COMPARATIVE ANALYSIS OF THE PRODUCTIVITY LEVELS ACHIEVED THROUGH THE USE OF PANELISED PREFABRICATION TECHNOLOGY WITH THOSE OF TRADITIONAL BUILDING SYSTEM

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COMPARATIVE ANALYSIS OF THE PRODUCTIVITY LEVELS ACHIEVED THROUGH THE USE OF PANELISED PREFABRICATION TECHNOLOGY WITH THOSE OF TRADITIONAL BUILDING SYSTEM

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STATEMENT OF ORIGINALITY

I declare that this thesis is my own work, except where due acknowledgement is made, and that it has not been previously included in a thesis, dissertation or report submitted to this University or to any other institution for degree or any other qualification.

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Wajiha Mohsin Shahzad

ABSTRACT OF RESEARCH

Several studies have documented benefits of prefabricated building system compared to the traditional approach. Despite the acknowledged benefits of prefabrication, its application is generally low in the New Zealand construction industry. This low uptake is largely attributed to the fact that the documented benefits of prefabrication technology are anecdotal, or based on investigations of isolated case studies. This study aims to contribute to filling this knowledge gap by analysing cost savings, time savings, and productivity improvement achievable by the use of panelised prefabrication in place of the traditional building system. A two-phased mixed method of research was adopted for the study. The first phase involved the use of case study-based archival research to obtain qualitative data from records of 151 completed building projects in three cities of New Zealand – Auckland, Christchurch and Wellington. The second phase involved the use of questionnaire survey to obtain feedback from industry stakeholders. Results showed that the use of panelised prefabrication in place of traditional building system contributed to 21 percent cost saving, 47 percent time saving and 10 percent average improvement in the productivity outcomes in the building projects. Results further showed that 17 factors could significantly influence the levels of benefits achievable with the use of prefabrication technology. 'Building type' and 'location' were the factors having the most significant influence on the benefits achievable by the use of panelised prefabrication in place of the traditional building systems. Other factors that influence the benefits of prefabrication included (in diminishing order of influence): logistics, type of prefabrication, scale/repeatability, standardisation, contractor's level of innovation, environmental impact, project leadership, type of procurement, whole of life quality, site conditions, site layout and client's nature.

Key words: Construction, Cost, New Zealand, Prefabrication, Performance, Productivity, Time.

ETHICAL APPROVAL

Massey University Human Ethics Committee (MUHEC) granted ‘Low Risk Notification’ to this research project on 6 March 2013 (Appendix A).

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Thank you cannot truly address all that my husband Mohsin has done during the decade of our togetherness. All I will say is I would not be the person I am today if we were not together. Many heartfelt thanks to you Mohsin. And many heartfelt thanks to you all.

DEDICATION

To my amazing parents

Khalida Gulzar & Gulzar Ahmed

LIST OF ABBREVIATIONS

ACENZ	Association of Consulting Engineers New Zealand
ANOVA	Analysis of Variance
BCSPT	Building and Construction Sector Productivity Taskforce
BRANZ	Building Research Association of New Zealand
CRC	Cooperative Research Centre
DBH	Department of Building and Housing
GFA	Gross Floor Area
IPENZ	Institute of Professional Engineers New Zealand
JIT	Just in Time
LVL	Laminated Veneer Lumber
NZIA	New Zealand Institute of Architects
NZIOB	New Zealand Institute of Builders
NZIQS	New Zealand Institute of Quantity Surveyors
MBI	Modular Building Institute
MNOVA	Multivariate Analysis of Variance
MUHEC	Massey University Human Ethics Committee

OECD	Organization of Economic Co-operation and Development
OSM	Off-Site Manufacturing
PCA	Principle Component Analysis
Prefab	Prefabrication
RMBF	Registered Masters Builders Federation
SPSS	Statistical Package for the Social Sciences
TBS	Traditional Building System
UK	United Kingdom
USA	United States of America

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CHAPTER 1: INTRODUCTION

1.1 Background

Construction businesses comprise the third largest industry in New Zealand and include over 500,000 businesses that provide employment opportunities to 8 percent of the New Zealand workforce (Housing Affordability Report, 2012). Statistics New Zealand (2013) reports that the industry is a key contributor to the economy and contributes over 4.6 percent to the Gross Domestic Product (GDP) with a gross capital formation of over $6 billion annually.

Despite the significant importance of the industry to the economy and the social wellbeing of the citizens, its productivity performance has steadily declined. For instance, Page (2012) reported a steady decline in the productivity of the industry over the last two decades with an annual drop of 0.1 percent since 1990. This situation in the construction industry contrasts with other sectors of the New Zealand economy, which are showing an upward trend with an annual productivity rise of 0.2 percent. Similarly, the Building and Construction Productivity Partnership Taskforce (2012) observed that the productivity of the sector is declining compared to the output of the construction industries in other developed economies. The Building and Construction Sector Productivity Taskforce (BCSPT, 2012) report also warns that "New Zealand construction industry productivity has been disappointing and it is limiting the sector's ability to respond positively to change" (p.12). The report highlighted the urgent need to address this unhealthy development via the use of modern technologies such as prefabrication.

On account of the declining productivity trend, there has been increasing interest in the improvement of the productivity performance of the New Zealand construction industry. This is more so in that it concludes that a 10 percent efficiency gain in the building and construction sector results in a 1 percent change in the New Zealand real GDP (Nana, 2003). Efficiency gain in this context is defined as achieving the increased output from the existing or fewer inputs and having a good quality end-product at a competitive price (BCSPT, 2012).

Prefabrication technology, also sometimes known as 'prefab' or 'offsite manufacturing' (OSM) of building components is a relatively modern and innovative construction approach. The technology aims to take the bulk of construction activities away from project site so as to minimise onsite inefficiencies and hazards. Prefabrication technology entails the manufacturing of building components under a controlled environment in a specialized factory setting.

Prefabrication technology has been acknowledged to offer numerous benefits compared to traditional building system. It is believed that taking advantage of the prefabrication of building components holds brighter prospects and will be able to improve the reported low productivity trend in the New Zealand construction industry. Owing to the various established benefits of prefabrication, this technology has been considered globally by many industry-driven commissions of enquiry as an effective solution to several problems faced by the construction industry.

Various studies advocate that the use of prefabrication technology offers a better control of conditions, which in turn has the potential to curtail project cost overruns. Similarly time overruns can be avoided with the use of the prefabrication system (CACPUCI, 2009, Shahzad and Mbachu, 2012b, Blismas et al., 2006).

Despite all of the acknowledged benefits of prefabrication, its application is generally low in the New Zealand construction industry. Earlier in her Masters research, the researcher Shahzad (2011) observed that the low rate of the industry-wide uptake of prefabrication is not consistent with its benefits. The reported low uptake of prefabrication technology in the construction process is attributed to the fact that most of the documented benefits of prefabrication technology are anecdotal, not quantified or based on investigations of isolated case studies (Davis, 2007, CRC, 2007). Bell (2009) also reported that it is due to the lack of quantifiable or to the evidence-based benefits of prefabrication that is contributing to the low uptake of this beneficial construction approach. Clients do not base investments on anecdotal evidence, they need objectively quantifiable evidence of the technology to encourage them to invest in its use in project implementation (Parke, 2014).

This research study is focused on filling the identified knowledge gap by aiming to provide objectively quantifiable benefits of the technology compared to the traditional building systems. The quantifiable benefits relate to the cost saving, and time savings and productivity improvements achievable in some case study projects over and above the outcomes for the traditional building system. As a result, case studies of building projects implemented using the framed/panelised prefabrication have been investigated in three main cities in New Zealand - Auckland, Christchurch and Wellington. Five types of buildings that were completed using panelised prefabrication were investigated. These included apartments, commercial buildings, community buildings, educational buildings and residential houses. Using a complementary questionnaire survey, the study also investigated the level of influence of various factors that contribute to the benefits of prefabrication technology. The results from the case studies were triangulated with the survey results for the purpose of reliability and validity.

1.2 Statement of Research Problem

The construction industry can benefit from prefabrication technology in many ways that support significant improvement in its productivity and performance (Tam et al., 2007). As a result, there have been increasing recommendations to uplift the productivity performance of the industry by utilising the benefits of prefabrication technology, especially where it delivers superior outcomes compared to the traditional building system (Bell, 2009).

In spite of the acknowledged benefits of prefabrication, its industry-wide uptake is still very low. This low uptake of prefabrication in New Zealand construction industry is attributed to various factors including lack of evidence-based benefits of the prefabrication system compared to traditional building system, reluctance by the stakeholders to change the industry and market culture and complexity of processes involved prefabricated construction being the most influential factors (Bell, 2016, Page, 2012, Scofield et al., 2009). For a reliable and convincing case for the improved uptake of the prefabrication technology, there is a need to provide empirical evidence in terms of its quantifiable benefits compared to the traditional building system.

This study contributes to filling the existing knowledge gap on the evidence-based and quantifiable benefits of prefabrication technology by aiming to analyse the cost savings, time savings, and the productivity improvements achievable via the use of prefabrication in place of the traditional building system. This is counter to the background that the documented benefits of the technology have been anecdotal or are mostly based on information provided by isolated case studies and hence is not adequate, thorough or convincing enough to clients in terms of investment decision-making.

In order to provide the evidence-based cost and time saving benefits of prefabrication, case studies of building projects implemented using prefabrication in Auckland, Christchurch and Wellington were investigated. Records of completion times and final cost of project on completion were collected for 151 projects. Case study investigations were carried out for apartments, commercial, community and educational buildings, as well as for detached houses. For each of the buildings included in the case study investigations, details including final contract sums, completion dates, duration of construction, location, gross floor areas (GFA), and number of floors were collected. Based on the data, the equivalent completion times and the final cost estimates for similar buildings implemented using the traditional building system were obtained from estimates provided by some practising quantity surveyors and building contractors. The productivity outcome for each building project was computed as the product of the cost and time savings achieved with the use of prefabrication (Takim and Akintoye, 2002).

1.3 Research Aim, Questions and Objectives

1.3.1 Research Aim

The overarching aim of this study was to quantitatively analyse the cost savings, time savings and productivity improvement that could be achieved by the use of panelised prefabrication system in place of the traditional building system in the case study building projects. The study also aimed to explore further factors influencing the added benefits of prefabrication and to triangulate the case study results with expert opinions supplied via questionnaire surveys of key industry stakeholders.

