 36.

Vaidyanathan, K. and Howell, G. (2007) 'Construction supply chain maturity model – conceptual framework', *Proc. 15th Annual Conference of the International Group for Lean Construction (IGLC)-15,* East Lansing, Michigan, USA, pp.170–180.

Venables, T., Barlow, J., & Gann, D. (2004). *Manufacturing excellence*: UK capacity in offsite manufacturing: Innovation Studies Centre.

Viana, D. D. (2015). Integrated production planning and control model for engineer-to-order prefabricated building systems.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European journal of purchasing & supply management, 6*(3), 169-178.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European journal of purchasing & supply management, 6*(3-4), 169-178.

Vrijhoef, R., Koskela, L., & Howell, G. (2001). *Understanding construction supply chains: an alternative interpretation*. Paper presented at the Proceedings of 9th International Group for Lean Construction Conference.

Walter, M 2010, *Social research methods*, 2nd edn, Oxford University Press, South Melbourne, Vic.

Waskett, P. (2003). *Current practice and potential uses of prefabrication*. BRE (Building Research Establishment): DTI (Department of Trade and Industry), project report (203032)

Wilkinson, S. (2001). An analysis of the problems faced by project management companies managing construction projects. *Engineering, Construction and Architectural Management*.

Winch, G. (2003). Models of manufacturing and the construction process: the genesis of re-engineering construction. Building research & information, 31(2), 107-118.

Womack, J. P., & Jones, D. T. (2010). Lean thinking: banish waste and create wealth in your corporation: Simon and Schuster.

Wong, A. & Fung, P. (1999). Total quality management in the construction industry in Hong Kong: A supply chain management perspective. Total Quality Management, 10, 199-208..

Xue, X., Li, X., Shen, Q., & Wang, Y. (2005). An agent-based framework for supply chain coordination in construction. *Automation in construction, 14*(3), 413-430.

Yin R. K. Applications of case study research. 2012; 3rd ed, Thousand Oaks, CA: Sage

Yin, R.K. (2014). *Case study research: design and methods*, Sage Publications, Thousand Oaks, California.

Ying, F. J., Tookey, J., & Roberti, H. (2014). *Development of SCM competencies in construction*: lessons learned from New Zealand.

Ying, J. F., Tookey, J., & Roberti, J. (2015). SCM competencies in construction: issues and challenges in New Zealand. *Journal of Engineering, Design and Technology*, *13*(4), 522-538.

Zhai, X., Reed, R., & Mills, A. (2014a). Embracing off-site innovation in construction in China to enhance a sustainable built environment in urban housing. *International Journal of Construction Management*, *14*(3), 123-133.

Zhai, X., Reed, R., & Mills, A. (2014b). Factors impeding the offsite production of housing construction in China: an investigation of current practice. *Construction Management and Economics*, *32*(1-2), 40-52.

Zhang, X., & Skitmore, M. (2012). Industrialized housing in China: a coin with two sides. *International Journal of Strategic Property Management*, *16*(.2), 143-157.

Zhao, X., & Riffat, S. (2007). Prefabrication in house constructions. International Journal of Low-Carbon Technologies, 2(1), 44-51.

Appendix A

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PARTICIPANTS INFORMATION SHEET

SUPPLY CHAIN INTEGRATION IN PREFABRICATED RESIDENTIAL CONSTRUCTION IN NEW ZEALAND

Project Description:

Housing Affordability in New Zealand has become a national problem attributed to the high level of private debts of the people. Current housing market of the country cannot cater to the spikes in demand for affordable houses. The shortfall in the supply of houses is triggered by anti-development attitudes, tighter building regulations, and artificial restrictions on land supply. Even though the NZ government has been taken several initiatives to control the situation, a more focused industry level approach is also essential to control the situation more effectively.

It is palpable that the efficient use of materials onsite and standardized designs can save overall project cost and time. Increase the use of prefabricated items is one of the solutions to achieve above (PrefabNZ, 2014). Despite the fact that prefabrication technology can facilitate the above, it is not very commonly practised in housing construction in New Zealand (Shahzad, 2016, Samarsinghe, 2014, PrefabNZ, 2014). Literature suggests that a more integrated supply chain of the prefabricated products would be an appropriate solution to increase the uptake of prefabrication elements into the housing construction industry.

Therefore, the intention of this research is to develop a framework to measure the current maturity level of prefabrication supply chain in the housing industry and provide solutions to achieve a more integrated supply chain practice to increase the uptake of prefabricated elements into housing construction. Before developing the model, it is important to investigate the nature of the SC supply chains and supply chain relationships in the prefabricated residential construction and to identify the barriers and enablers for supply chain integration. The main purpose of this interview is to investigate the prefabricated residential construction in terms current supply chain practices, barrier and enablers to supply chain integration.