1.3.2 Research Questions

The central question that underpinned this study was formulated as follows: How do productivity levels achieved through the use of panelised prefabrication technology compare with those of traditional building system? The following sub-research questions were set forth to inform the research design, data gathering and analysis, and hypotheses testing:

1. To what extent can panelised prefabrication technology deliver superior value in terms of cost savings, time savings and improvement in productivity, when used in place of traditional building system?
2. What are the relative levels of influence of the factors impacting on the benefits accruable from the use of panelised prefabrication, and which are the most influential of these factors?
3. How would the findings from archival research compare to those of the questionnaire survey? What are the implications of the outcome of this comparison on the reliability and validity of the research findings and their ability to be generalised beyond the scope of the study?

1.3.3 Research Objectives

To achieve the research aims and questions, the study set out to accomplish the following objectives:

1. To quantify the benefits that panelised prefabrication technology can offer in terms of cost savings, time savings and productivity improvements, over and above the corresponding benefits achievable with the use of traditional building system.
2. To identify and prioritise the factors that can significantly influence the benefits achievable by the use of prefabrication technology.
3. To examine how the benefits analysed from the case studies of completed project records compared to those from industry stakeholders' feedback with a view to ascertaining the implications of the outcome of this comparison in terms of the reliability and validity of the research findings and their ability to be generalised beyond the study scope.

1.4 Research Propositions

The following research propositions were put forward to gain an understanding of the nature of the empirical data required for the study. The propositions also provided directions for the formulation of the research strategy and the choice of methods of data collection and analysis in order to achieve the set research objectives.

1. The use of the panelised prefabrication system in place of the traditional building system does not offer some significant levels of benefits in terms of cost savings, time savings and overall productivity improvement across the building types and locations.
2. 'Building type' and 'location/city' are not the factors that have the most significant impact on the productivity benefits offered by the prefabrication technology.
3. The benefits of prefabrication technology analysed from the completed project records are not significantly different from those analysed from the feedback from industry stakeholders.

1.5 Research Motivation

The motivation for this study was informed by the following needs identified by the industry organizations and in the literature:

1. The Building and Construction Sector Productivity Partnership Taskforce recommended that the increased uptake of prefabrication technology is one of the key priorities to achieve its target of improving the productivity of the New Zealand construction industry by 20 percent by the year 2020 (BCSPT, 2012).
2. To gain a better understanding/perception of benefits associated with the use of prefabrication technology has been identified as the first step towards the increased uptake of this technology in New Zealand (Bell, 2009).
3. Certain prevailing misperceptions pose the greatest challenge to the increased uptake of prefabrication (Shahzad, 2011, Burgess et al., 2013, Bell, 2009).

In spite of the above issues around the technology, there is a lack of quantifiable evidence to support claims about the numerous benefits of prefabrication to convince clients to invest in the technology and this in part hinders the uptake of prefabrication in the New Zealand construction industry (BCSPT, 2012).

This study is primarily motivated by the need to fill this knowledge gap by seeking to quantitatively investigate the benefits accruable from the use of prefabrication technology for the implementation of various building projects. Another motivation of undertaking this study is to improve the level of understanding and appreciation of prefabrication benefits among the construction industry stakeholders. Clearly outlining the evidence-based benefits will convince clients and project teams to wisely invest in the technology and will subsequently improve the uptake of prefabrication in the New Zealand construction industry. Likewise, the improved uptake of prefabrication technology will in turn improve the productivity performance of the industry.

1.6 Scope and Limitations

The scope of this PhD research study was limited to the context of New Zealand construction industry only. The study was based on the records of building projects completed in three cities of New Zealand i.e. Auckland, Christchurch and Wellington. The choice of these three cities was made on the basis of the highest intensity of construction activities taking place in the cities. As this research is based on case studies of building projects in New Zealand and the feedback collected from the New Zealand construction industry practitioners, it therefore presents only the New Zealand scenario.

Within the three selected cities of New Zealand, five different types of buildings were investigated: Apartments, commercial buildings, community buildings, educational building and residential houses. The aim was to ascertain how the benefits of prefabrication may vary across building types. A total of 151 building projects were investigated for this study, comprising 21 apartment buildings (14 percent), 32 commercial buildings (21 percent), 21 community buildings (14 percent), 26 educational buildings (17 percent), and 51 residential houses (34 percent). Residential building projects therefore constituted the majority of the buildings investigated. The scope and the nature of buildings investigated is justified in section 3.9.2 of the Methodology chapter.

There are at least five types of prefabrication construction approaches; these include component-based prefabrication, framed/panelised prefabrication, modular prefabrication, whole building prefabrication and hybrid prefabrication. Panelised prefabrication is the most popular and commonly used type of prefabrication in New Zealand construction industry (Scofield et al., 2009). This type of prefabrication is regarded as the most effective type of prefabrication offering the highest cost and time saving benefits (Burgess et. al., 2013) On the basis of these findings, panelised prefabrication was selected for investigation of prefabrication benefits in the study.

1.7 Benefits of Research Findings

This study is likely to benefit the New Zealand construction industry and its stakeholders in the following ways:

1. By improving the level of understanding and appreciation of the benefits achievable with the use of panelised prefabrication technology.
2. By providing information and enriching knowledge of clients, consultants and contractors on how much investment dollar and completion time they can save by opting for panelised prefabrication in place of traditional building system in favourable circumstances; this will motivate increased investment in the technology.
3. By enhancing the project level productivity of construction process.
4. By developing and validating a methodology for investigating cost and time saving and associated productivity improvement in wider settings.

1.8 Thesis Structure

The thesis comprises seven chapters as follows.

Chapter 1 introduces the research, highlights statement of research problem, study objectives, research motivation, research propositions, scope of research work and the importance of research findings.

Chapter 2 focuses on review of related literature on the subject with a view to putting the work in the context of previous studies. The chapter begins with introduction of construction productivity, discusses various factors that influence construction productivity and the implications of improved productivity performance of the construction industry on the New Zealand's economy and social well-being. The chapter further explains the basics of prefabrication technology and how it could be leveraged to contribute to the improvement of construction productivity. Furthermore, the chapter covers the following prefabrication-related topics; prefabrication benefits, applications and limitations of prefabrication technology and factors that influence the benefits of prefabrication. Also various aspects of prefabrication and comparison with traditional building system are presented. The chapter ends with the summary of literature review, with highlights on the gaps in existing literature and the research contribution to filling the identified gaps.

Chapter 3 discusses the methodology employed in the study. The chapter is broadly divided into two sections. The first section is dedicated to the discussion of methodology for case studies of building projects. The second section discusses methodology for the questionnaire survey. Each section presents discussions on data collection, selection of sampling frames, sampling techniques, method of data analysis, triangulation of findings and ethical approval sought for this research from Massey University Human Ethics Committee (MUHEC).

Chapter 4 is focussed on the case studies of the building projects. The chapter presents and discusses the empirical data, analysis of the data and results. Connections were made between the current findings and related findings in the literature.

Chapter 5 presents and discusses the questionnaire survey phase of the research. The chapter focuses on triangulating the results obtained from the case study and to explore further constructs influencing prefabrication added benefits.

Hypothesis testing and general discussion on results are presented in Chapter 6. This chapter also discusses the reliability and validity of the evaluations in terms of the research design.

Chapter 7 is the closing chapter and it focuses on the conclusions drawn from the study; it highlights the contribution of the study to the body of existing knowledge and makes recommendations for future research work.

The report includes appendices, which comprise documents used for gathering the research data, tables used for data presentations and analyses, proposition testing, and summary of the key findings of the study.

CHAPTER 2. LITERATURE REVIEW

2.1 Overview

This chapter presents the outcomes of an extensive literature search on various aspects associated with this study. The chapter begins with a detailed discussion of construction productivity and its significance and encompasses productivity in relation to the context of this study. This research study looks at the concept of productivity in terms of measuring productivity, productivity issues in the New Zealand construction industry and the factors that influence the productivity. This description is followed by an introduction of prefabrication technology, its application, the types of prefabrication, and the benefits and limitations offered by this technology plus how prefabrication is viewed in the New Zealand context, as well as in the global context. In the next section traditional building systems are discussed in detail including various types of traditional construction practices, their application and potential issues with these methods. This discussion follows a comparison of prefabrication technology and traditional building systems (TBS). The chapters conclude with a summary from a review of the literature highlighting the gaps in the existing literature.

2.2 Construction Productivity

2.2.1 Productivity in Context

Various researchers see productivity as a measure of how well available resources can be utilized to achieve the targeted outputs, while achieving the set objectives (Ranasinghe et al., 2011, Kelly, 2009, Davis, 2007, Durdyev, 2011). A very simple and basic definition of productivity is the ratio comparing the volume of the output with the volume of the input of resources. The whole concept of productivity revolves around exploring and implementing innovative measures in order to achieve maximum outputs with minimum inputs, by re-engineering the processes already in place. In general, productivity is an intricate concept that can take on diverse meanings depending on the targeted objectives; the objectives in turn determine the measures to be employed in its assessment in relation to the benchmark used for comparison (OECD, 2001). Durdyev and Mbachu (2011) reiterate the importance of benchmark for comparison because, productivity outcome in itself is meaningless except if it can be compared with a benchmark. This comparison of productivity could be intra-entity or inter-entities. For intra-entity comparison, productivity outcomes within a given entity are compared across a time period with a view to understand the productivity trend. Whilst in the case of inter-entities comparison productivity outcomes across similar entities are compared to determine the relative levels of productivity of the entities at a snapshot or across a time horizon. Depending on the objectives to be achieved, the resources employed, the measures adopted and the benchmarks used for comparison, the concept of productivity may be viewed from different perspectives. The Australian Productivity Commission (PC, 2008) and Diewert and Lawrence (2006) identify labour productivity and multifactor productivity as two of the popular perspectives of productivity.

Labour productivity is a measure of the volume of output per hour worked. Measure of labour productivity represents time profile of labour efficiency to gain the outputs. Construction industry is labour intensive and the measure of labour productivity represents the most important contributor to the industry. Even so, this approach only partially measures the capacities of labour as labour productivity depends on other input factors like capital inputs, economies of scale and technical and technological skills of organization (OECD, 2001).

$$\text{Labour productivity} = \text{Output volume/Hours worked}$$

Multifactor productivity (MFP) is a measure of the volume of output from a bundle of both labour and capital inputs. Multifactor productivity measures how well capital and labour resources are utilised to achieve the outputs. OECD manual (2001) recognises multifactor productivity as a good indicator in terms of gauging the contribution of the industry to the national level of the economy.

Multifactor productivity = Output volume/[Labour + Capital inputs]

Diewert and Lawrence (2006) postulate that both measures of productivity are equally effective depending on the context they are applied in. The Australian Productivity Commission (2008) suggests that the multifactor measure of productivity provides a better understanding of the overall improvement in an economy's efficiency as it measures the growth in economic output that is directly attributed to the growth in measured capital and labour inputs. On the other hand, Diewert and Lawrence (2006) posit that labour productivity measures are more heavily relied on for international comparisons in part because very little comparative multifactor productivity data is currently available. In a recent study, Abbott and Carson (2012) interrogated various means of measuring productivity and showed their dissatisfaction with prevailing productivity measuring practices as they are usually applied to the annual industry data. They further suggested the strong necessity for developing an approach that is more suitable for measuring the productivity of construction activity at the project level. Productivity partnership (BCSPT, 2012) also report dissatisfaction on productivity measurement approach prevailing in New Zealand, for example, productivity at national level. The report also strongly emphasised the significance and need to measure productivity at the individual level, the project level and the firm level.

2.2.2 Concept of the Productivity in the Context of this Study

The main focus of this study is to investigate the project level onsite productivity performance of construction projects. For effective measurement of construction project level productivity, the argument of Durdyev and Mbachu (2011) was conceptualized instead of utilizing the above economic perspectives on productivity. They (Durdyev and Mbachu, 2011) argue that, at the level of the individual construction projects, emphasis is placed on the achievement of the three key project objectives - schedule, cost and quality targets – as the key determinants of productivity. The measure of productivity at this level ought to be in terms of how well the targets set for the three objectives are achieved, by the deployment of the company resources (manpower, machinery, money and materials) using the process or method adopted for the project, while complying with the requirements of the statutory/ regulatory environment within which the project is carried out. With the increasing emphasis on the environmental impact or carbon footprint of the construction process, especially for public sector projects, the three key productivity measures need to be extended to include the environmental impact and statutory/regulatory compliance for a holistic productivity measure. However, the parameters of quality, environmental impact and statutory compliance are difficult to measure due to the lack of available data and acceptable metrics for their measurement. Therefore, the focus of this research will be limited to two key productivity objectives, schedule and cost parameters.

2.2.3 Productivity in New Zealand Construction Industry

The productivity performance of the construction industry is not only critical for determining the sector's ability and efficiency, it is equally as important for the country's economy. New Zealand's construction industry, consisting of 500,000 businesses, is regarded as the 3rd largest industry of the country based on business counts. Based on employment generation parameter, it is the fifth largest sector of New Zealand generating eight percent of national employment and hence is a key contributor to the country's GDP (PWC, 2011). Davis (2007) documents that the productivity performance of the New Zealand construction industry is very low compared to the construction industry in other countries. New Zealand's construction industry represents four percent of GDP, while the construction industries of Australia, UK and USA represent seven percent, eight percent and nine percent of GDP, respectively (BCSPT, 2012).

Scofield et al. (2009b) regarded the construction industry of New Zealand as an inefficient sector with an extensive lack of productivity. Various studies have been carried out to evaluate the productivity levels of the New Zealand construction industry and most of these studies confirm that there has not been an increase in the productivity of this sector from 1993 for next 15 years (Black et al., 2003, Law and Mclellan, 2005, Law et al., 2006). Further to this, the Department of Building and Housing report (DBH, 2009) highlights the amazingly poor labour productivity which is directly constraining the overall improvement of productivity. While there is a continuous reported decline in construction productivity levels, all other major sectors are showing trends of increasing productivity (Page, 2012).

2.2.4 Factors Influencing Construction Productivity in New Zealand

Extensive work has already been done to identify the factors that influence the New Zealand construction productivity. Davis (2007) reports that the declining construction productivity trend is attributed to the following reasons: the scarcity of skilled workmen, the down turning quality of available labour, the low investment in the construction sector, little acceptance of innovation, and the fragmentation of the industry and regulation. Further to this, Mbachu and Nkado (2006) point out that the lack of team work and the uncoordinated efforts of project stakeholders which includes clients, consultants and contractors limits the efficiency and performance of day-to-day tasks which later translates into project productivity. A coordinated team effort of all the project stakeholders is likely to improve the productivity of projects. Prevailing procurement practices, shortage of skilled construction labour and lack of inclination towards accepting innovative project techniques are documented as some other obvious reasons associated with the low levels of productivity (DBH, 2009). Wilkinson and Scofield (2010) investigated various procurement approaches and recognized that the selection procurement approach has pronounced effects on onsite productivity targets of time, cost and quality.

Mojahed and Aghazadeh (2008) investigated the various factors that have an influence on construction productivity and recorded that the five factors that have the greatest significance include: the skills and experience of the workforce, management, job planning, motivation, and material availability.

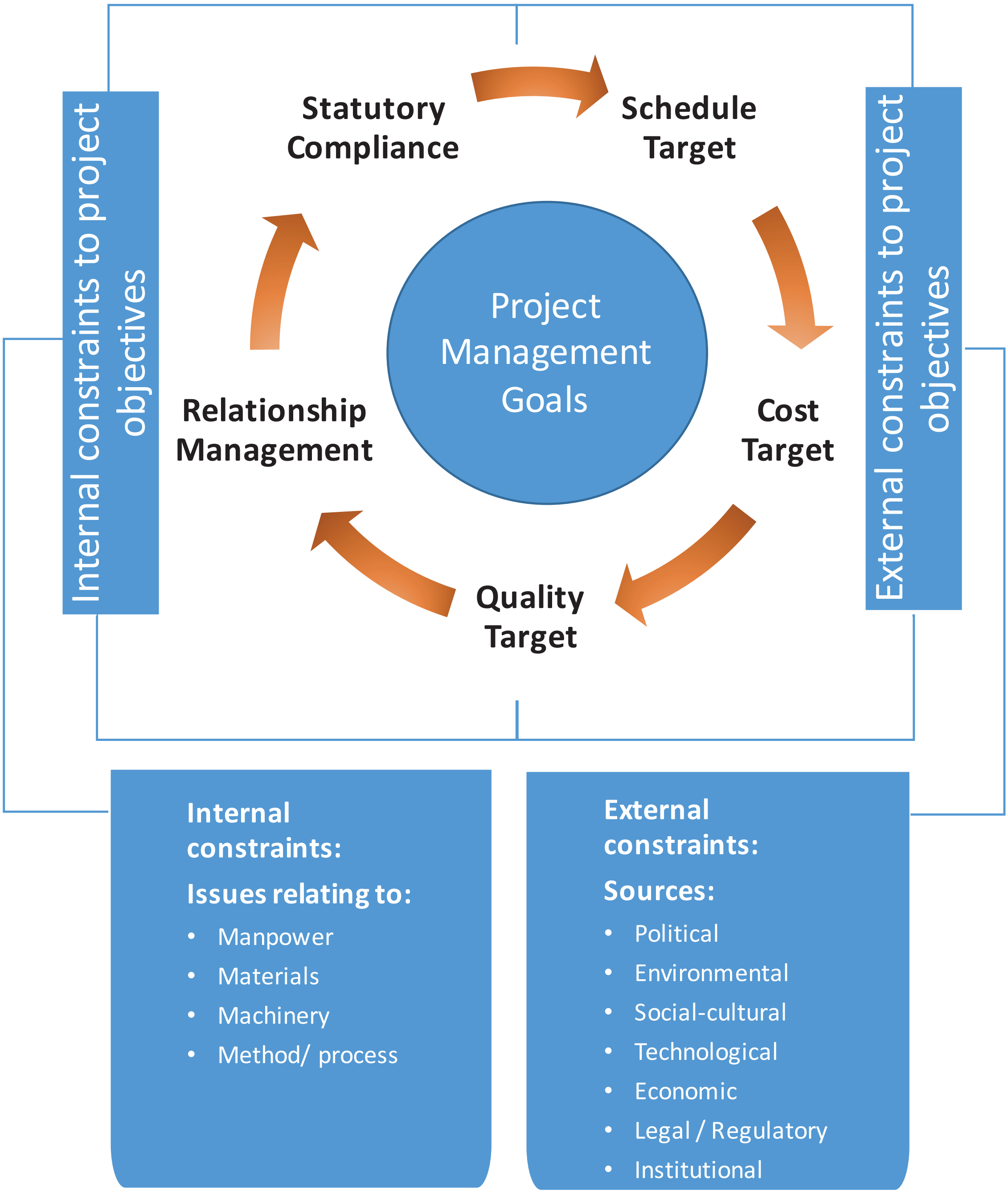

Figure 2.1: External and internal constraints of construction productivity [Source: Durdyev (2011)]

In recent years Durdyev (2011) provided a robust identification of constraint to the construction productivity, by broadly categorizing them as external and internal constraints. According to which, significant internal constraints comprise inadequate construction supervision, lack of coordination among the project team, amount of rework required, workforce skills, robustness of construction techniques and buildability concerns. Whereas significant external constraints consist of the lack of competition within the industry, resource management act, the soil conditions of the project and market conditions.

Page and Norman (2014) identified the failure to pass on the increasing prices of inputs to the buyers of the construction services as responsible for the continuous decline of the construction industry over the past two decades.

2.2.5 Improving Construction Productivity

The construction industry is showing a great deal of interest in improving its productivity performance. The Building and Construction Productivity Partnership Taskforce was established to dissert on the current and future productivity performance of New Zealand construction industry. The specific aim of the productivity partnership is to achieve 20 percent improvement in the productivity of the New Zealand construction industry by year 2020. Re-engineering the manner in which the construction industry operates under different indicators and improving the skills of construction industry in general will achieve this target. In a recent study (Zuo et al., 2013) investigated the strategies that can improve the construction productivity in the New Zealand context. They documented six factors that can significantly contribute to improved productivity performance including: (1) Use of prefabrication technology (2) Management training for the construction sector, (3) Innovation, (4) Training of more skilled labour, (5) Standardization and (6) Education and training.

2.2.6 Productivity Measurement for this Study

In terms of this study project level productivity performance has been measured as a product of time saving and cost saving. The rationale for computing the productivity improvement as a product of time savings and cost savings draws upon two streams of thoughts.