I invite you to voluntarily participate in this research. Your participation in this research is anonymity, and you may withdraw from this research at any time, without providing an explanation. The data obtained will be stored securely under strict access and password protection. The project findings will be published in conferences and journals. The participants will be notified of the publications when requested.

Your participation in this research is highly valued. Please feel free to contact the research or supervisors if you have any concerns, questions or doubts.

Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Northern, Application 4000018285. If you have any concerns about the conduct of this research, please contact Dr Lily George, Acting Chair, Massey University Human Ethics Committee: Northern, telephone 09 414 0800 x 43923, email humanethicsnorth@massey.ac.nz.

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INTERVIEW CONSENT FORM

SUPPLY CHAIN INTEGRATION IN PREFABRICATED RESIDENTIAL CONSTRUCTION IN NEW ZEALAND

Researcher: Nishadi Sooriyamudalige

Project Main Supervisors: Dr Niluka Domingo

- I have read and understood the information provided about this research project in the Information Sheet.
- I have had an opportunity to ask questions and to have them answered.
- I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.
- I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.
- I agree to participate in this interview.

....	……………………….	………………………..
Name of participant	Date	Signature

Note: The participants should retain a copy of this form

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INTERVIEW QUESTIONS

SUPPLY CHAIN INTEGRATION IN PREFABRICATED RESIDENTIAL CONSTRUCTION IN NEW ZEALAND

Q.1) What is your role in the company and relevancy to the NZ residential construction industry?

Q.2) How long have you been working with the company?

Q.3) What are the types of prefabrication you dealt with?

Q.4) What are the most commonly used types of prefabrication in residential construction?

Q.5) Do you think prefabrication can improve the productivity issue in housing construction?

Q.6) If yes, in which ways? If no, why?

Q.7) What do you think about the supply chain of prefabricated residential construction/module manufacturing/panel manufacturing?

- What are the different stages in the supply chain?
- What are the relationships in the supply chain?
- What kind of relationships is those (collaborative or dependent)?
- What kind of information they share and how do they share information?
- What are the cruisial stages in the supply chain?
- What knind of programmes, softwares are used to streamline the process?

Q.8) What are the issues associated with the supply chain of prefabricated residential construction/module manufacturing/panel manufacturing?

Probing Questions- Project planning

Desinging of the project

Supplier and customer relationships

Information sharing and technology

Performce monitoring

Transpostation and staorage capcity

Material and labour availability

Any external factors

Q.9) What are your suggestions to improve the supply chain of prefabricated residential construction/module manufacturing/panel manufacturing?

Probing Questions- To streamline ans standerised the process

For design flexibility/design changes

To maintain a stable relationship with suppliers and clients

To improve the productivity

To handle transportation

To labour/material shortage

To minimise the design errors in on-site installation

Any other suggestions

Q.10) Any further thoughts?

Appendix B

A Prefabrication Construction Supply Chain Maturity Model

The intention of this questionnaire is to evaluate a model developed as a part of my PhD research. The aim of the study is to guide the prefabrication element manufacturers to improve the efficiency of the supply chain.

It would be very appreciative if you could kindly spend 10-15 minutes of your valuable time to complete this questionnaire and assist me with the research. The information you provide will be used for academic purposes only, that will be dealt with strict confidence, and only summary results may be released.

This research project has been approved by the Ethics Committee of the Massey University (Ethics Notification Number: 4000018285). If you have any concerns about the conduct of this research, please contact A/Prof David Tappin, Chair, Massey University Human Ethics Committee: Northern, telephone 64 9 414 0800 x 43384, email humanethicsnorth@massey.ac.nz.

Nishadi Sooriyamudalige
Massey University
Email: n.sooriyamudalige@massey.ac.nz

* Required

Participants Consent

1. Do you wish to be a participant in this research? *

Mark only one oval.

- ( ) Yes (which means you give consent to become a participant)
- ( ) No

2. Name (Provide only if you wish to receive summary results)

____

3. E-mail (Provide only if you wish to receive summary results)

____

Model Evaluation

Please give your opinion on the model

(For close-ended questions- 1- Strongly agree, 2-Agree, 3-Neither Agree/Disagree, 4-Disagree, 5-Strongly Disagree)

4. Is the maturity model clear to you?

Mark only one oval.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

5. Are the contents of the model clear to you?

Mark only one oval.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

6. Is the model user-friendly to be used by the prefab manufacturing companies?

Mark only one oval.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

7. Do you think the model will be used by prefab manufacturing companies?

Mark only one oval.

	1	2	3	4	5	
Strongly Agree	◯	◯	◯	◯	◯	Strongly Disagree

8. Do you think the model captures all the attributes of the assessment criteria?

Mark only one oval.

	1	2	3	4	5	
Strongly Agree	⬭	⬭	⬭	⬭	⬭	Strongly Disagree

9. Do you think that the developed maturity levels are appropriate and sufficient?

Mark only one oval.