First, in the construction industry context, productivity performance depends largely on the cost-and-schedule performance of construction activities (Takim and Akintoye, 2002). This strategic perspective of the concept of productivity differs to some extent from the economist's perspective of productivity that is based solely on the output versus input resource ratio, featuring variants such as labour, capital and multi-factor productivity measures. Mbachu and Shahzad (2012b) clearly made this distinction. The mathematical expression for an integrated productivity measurement based on the two key parameters of cost and time saving draws on the fact that productivity is directly proportional to the cost and schedule performance as follows:

$$P \propto (S_p, C_P) \qquad \text{Equation 2.1}$$

$$P = \beta(S_P \times C_P) \qquad \text{Equation 2.2}$$

Where:

P is the productivity performance achieved in a project

β is an empirically determinable constant of proportionality that depends on the dynamics of the operational environment. The constant could be taken as unity, for example, the value of 1, for projects executed under normal operating conditions as assumed in the study

S_p is the schedule performance

C_p is the cost performance

2.3 Prefabrication Technology

2.3.1 Understanding Prefabrication

While prefabrication is also commonly known as 'Prefab', different researchers have defined it differently however the whole concept of prefabrication revolves around shifting a large quantum of onsite construction activities to a remote offsite location. These offsite activities generally take place in an enclosed building, controlled yard or factory setting. The Modular Building Institute (MBI, 2010) precisely defines 'prefabrication' as the process of manufacturing major building components in a controlled environment away from the project site. These manufactured building components are then transported to the project site for their subsequent installation onsite. The only difference between prefabrication and traditional building system is that the bulk of the building components are manufactured offsite instead of onsite (Arif and Egbu, 2010, Azman et al., 2010, Pan et al., 2007). Prefabrication is deemed as an innovative construction technique, which aims at minimizing the construction activities taking place at the construction site by shifting as much of the activities as possible to the construction yards, which are located away from project site and maintain a controlled factory working environment. This is to ensure a better quality product, improved health and safety conditions and shortened project delivery (Arif and Egbu, 2010, Azman et al., 2010). Prefabrication is also recognized as an industrialized building construction approach (Kamar et al., 2011). Bell (2012) argues that term prefabrication is a process or approach and cannot just be associated to a product.

Prefabrication is regarded as environmentally friendly, safer and more productive than the traditional construction methods (Barret and Weidmann, 2007). This technology is deemed suitable for all kinds of building and construction projects, Ngowi et al. (2005) rejects the perception that prefabrication is a method for only manufacturing kit set homes, instead they argue that this technology is suitable for all types of construction projects. There is increasingly little differentiation between the traditional building types and the 'componentised' and the 'panelised' prefabrication types. It is actually very difficult to differentiate between traditionally built buildings and prefabricated construction. This is because currently traditionally built buildings involve some form or another of 'componentised' and 'panelised' prefabrication units. In this context the differentiation between the two is compared by checking the value or the proportion of the prefabrication components compared to the onsite manufactured components. On this basis, a building is classified as a prefabricated building where the prefabricated component is more than 50 percent of the total building value, or vice versa.

Prefabrication is a very beneficial construction approach with widely accepted benefits including shorter project duration, improved quality product, enhanced control of construction activities, improved safety of workers, environmental friendliness and reduced project cost (Gibb, 1999, Lusby-Taylor et al., 2004, Lu, 2009). All of the beneficial features of prefabrication result in improved productivity of the construction process (Bell, 2009). Even so, Tam et al. (2007) documents that prefabrication technology so far has been unable to give satisfactory outputs to the construction industry. This finding is in contrast to popular beliefs about the overwhelming benefits of the technology. For instance, based on the numerous benefits of the technology, including its potential to significantly improve the productivity and performance in the construction industry, the Committee on Advancing the Competitiveness and Productivity of the U.S. Construction Industry (CACPUCI, 2009) recommends the application of the technology as one of the most important strategies for improving the efficiency and productivity of the U.S. construction industry. Similarly, a New Zealand study supported by BRANZ (Shahzad, 2011) posits that productivity benefits offered by prefabrication technology are in line with the current needs of the country's construction sector. The Building & Construction Productivity Partnership Task Force (2012) identifies prefabrication as one of five breakthrough strategies for New Zealand to achieve its target of 20 percent increase in productivity by year 2020.

Figure 2.2: More for less outcomes of prefabrication technology [Source: (Bell and Southcombe, 2012)]

In spite of the low prefabrication uptake by the New Zealand construction industry (BCSPT, 2012), it is not correct to say that prefabrication is a new technology for New Zealand. New Zealand construction industry has used this technology historically. Scofield et al. (2009b) document that prefabrication technology was introduced to New Zealand in the early 1800s when panelised kit set homes were imported from UK and USA. Scofield et al. (2009b) note that the construction industry prefers to continue with the traditional building practices as they find them easier to meet the market demands while achieving compliance of the Building Act. Becker (2005) observed that even though current use of prefabrication is low in New Zealand construction industry, the industry is ready to adopt innovative construction methods including prefabrication. In his opinion New Zealand building regulations are based on performance and they are flexible to allow alternatives and innovation to achieve performance.

2.3.2 Types of Prefabrication

Investigations reveal that various tabulations exist for the classification of the prefabrication deliverables. Gibb (1999) systematically classified prefabrication into four categories including: panelised system, volumetric system, non-volumetric system and whole building system. In subsequent years (Langdon and Everest, 2004)) presented a prefabrication classification from an interface/connection perspective. They broadly classified prefabrication into two categories: open-ended prefabrication and closed-ended prefabrication. The authors further explained the difference between the types of prefabrication is that the open-ended prefabrication is a simple system comprising simple components or panels that are made of single or composite materials such as timber and steel, that are manufactured at remote offsite locations. Contrary to this, close-ended prefabrication is a complex system that can only be manufactured in a factory-controlled environment. Close-ended prefabrication comprises modules/pods and the whole buildings manufactured in factories. In years to come, Bell (2009) classified prefabrication into three categories based on a geometric frame of reference as volumetric, such as, modular and whole building prefabrication), non-volumetric types, for example, a panelised system, and the hybrid, a combination of the volumetric and non-volumetric). Shahzad and Mbachu (2012b) extended Bell's (2009) three classifications of prefabrication techniques to five including a component based prefabrication (prefabricated building components and units such as precast columns and beams), panelised prefabrication (such as precast wall and floor panels), modular prefabrication (modules or pods), hybrid prefabrication (a combination of modular and panelised prefabrication) and whole building prefabrication, or complete building, short of foundations and onsite services connections.

2.3.2.1 Component Based Prefabrication

Component based prefabrication is generally known as kitset in terms of the New Zealand construction industry. This type of prefabrication refers to components or sub-assembly manufactured in offsite locations. The prefabricated components are transported to the project site for installation. These prefabricated components are manufactured in different shapes and sizes and use different materials depending on the design requirements of the project (Gibb et al., 2007). Some examples of prefabricated components or sub-assembly include pre-cut roof trusses, wall frames, joists, beams and fittings and fixtures like doors, windows, ductwork and cabinetry and so forth which are engineered and manufactured in remote locations away from the project site, and brought to the project site for installation as and when needed (Langdon and Everest, 2004). The installation of kitset or component based prefabrication is usually carried out by the builders. With the use of componentized prefabrication, builders can reduce the overhead costs by shifting the large volume of construction activities to factories thus reducing the job time on the construction site (Gibb et el., 2007). This system has the flexibility to conveniently meet the requirements of standards and building codes through quick adaption.

A recent New Zealand study (Bell and Southcombe, 2012) reports that 98 percent of new houses built in New Zealand make use of component based prefabrication and the component based prefabrication is a well-established business in New Zealand. However, the study further explains that this component based prefabrication is not regarded as prefabrication due to the prevailing misperception that prefabrication refers to only modular or completed buildings.

2.3.2.2 Panelised Prefabrication

Panelised prefabrication refers to the manufacturing of building panels, for example, the walls and floors that constitute the structural frame of any building at offsite locations under a controlled environment. Building panels and frames are manufactured in a factory setting and are later transported to the construction site. These panels are designed and manufactured in transportable sizes with a strong focus on interfaces to keep the process of onsite assembly simple. Once manufactured in factories according to the design and building requirements, these panels are transported to the project site where each panel is installed in its designated place within the structural frame (Gibb et al., 2007).

It is observed that panelised prefabrication is the most common type of prefabrication in use in New Zealand (Burgess et al., 2013). The Panelised prefabrication industry in New

Zealand is very well established and is keeping track of innovation and development (PrefabNZ, 2013). A similar situation is observed in the UK construction industry where panelised prefabrication dominates the residential market (Langdon and Everest, 2004). This type of prefabrication offers flexibility of design, good quality product, speedy construction and almost no delays in construction schedules due to unforeseen conditions (Chiu, 2012). In addition, the cost of transportation of panelised prefabrication is much less than the transportation cost of prefabricated modules. Bell (2009) highlights that the prefabricated panels that are manufactured in factories under high quality control and using high tech equipment, become much easier to produce in any shape and size to meet the design requirements while complying with the building codes.

2.3.2.3 Modular Prefabrication

Modular prefabrication, which is also known as volumetric prefabrication, takes the prefabricated construction to another level. This is a type of prefabrication where complete 3D building units providing living space are manufactured in offsite factory settings. It is pertinent to mention that these units that are also known as pods and modules only form a part of the building, they are not the complete buildings. Haas et al. (2000) describe modular prefabrication as the preconstruction of the complete building system at a remote offsite location in such a manner that the whole building is constructed in the form of modules that can be stacked side by side or upon each other to form a complete building at project site. Poorang and Farr (2013) also provides a definition of the modular prefabrication as consisting of self-contained modules with proper interfaces which are ready to be transported from the factory or offsite location to the building site for installation or assembly.

Prefabricated modules require only a small amount of work to be completed on the project site, since the modules are transported to project sites where they are placed in designated areas using cranes and are secured together to construct the whole building. Some examples of modular systems include pods for various functional units such as rooms, bathrooms, toilets, plant rooms, lift shafts or service risers. Modular prefabrication is more practical for the construction of high rise buildings (Langdon and Everest, 2004). The biggest challenge associated with the use of modular prefabrication is the transportation of the modules from the yard to the project site, which is an extensive process. Although the handling and transportation of large sized modules does not require great care, it incurs high cost. Despite the challenges associated with modular prefabrication, it is regarded to be an efficient productive construction approach subject to systematic analysis of the project and the early phase of the project design (Song et al., 2005).

Although modular prefabrication is not very common in New Zealand, the modular industry is gaining momentum. Modular prefabrication is not likely to be a success for residential houses due to the likes of homeowners for customized home designs (Bell, 2009). This makes the choice of modular prefabrication more suitable for other buildings, such as, commercial buildings, classrooms, police stations, retirement villages and student housing and so forth (Burgess et al., 2013).

2.3.2.4 Whole Building Prefabrication

Whole building prefabrication refers to the complete manufacturing of a building in a factory. The building is completed in a factory and is then transported to the project site, where it is installed on a foundation that is already prepared. For this type of prefabrication, all the construction related activities are carried out at offsite locations and the only activity that remains for the site is fixing the building on the foundation. Whole building prefabrication is also known as 'transportable prefabrication' and 'portable prefabrication'. It is important to note that whole building prefabrication is different from mobile homes as they are installed permanently in their designated locations unlike mobile homes. Bell and Southcombe (2012) explain that whole building prefabrication is different from re-locatable and portable buildings. While whole building prefabricated offsite is transported only once from the construction yard to the project site and is fixed to the permanent foundations re-locatable buildings are designed so that they can be moved a few times during their life span. Similarly, portable buildings, for example, portable toilets, site offices and so forth are lightweight and small sized structures are designed to be able to be moved frequently as and when needed.

The many advantages of whole building prefabrication include; better compliance of building standards, improved quality of construction, enhanced life cycle value, shorter project duration, minimal disruption on site and reduced carbon footprints (Build139, 2014). Since these buildings are designed to be transported, their design is very strong to withstand their own weight while being lifted, transported and installed (Chiu, 2012).

The concept of whole building prefabrication is considered to be very useful during the reconstruction of disaster hit areas as well as in remote locations where there is a shortage of construction material and skilled labour (Chiang et al., 2006).

2.3.2.5 Hybrid Systems

Hybrid prefabrication is defined as a combination of modular prefabrication and panelised prefabrication to combine the advantages of both. A good example of hybrid prefabrication can be a building in which modular prefabrication is employed for the high service areas of the building and panelised prefabrication is used for other functional areas of the building. The hybrid system of prefabricated construction has the potential of increasing the speed of project completion while fulfilling the requirements of project design and building codes. Hybrid prefabrication is considered equally usable for the housing sector as well as for other types of building projects (Langdon and Everest, 2004).

2.3.3 Benefits of Prefabrication

Prefabrication is undoubtedly a very beneficial construction technology which answers almost all the prevailing productivity and performance issues faced by the construction industry (Chan and Poh, 2000, Chan and Hu, 2002, Chiang et al., 2006). This technology is internationally recognised as an efficient, cost effective and sustainable approach for the construction industry. An extensive amount of work has been done to investigate the benefits of this technology. Several studies have explored the benefits of prefabrication technology. These benefits include reduced project cost, shorter project duration and on time delivery of projects (Lusby-Taylor et al., 2004), enhanced quality of construction (Gibb, 1999, Lusby-Taylor et al., 2004), improved onsite health and safety (Lu, 2009), reduced onsite wastage and environmental impact, and reduced whole life cycle cost (Barret and Weidmann, 2007). Lu (2009) observed that prefabrication not only saves construction costs it also offers more reliable estimates in terms of the upfront costs, total investment outlay and overall returns on investment. Other advantages of prefabrication technology over and above conventional construction methods include better compliance with the Building Codes, quicker processing of building consents/permits, and fewer building inspections (Burgess et al., 2013). In addition, the Modular Building Institute (MBI, 2010) maintains that prefabrication optimizes the use of construction materials, resulting in less waste generation.

Some of the previous work has outlined the advantages of prefabrication, as summarised below:

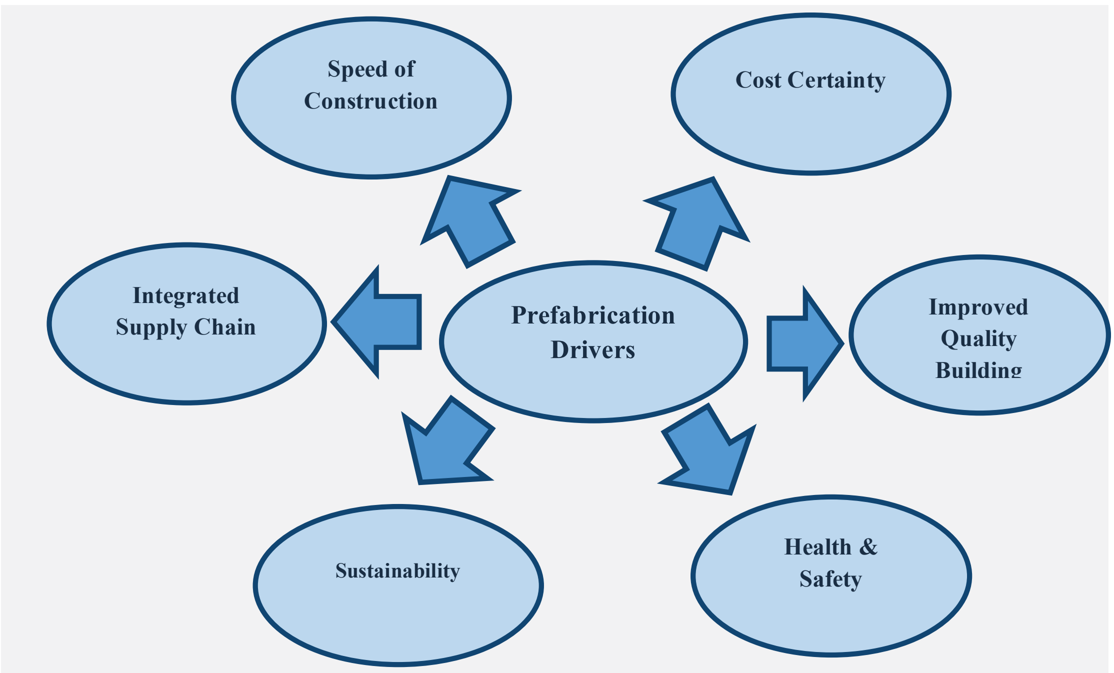

Figure 2.3: Drivers of prefabrication technology [Source: (Becker, 2005)]

2.3.3.1 Cost Savings

The cost savings that are incurred with the use of prefabrication technology are beyond any doubt (Gibb and Isack, 2003). The cost savings that are incurred with the use of prefabrication technology is regarded as one of the key benefits of prefabrication technology. Bell and Southcombe (2012) documented that prefabrication not only saves the cost of project completion it also reduces the whole life cycle cost of the project. Various researchers have reported about how prefabrication saves cost. Becker (2005) highlights that the use of prefabrication optimizes the use of construction materials which curtails any overheads associated with the wastage of material. Additionally, the material is stored in factory sheds so the likelihood of material theft and other losses are also controlled. This augments the savings in the construction costs. The resource efficient nature of prefabrication cuts down the overall cost of the project (MBI, 2010).

It's a common and acknowledged saying that 'time is money', and the same is true for prefabrication. As prefabrication shortens the project completion time this in turn reduces the project cost. A shorter project duration means less working hours required to be carried out by the construction workers and early returns on project investment as the building will be ready for use earlier. All of these factors ultimately translate into the savings of project cost (Bell, 2009, Page and Norman, 2014).

The use of prefabrication saves a lot of money when employed in high-rise buildings due to the repetitive use of similar pattern modules or components that are placed either side by side or on top of each other. Repetitive or customized manufacturing brings down the cost of production. Similarly, customized prefabricated houses provides a solution when it comes to affordable living (Cheung et al., 2002, Gibb and Isack, 2003, Chiang et al., 2006).

Another cost related benefit of prefabrication system is that it provides a better control on project cost, and the certainty of the final project cost is higher in the case of prefabricated construction compared to the traditional building approach (Lu, 2009).

Contrary to the widely reported cost benefits of prefabrication, Lange (2013) notes that a large number of New Zealand consumers believe that prefabrication is in no way a cheaper approach for construction. Many consumers believe that prefabrication is an expensive choice due to the huge capital invested in establishing the production yard, the high cost of transportation of prefabricated components and the requirement for specialized machinery.

The time and cost benefits of prefabrication technology are interrelated. It is observed that the easiest and fastest way to reduce the construction cost is to speed up the construction process rather than focusing on costs (May, 2013).

2.3.3.2 Time Savings

The time savings that are achievable with the use of prefabrication is regarded as one of the most important benefits of this construction approach. For example, the opportunity to work offsite and onsite in parallel i.e. manufacturing of components and their on-site installation takes place side by side and shrinks the overall construction completion time of the project (Gibb, 1999). The mechanization of the construction process hugely reduces the project completion time since the components which take weeks to complete manually can be manufactured in a matter of hours at prefabrication plants (Taylor, 2009). Working in a controlled environment also saves project completion time. Prefabricated manufacturing can take place all year round and there will be no undue delay in the project schedule owing to bad weather conditions including rain, snow, excessive cold and unbearable heat (Page and Norman, 2014).

The use of prefabrication technology in place of the traditional building system can save 30 - 60 percent of project delivery time (Bell, 2009). It is estimated that in the New Zealand housing sector one week of construction activity time savings translates into a cost saving of 1000 to 1600 New Zealand dollars (Page, 2012).