	1	2	3	4	5	
Strongly Agree	⬭	⬭	⬭	⬭	⬭	Strongly Disagree

10. How important do you think this model would be to improve the supply chain in prefab elements manufacturing companies?

____

____

____

____

____

11. Do you have any suggestions to improve the model?

____

____

____

____

____

Thank you for responding to this questionnaire.

Appendix C

INTERVIEW QUESTIONS

SUPPLY CHAIN INTEGRATION IN PREFABRICATED RESIDENTIAL CONSTRUCTION IN NEW ZEALAND

PART 1- SUPPLY CHAIN OF PREFABRICATED BATHROOM PODS/WALL PANELS

1. How long have you been established as a business in the NZ housing market?
2. How does your company contribute to the NZ residential construction industry?
3. What type of prefabrication products does your company produce?
4. Can you please explain your company's organisational structure?
5. Do you have any partnerships / subsidiary companies?
6. How many direct staff does your company employ?
7. How many contract staff does your company employ?
8. How long does it typically take to complete a house/bathroom pod/wall panel?
9. Is your manufacturing process synchronised?
10. What are the steps you have taken to improve customer satisfaction?
11. What role does your supply chain play in achieving your business goals?
12. What are the main problems /issues identified in the supply chain your currently use?
13. How do you manage unexpected delays in projects?

PART 2- INCEPTION AND DESIGN STAGE

1. What is your role in the company and how long have you been working with it?
2. Do you collaborate with clients and suppliers to develop the final design?
3. Are changes in a design approved through a formal, documented approval process?
4. Do you have any partnerships with your clients? And if yes, how do you maintain your client relationships?
5. Is a demand forecast developed for each client?
6. What type of software do you use when designing your products?
7. Do you share design information with your clients and other supply chain members?
8. Are your client's planning and scheduling information included in your delivery schedules?

9. Do you maintain any database for demand forecasting and is it integrated with production planning?

PART 3- PRODUCTION SCHEDULING STAGE

1. Do you have a documented (written description, flow charts, etc.) system for production planning and scheduling?
2. How frequently do you review your production process (daily/ weekly or monthly)?
3. How do you communicate production demand within your supply chain?
4. Do you collaborate with other supply chain members to develop your production plan?
5. What type of software do you use when you schedule your workload?
6. Do your current internal systems and processes adequately address the needs of the business?
7. Are your planning processes integrated and coordinated across all your company's divisions?
8. How is your shop floor scheduling integrated with the overall scheduling process?
9. How well do your information systems currently support the scheduling process?
10. What type of information system tools are currently being used to share information?

PART 4- PROCUREMENT STAGE

1. What is your role in the company and how long have you been working with it?
2. Is your procurement process documented?
3. How are your suppliers selected?
4. How are your supplier's performance measured? For example, do you have key performance indicators (KPI's) to benchmark their continual improvement?
5. Do suppliers manage "your" inventory of supplies?
6. Do you have collaborative relationships with your strategic suppliers?
7. Do you have electronic ordering capabilities with your suppliers?
8. Do you share planning and scheduling information with your suppliers and vice versa?
9. Do key suppliers have employees on your site(s)?
10. Are your supplier relationships managed and documented and if so, how?

11. Does your manufacturing arm of your company work closely with the whole procurement team?

PART 5- MANUFACTURING STAGE

1. Is cost control the main focus of the manufacturing process?
2. Do you measure real-time performance against a production, delivery and installation schedule?
3. How is productivity time streamlined?
4. How do you communicate with fellow production team members?
5. How do you manage changes during the production process?
6. Do you share planning and scheduling information with all the production team members?
7. What kind of a relationship do you have with the production team members? (Collaborative / adversarial)
8. Is your production process fully automated and integrated with other functions such as; design, procurement, manufacturing, certification during manufacturing such as plumbing and electrical, delivery, installation and final commissioning?
9. How do you manage unexpected delays during the production process with labour and materials or receiving design variations?
10. What strategies (if any) have been initiated to improve the efficiency and quality of the production process?

PART 6- TRANSPORTATION STAGE

1. Do you have to promise delivery times as part of your contractual arrangement with your customers?
2. How is the delivery process integrated with your company's information system and schedules?
3. Are your delivery processes integrated with your client's project schedules?
4. How do you measure the performance of delivering your products to site?
5. How do you manage unexpected delays?
6. What are the strategies you have been taken to improve the process of delivering on time?

7. What type of tools and machinery are you using for loading and unloading your products?

PART 7- ON-SITE ASSEMBLY STAGE

1. How do you perform on-site installations?
2. What type of machinery / equipment do you use to install your products?
3. How is the on-site assembly co-ordinated with clients and your team?
4. How long does it usually take to complete installations?
5. How many workers do you typically require to do a single installation?
6. What typically causes variations during on-site installations?
7. How long do on-site variations typically add to the overall project programme?
8. How is the on-site assembly process integrated into your client's project schedule?

END