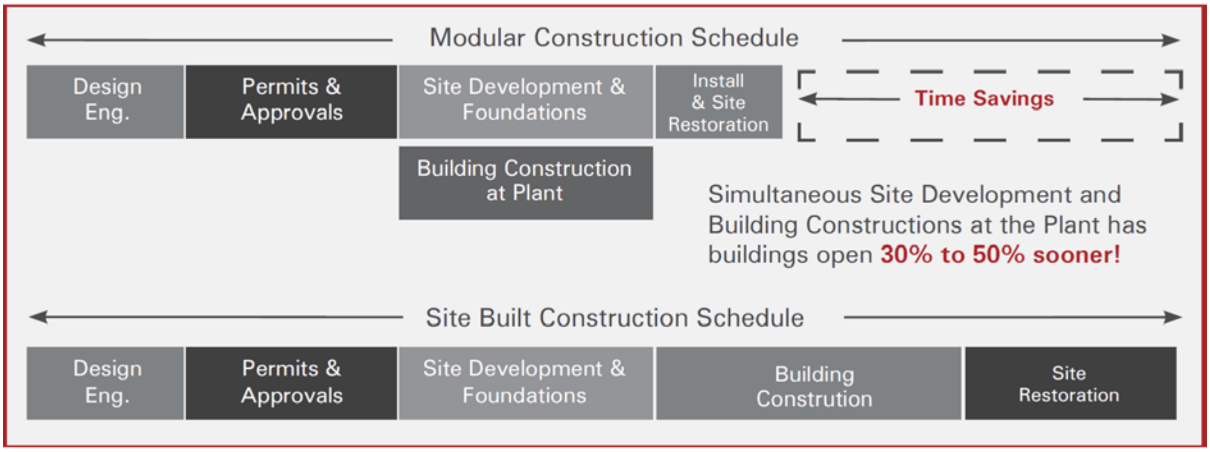

Figure 2.4: Construction process comparison between modular prefabrication and traditional construction approach [Source: (MBI, 2010)]

2.3.3.3 Improved Quality

The prefabricated manufacturing process provides the opportunity for mechanized production, improved supervision of workmanship and storage of material in a controlled environment to avoid any damage to its properties which enables manufacturing of good quality building components resulting in good quality buildings (Becker, 2005). Jaillon and Poon, (2010) argue that prefabricated components are generally free of defects, which is extremely hard to achieve in the case of site built projects. Prefabrication minimizes the construction defects arising from human error and a lack of skilled labour. An effective quality control system is much more difficult to achieve onsite unlike under a controlled factory environment. Gibb (1999) reported a very unique benefit of prefabrication technology, that any planned building can be tested using its prototype. Prototype testing has strong technical merit and is particularly very beneficial for buildings planned in seismic zones. And with the use of prefabrication, greater certainty in terms of the building's response can be achieved. State of the art machinery, such as, precision cutting machines enhances the quality of the product enormously.

Burgess et al. (2013) argue that quality is not just one benefit, it overarches many other economic benefits including greater value for the consumer, high end product, long life product, minimum requirement of maintenance and marketing benefits and so forth.

Construction defect reworks are costly jobs and can be avoided with the use of high end prefabricated products. In this manner the improved quality of construction again contributes to the cost savings associated with the use of prefabrication technology.

2.3.3.4 Sustainability

Prefabrication is highly regarded as a sustainable construction approach due to the following attributes: the amount of waste generated as an outcome of construction process reduces immensely and thus minimizes the carbon footprint of the development (Gibb, 1999, Shahzad, 2011, Burgess et al., 2013). Components are manufactured in remote areas and hence there is much less material handling on site, which results in better management of the construction site (MBI, 2010). According to an estimate 13 percent of all the construction material goes wasted at a project site, this huge amount of material waste is more easily controlled in construction yards (Bell and Southcombe, 2012) using prefabrication technology.

Luo (2008) highlights that prefabricated manufacturing consumes less energy and in addition, less dust, noise and waste are generated when the manufacturing process takes place in the factory setting instead of at the construction site.

Kaufmann (2009) documents that while a worker employed at a prefabrication yard on an average travels 15 miles a day to and from his work to home, a worker working in the traditionally built project site travels an average of 25 miles a day to and from work. The material transportation to the project site can be reduced up to 60 percent by replacing traditional construction methods with the prefabrication approach. The savings in distance travelled by the workers and materials, also contributes to environmental sustainability.

2.3.3.5 Health & Safety

The working conditions for workmen are pretty safe and comfortable since they do not have to work through harsh weather conditions and the likelihood of injuries is much lower with the use of prefabrication. Burgess et al. (2013) note that prefabricated construction is very safe for workers, this construction approach reduces fatalities up to 75 percent compared to onsite construction. Workers spend less time working under the risky conditions of the construction site. And the use of prefabricated components/modules reduces the disruption and safety hazards at the project site caused by the material stacking (CRC, 2007).

Some other significant benefits of prefabrication are listed below:

- As prefabrication of building components is a mechanized process taking place in a factory setting, it addresses the problematic situations arising from the shortage of skilled labour (MBI, 2010). Nadim and Goulding (2009) explain that it is a lot easier to meet the market demands without having to worry about availability or shortage of skilled labour as most of the manufacturing work is done by machines and robots.

- Workmen in the prefabrication manufacturing sector enjoy stable employment opportunities due to the heavy investments made by the manufacturers in setting up the prefabrication plants and providing training for the workmen (Bell, 2009).

- Prefabricated construction precisely conforms to the building codes due to the mechanized manufacturing, which eliminates all of the human errors (Tam et al., 2007).

2.3.4 Factors Influencing Prefabrication Benefits

In order to fully utilize the benefits of prefabrication technology, it is very important to understand the various factors that could influence the level of benefits that can be derived from prefabrication technology compared to the traditional building system. Some research has been carried out on the factors that influence the benefits of prefabrication. Chung (2007) explored the various aspects of prefabrication for Hong Kong's construction industry and noted that mass and repetitive production significantly influence the benefits of prefabrication. Effectively choosing the project phases, contributes to the reduction of the project completion time (Burgess et al., 2013). The sustainable features of prefabrication, such as, less waste of material, less use of water and energy, controlled management of hazardous materials and so forth enhance the cost savings of the project. Choosing the right type of prefabrication for a certain project, the location of the project from the manufacturing yard and the transportation of large sized assemblies were recorded as some of the other factors that vary the level of benefits associated with the use of prefabrication.

Various factors identified from the literature and from the feedback of industry practitioners, were grouped in seven broad categories according to the New Zealand context:

1) Project Characteristics
2) Planning and Design
3) Logistics and Site Operations
4) Skills and Knowledge
5) Sustainability
6) Procurement Strategy
7) Quality Control

The broad influence from the groups is discussed in the subsections that follow:

2.3.4.1 Project Characteristics

Project characteristics like building type and project location can influence the level of benefits achievable with the use of prefabrication.

Various types of buildings including commercial, educational and residential and so forth can benefit from prefabrication technology. Page (2012) document that prefabrication technology can beneficially be applied to all types of buildings as well as other infrastructure projects. There are different perspectives regarding the benefits of prefabrication for different building types. Langdon and Everest (2004) believe that prefabrication is more suitable for high rise buildings with high service areas. However, in New Zealand, prefabrication technology is more popular and is regarded as beneficial for single story houses (Bell, 2009).

The location, for example, the city where the project is located, often poses the biggest hurdle to achieve any benefits from the use of prefabrication technology. Prefabrication benefits depend largely on the project location due to the high transportation cost of prefabricated components/modules between the project site and the construction yard. Burgess et al. (2013) explain that the impact of the high transportation cost associated with the use of prefabrication technology can be reduced if an effective logistics control plan is in place for the transportation of the prefabricated components. In addition to this if large sized construction companies have multiple projects in hand, the impact of the transportation cost can easily be diluted. Apart from these two factors, the high construction demand in densely populated areas can also minimize the impact of the transportation cost. According to the observations of Burgess et al. (2013), the benefits of prefabrication are mainly be limited to seven main cities in New Zealand: Auckland, Christchurch, Dunedin, Hamilton, Napier, Tauranga and Wellington.

2.3.4.2 Design and Planning

The benefits of prefabrication technology are not possible without careful planning and design of project. The design of prefabricated projects is frozen at the very early project phase. The level of design standardisation/customisation is a very important factor. Yau (2006) asserts that while designing and finalizing the project design, either panels, components or modules need to be designed following the standardisation principles of prefabrication designs. Standardisation and repeatability of components can achieve maximum project efficiency by saving manufacturing time and cost. Yau (2006) documents that contrary to standardisation, customized designs are not suitable for prefabricated construction. Repeatable component design contributes immensely to the benefits of prefabrication for a project.

Another important design consideration is the choice of prefabrication type that can make the construction process more effective. Panelised prefabrication is regarded as suitable for almost all building types. Page and Norman (2014) note that panelised prefabrication is the most common form of prefabrication in use in New Zealand. However, Langdon and Everest (2004) observe that modular prefabrication is most suitable for high rise buildings. Modular prefabrication is gaining popularity for health care, educational and commercial buildings. Whole building prefabrication is regarded to be most effective for portable houses, holiday baches, site offices and so forth (Jaillon and Poon, 2010).

It is believed that prefabrication technology improves the whole life cycle quality of the project (Bell, 2009). The choice to use prefabrication technology is often made to achieve an overall improvement in the entire life cycle of building project by the clients, for example, homeowners. However most clients who are generally investors are not bothered by this factor as they are more interested in the early completion of projects which will enable the early returns on investments (Blismas and Wakefield, 2007).

2.3.4.3 Logistics and Site Operations

Logistics and site operations are critical factors for gaining benefits from prefabrication technology. The logistics for prefabricated components are very expensive and also require special care during the design phase. Prefabricated components and modules are designed to be of high strength to bear the stresses coming on the components during the transportation (Bell and Southcombe, 2012). The effectiveness of the prefabrication technology requires good control of logistics management. Failure to implement logistics control, can cause delays in project completion and result in financial implications as well (Fang and Ng, 2010).

Site working conditions and layout contribute to the benefits of prefabrication. A clean, tidy and organised working environment in the prefabrication yard provides better working conditions for the workers resulting in improved efficiency. In the prefabrication yard since all of the workers have allocated working spaces, none of them are distracted due to others work, material deliveries or staking of material on site. Factory conditions reduce the health and safety risks for workers. Workers in the factory are less exposed to noise, dust and risks of falls and injuries.

Any extra cost incurring on the project due to subsoil conditions requiring specific component costs can also influence the value of the overall project.

2.3.4.4 Skills and Knowledge

Factors that relate to skills and knowledge have a significant influence on the performance of the prefabricated projects. They include the quality of the project leadership, project management skills, attitude of project team and the contractors' level of experience with innovation. The nature of the client and the client project management capabilities also influence the performance of the projects. An example of project management capabilities is the experience of the project team with the use of strategies like just-in-time (JIT) delivery. JIT has tremendous potential for managing the transportation of prefabricated components from the prefabrication factory to, and within, the construction project site. This strategy curtails the space constraints for storage of material and the movement in congested project site (Pheng and Chuan, 2001). The handling of the prefabricated components requires specialised skills from design, manufacturing, cranage and installation (Bell, 2009). Without adequate skills for the design and handling of the prefabrication, various benefits of prefabrication like cost saving, time saving and quality improvement cannot be achieved.

2.3.4.5 Sustainability

Prefabrication technology is a very sustainable approach of construction. Prefabrication technology improves the environmental impact performance for the project. Prefabrication reduces the extraction of new materials by reusing components and materials more than once. Prefabricated construction is high end and due to high quality of factory-manufactured components, prefabricated buildings are watertight. The water tightness of buildings makes them energy efficient and the amount of heat loss is minimal for prefabricated buildings. This way the whole life cycle value of the project is improved.

2.3.4.6 Procurement

Prefabricated projects are very different from the traditional building system. Prefabrication requires good skilled manufacturers, close quality monitoring, selection of competent designers and project managers and right suppliers (Wilson, 2006). The choice of procurement system, for example, the traditional design, contract & build or project management procurement approach impacts the overall efficiencies of the project. While making a choice for which procurement system, certain prefabrication considerations should be taken into account, keeping in mind the need for planning the detailed work-flow. A detailed work-flow plan is essential to achieve the benefits of parallel offsite and onsite activities of manufacturing and assembling. In order to achieve the maximum efficiency benefits of prefabrication, a clearly identified procurement strategy needs to be determined at the very beginning of the construction process. This includes the type of building contract, the different contract types, for example, lump sum fixed price, cost reimbursement and so on, as the different strategies will have different influences on project outcomes.

2.3.4.7 Controlled Environment

Prefabricated construction is known for its better quality. The improved quality of the prefabrication is not a simple output; it is in fact that the quality of the prefabrication is built into the entire process. The controlled factory environment in which the manufacturing of prefabricated components takes place results in high quality construction. The controlled environment of the factory safeguards the workers against the harsh weather conditions. And not only are the workers safe from exposure to harsh weather conditions and other health & safety issues, it also protects the construction material. Construction material, especially timber, stays dry which prevents it from twisting and wrapping. Exposed weather conditions also cause delays in project completion times. The controlled working environment reduces the project cost and improves the quality of the project by saving the construction material and labour (Burgess et al., 2013). Improved quality also enhances the life cycle value of the project.

2.3.5 Areas of Application of the Prefabrication Types

Prefabrication technology offers a wide range of products from small components such as doors and windows to complete ready to use transportable buildings. The technology is smart enough to make use of any construction material such as timber, concrete, metals or plastics or a combination of these. The wide range of prefabricated deliverables makes their application possible for all type of construction projects. Contrary to the prevailing perception that prefabrication is only suitable for housing projects or temporary accommodations, this technology can be used for any type of building including commercial, educational, healthcare, community and recreational buildings. The fact remains that prefabrication technology can be applied to any kind of construction project and this includes permanent or temporary buildings and infrastructure structures (BRANZ, 2013). Some other studies (Gibb, 1999, Bell, 2009, Shahzad and Mbachu, 2012a) endorse that the use of prefabrication cannot be limited to one or two types of building projects as, in fact, prefabrication technology is equally suitable and effective for other civil engineering projects.

However, depending on the design requirements and the nature of the building, various types of prefabrication can have different efficiencies and effectiveness. A research study (Langdon and Everest, 2004) found that modular prefabrication is most suitable for highly serviced areas. Whole building prefabrication is considered to be more suitable for portable houses, temporary outdoor structures, holiday homes and temporary site accommodations. Another study (Jaillon and Poon, 2010) noted that the whole building prefabrication is mostly suited to portable or temporary applications such as out-door structures, holiday homes, site accommodations, or where quick speed of assembly is a necessity.

2.3.6 Limitations to the Uptake of Prefabrication

Despite the globally recognized benefits of prefabrication, the adoption and application of this technology is reported to be low in various parts of the world (Chiang et al., 2006, Tam et al., 2007, CRC, 2007, Aldridge et al., 2002). Similar low uptake of prefabrication has been observed in the New Zealand construction industry and this low uptake has been associated with the low productivity outcomes of the New Zealand construction sector (Shahzad and Mbachu, 2012b). This low uptake is a result of various constraints associated with the use of this technology as well as some negative perceptions that prevail about the use of prefabrication. Extensive work has been done to explore the reasons behind the low acceptance of prefabrication. Several studies explored the issues with the prefabrication technology in general.

There is a general reluctance observed in the construction industry to change and adopt innovative construction methods including prefabrication. This reluctance to change is associated to the fears of ambiguous risks that might arise during the project completion (Chiang et al., 2006).

Prefabrication process requires a specific yard or factory location equipped with high-end equipment, where working conditions can be controlled and closely monitored. In short, prefabrication cannot just take place anywhere as it involves a high initial set up cost. The capital required for the setup of a prefabrication plant is one of the most significant reasons the construction industry is reluctant to make a shift to this construction technology (Tam et al., 2007).

While it is an established fact that prefabrication technology reduces the construction time of a project, the time required to design a prefabricated project is longer and more extensive compared to the traditional building system. Another limitation that has been observed is that the precision of product design, particularly the design of component interfaces requires much more detailed design considerations, leading to a longer design period (Kelly, 2009, CRC, 2007). In addition to this there is another design related issue that limits the ability of old fashioned designers to use this method of construction. Rivard (2000) notes that design of prefabricated construction essentially requires expertise in computer integrated design, which makes it impossible for old fashioned designers to adopt this technology.

The Modular Building Institute (2010) observed that there is a lack of flexibility in the existing building codes to adjust to the requirements of prefabricated construction. This is due to the fact that building codes have always been developed keeping in mind the conventional construction methods and not much attention is paid on prefabrication as an alternate construction method.

For prefabrication technology it is critically important to freeze the project design at the beginning of project. This technology does not offer the flexibility to change the project design once the construction is started. This inflexible nature of prefabrication technology makes the choice of using it very limited from a client's point of view (Scofield et al., 2009b).

Prefabricated construction is most economical and time saving when the building designs are standardized and repetitive. Hence the benefits of prefabrication are forfeited when clients require bespoke designs. In general, New Zealand house owners are inclined towards customized houses and the lack of flexibility of prefabrication for bespoke designs discourages the use of this technology. Bell (2009) notes that the building owner's penchant for bespoke designs which allows them to make changes to suit lifestyle preferences throughout the design and initial construction stages. The conventional building approach offers this flexibility to a large extent and also allows room for more proactive change management, whereas the prefabrication approach usually limits the extent of the owner's changes to the standard designs. If significant changes are made, especially at the construction phase, the outcomes for the prefabrication technology in terms of costs, speed and wastage will be less desirable compared to the corresponding outcomes for the conventional system.

Bell (2009) interrogated the socio-cultural perspective of prefabrication uptake. She notes the several misperceptions that exist about the use of prefabrication technology based on cultural issues and social interpretations. A stigma of 'poor quality' is attached to the prefabricated construction due to negative experiences in the past. During the post-world war reconstruction era, a lot of prefabricated construction was done to resettle the war damages and to provide accommodation to the homeless victims. Most of this construction was of a temporary nature and was carried out on a fast track basis to meet the needs. As the main focus of reconstruction was to meet the demand, much less emphasis was put on the quality and aesthetics of these buildings and ever since then prefabrication has been regarded as a lower quality construction approach. Many people still think that prefabricated buildings are only temporary buildings like holiday homes and so forth.

The challenges associated with the logistics of large sized prefabricated components or modules also pose a factor limiting the uptake of prefabrication. It becomes even more challenging if the project site is located in urbanised and congested areas. The transportation of prefabricated components incurs a high cost and requires the utmost care during the design phase. All of the prefabricated components are designed to be of a transportable size and strong enough to bear the stresses coming on them during the transportation. Other issues limiting the prefabrication uptake include, onsite connection or interface problems, requirement of specialty cranes at the project site for lifting and handling and the reality that construction-phase changes are bound to be made due to the variability of site conditions from the initial design assumptions. In these circumstances, the conventional building method proves to be more suitable than the prefabricated system.

A recent Masters study (Shahzad, 2011) supported and endorsed by BRANZ, investigated the barriers constraining the uptake of prefabrication technology in the context of the New Zealand construction industry. Various factors that constrain the uptake of prefabrication technology in New Zealand are shown in figure 2.5. Among these factors, the key constraints limiting the uptake of this technology are as follows:

i. Industry and market culture: Reluctance to change by key stakeholders.

ii. Skills and knowledge: Education and training being largely focused on current traditional practices, rather than innovative ideas of the future, and the resultant poor diffusion of the emerging skills and knowledge of the technology in the industry.

iii. Logistics and site operations: The legal restrictions on the transportation of large components and the requirement for expensive escorts.

In sum, prefabrication is still globally viewed as the way of the future in the construction industry. Its benefits certainly outweigh its shortcomings. The question is, why is it then that the technology suffers low industry-wide uptake? Part of the answer to this problem could be the lack of empirical evidence with which to support the numerous benefits credited to the technology. To enable a choice to be made between prefabrication and conventional building systems, owners would want credible and quantifiable evidence of the marginal benefits the technology offers. Current evidence is still anecdotal or is not robust enough due to hasty conclusions being made on isolated case study results.

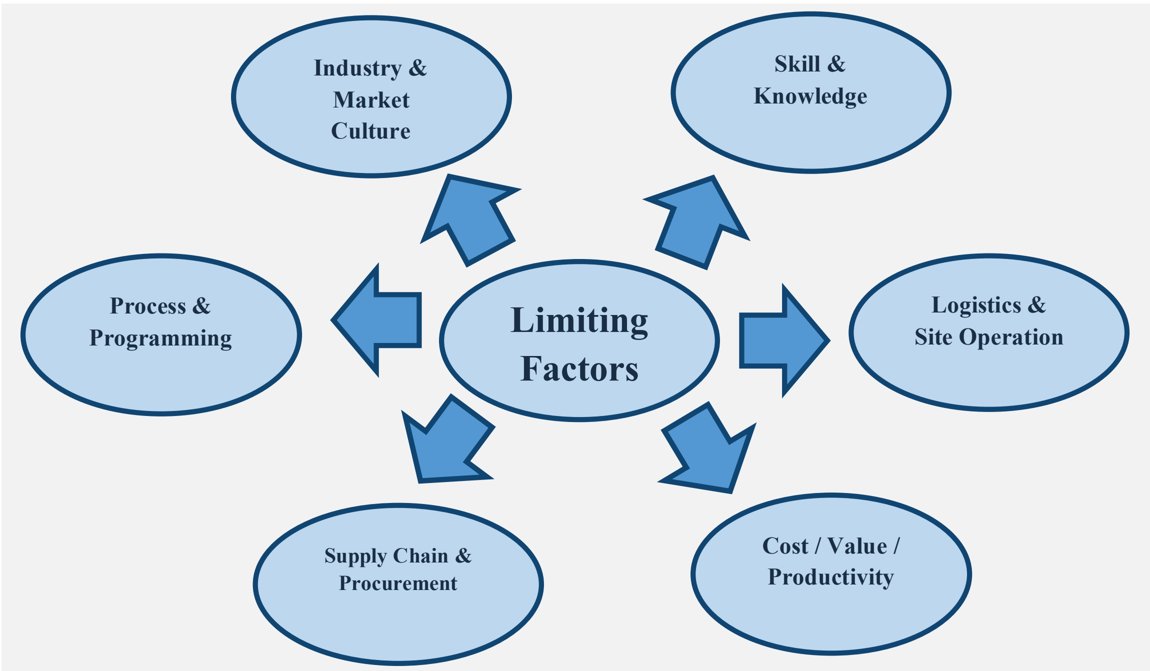

Figure 2.5: Factors that limit the uptake of prefabrication technology [Source: (Shahzad, 2011)]

2.3.7 Prefabrication for Construction Productivity

Prefabrication is a very beneficial technology and all of the benefits of the prefabrication directly or indirectly contribute to the improvement of project productivity, which eventually contributes to the improvement of firm level and industry level productivity. Sustainability, improved quality, cost and time savings associated with the use of prefabrication has resulted in recognition of this technology as the future of the construction industry (Hampson and Brandon, 2004). Ngawoi et al. (2005) reported the predominant de-motivators that impact the productivity of construction projects include: poor quality, requirement of reworks, overcrowded and congested work place, distractions to the workers, tool availability, inspection delays, material availability and labour incompetence. All these demotivating factors can be addressed with the use of prefabrication. In a prefabrication yard all of the workers have their allocated spaces, where they can keep the required tools and there is no interference or distraction to the workers. The carefully designed and controlled environment at the manufacturing yard ensures the good quality of the product that minimizes the requirement of reworks. Due to the high tech nature of manufacturing only trained labour is employed or alternatively the labour is trained to be equipped with essential skills, which addresses the problem of labour incompetence as well.

The National Research Council (NRC) of USA accepted the challenge of devising a strategy for advancing the productivity and efficiency of the US construction industry. After carefully exploring all the ideas that can significantly enhance the construction productivity, the NRC selected five breakthrough approaches to achieve improvement in construction productivity. Among the breakthroughs were “greater use of prefabrication, preassembly, modularization, and off-site fabrication techniques and processes” (MBI, 2010).

The use of prefabrication technology has been repeatedly recognized as a breakthrough technology to improve the declining productivity trend of the construction process in the context of New Zealand as well (Page and Norman, 2014, Zuo et al., 2013, BCSPT, 2012). Page and Norman (2014) conducted a thorough research study on prefabrication in the context of productivity improvement for the New Zealand construction industry and concluded that prefabrication is definitely the future of New Zealand construction. The building and construction sector productivity taskforce (2012), selected the improved perception and improved uptake of prefabrication technology as one of the critical approaches without which construction productivity cannot be enhanced from its current levels.

2.3.8 Prefabrication in New Zealand Context

Prefabrication is not a new concept for New Zealand. Scofield et al. (2009b) explain that prefabrication was introduced to New Zealand as early as 1800, when panelised housing kits were imported from the UK. She further explains that the New Zealand construction industry however preferred to continue with the traditional construction methods as they thought them to be easy and more suitable. Undeterred by the benefits of prefabrication, the uptake of this technology is observed to be low in New Zealand. Becker (2005) advocated that although the use of prefabrication is very low in the New Zealand construction industry, the industry now seems to be willing to try this innovative construction approach. BCSPT (2012) observed the low productivity of the New Zealand construction industry can be answered by the increased use of prefabrication, as prefabrication technology has the potential to curtail the productivity issues arising during the use of traditional construction methods.

At present 17 percent of all New Zealand construction taking place is prefabricated, with a huge potential of almost double the uptake of prefabrication (Burgess et al., 2013).

In a very recent study (Page and Norman, 2014) continued to examine the potential of prefabrication for the New Zealand construction industry. They observed that a very limited amount of standardization is taking place in the New Zealand construction industry and most of the prefabrication occurs for wall panels and roof framing. The report reveals that currently around $2.95 billion of prefabrication occurs in New Zealand each year and if more uptake of prefabrication can be promoted based on the components that are easy to be prefabricated, the occurrence of prefabrication can rise to $5 billion per year.

Page and Norman (2014) note that apart from the tangible benefits of prefabrication, such as, design, labour, material and transport and so forth, there are various intangible benefits of prefabrication like health and safety, life cycle cost, sustainability and quality. All of these tangible and intangible benefits ultimately contribute to the improvement of productivity at the project level and at the industry level.

All of this research suggests that the uptake of prefabrication is a must for the improvement of the productivity of the construction industry in New Zealand.

2.4 Traditional Building System

2.4.1 Understanding the Traditional Building System

The construction industry is project oriented and each construction project is unique in nature. Traditionally all of the manufacturing and assembling activities involved in a construction project take place at the construction site. It is very difficult to exactly define a traditional building system, as construction methods are continuously changing and improving ever since their evolution. In regard to the construction approach associated with traditional building techniques in which the bulk of building components are manufactured onsite, customarily all of the materials required for the construction project are brought to the project site, where they are stored, prepared and laid to construct the structure of the building project. Most of the working conditions at the project site during the construction process are uncontrolled. In other words, the construction process, where the prevailing construction practices are being used and traditional construction materials are used for construction purpose is known as the traditional building system. Jaillon and Poon (2008) document that the traditional building system is time consuming and labour intensive as almost all the activities related to the construction process take place at the project site. This approach is in total contrast to prefabricated construction since a portion of the construction activities occur away from the project site in a controlled factory environment.

Each construction project has its own requirements of workmanship and most of the workers are not required to do the same work every day. Labour while not employed to their full potential, reduces the overall labour productivity of the project and this also has financial implications. As discussed earlier, because the conditions on project sites are not controlled, a huge amount of construction material is wasted due to weather conditions and theft and so on.

With the introduction of more innovative construction approaches, the traditional building system is not as lucrative to the project stakeholders anymore. Particularly keeping in mind the some of the prevailing problems of the construction process, for example, cost overruns, delays and poor quality workmanship, traditional construction methods are now being replaced by modern and innovative construction techniques, such as, prefabrication. Ahmad (2008) observes that traditional construction practices carry a stigma of poor health and safety conditions for the workers. A recent study (Burgess et al., 2013) note that 75 percent of fatalities on a conventional project site can be controlled by replacing the traditional building system with prefabrication technology.

Traditional building practices have extensive impacts on the environment in terms of pollution, waste generation, energy consumption and habitat destruction. The U.S. Green Building Council carried out a detailed study (Larsen et al., 2011) on the impacts of the traditional construction process. This study documents that traditional construction practices are responsible for one third of carbon emissions and generate enormous waste during the construction and operation phase (up to 40 percent of the total waste generated in U.S.). In addition they require a huge amount of infrastructure to extract, process and transport the construction materials. A similar amount of waste is generated in New Zealand by construction activities (Burgess et al., 2013).

2.4.2 Types of Traditional Construction

Depending upon the type of construction material used, there are many types of traditional construction methods. Some of the common and widely used construction methods include timber construction, concrete construction, steel frame construction and composite construction. These construction methods, their application and benefits are summarised below.

2.4.2.1 Timber Construction

Timber construction is one of the oldest methods of construction. Historically, the New Zealand construction industry has used onsite timber construction. Timber is commonly used for the construction of single storey housing buildings, in many countries around the world where timber is easily available (Shackleton et al., 2011). Without any doubt timber can effectively be used for construction of multi storey buildings (Thelandersson and Larsen, 2003). Efficient application of timber can be made in the form of various building components including columns, floor framing, roof framing, floor decks, roof decks, load bearing walls and non-load bearing walls.

In the New Zealand construction industry, timber construction is widely used in the residential sector. However, large-scale timber construction has also been utilised for many decades now. Recently, the laminated veneer lumber (LVL) is being used for almost all types of building construction including commercial and industrial buildings in New Zealand (JNL, 2014). LVL refers to the prefabricated structural components made of thin peeled veneers glued together with a strong adhesive forming high strength, reliable, easy to use, economical and environmentally friendly timber components (Wood, 2012).

2.4.2.2 Concrete Construction

Concrete is a composite construction material, which is formed using cement, aggregate and water. Owing to the aspect of good value for money, the versatile nature of concrete and durability, concrete construction is most common construction technology used for almost all building and civil engineering works from structures, foundations, roads, bridges, to dams and reservoirs (Kosmatka et al., 2002).

2.4.2.3 Steel Construction

Steel construction refers to structures made of steel frame built by joining together the steel columns and beams. Steel construction is mostly used for warehouse buildings, workshops, sports facilities and commercial buildings. Lawson et al. (2009) define the benefits of steel construction which make it an ideal choice of stakeholders. These benefits include versatility of use to meet any design requirements, strength of structure, fast speed of assembly, environmental sustainability, high quality construction, minimum requirements of re-works and the potential of re-use of steel at the end of building life. Steel used in construction can be re-used again and again for several times. Burgan and Sansom (2006) document that steel construction can contribute to sustainable development by economic growth, social progress and environmental safety. Whereas steel is regarded as the most sustainable construction material, the versatile nature of steel gives extensive freedom to designers to design ambitious buildings.

2.4.2.4 Composite Construction

Composite construction is the form of construction in which two or more different construction materials are joined together to obtain strength, durability and cost effective benefits. One very common example of composite construction is steel reinforced concrete components, in which steel reinforcement bars are embedded in concrete to improve the strength of the finished components. It also reduces the random cracking of concrete, controls the displacement of components and saves the project cost. Other examples of composite construction include steel reinforced timber beams, which are known as flitch and timber reinforced concrete.

2.4.3 Benefits of Traditional Building System

Traditional construction and building practices have been changing ever since their origin to make them easier and more beneficial. Traditional building systems are a well-developed and well established means of carrying out any building project (Radosavljevic and Bennett, 2012). In terms of traditional construction methods that make this approach a suitable choice for all project stakeholders. Few significant benefits of traditional construction approach are discussed here:

- Traditional building system is a flexible construction approach with regard to the design and construction process. Clients often prefer the traditional building system as they can easily make design changes to suit their requirements during the design as well as the construction phase (Radosavljevic and Bennett, 2012).
- Traditional building system is very common and widely used, particularly of the house construction. Due to a large business size, there is a plenty of tradesmen and specialist available to carry out traditional construction processes.
- Traditional building system has proven track record and every stakeholder from designer, quantity surveyor, lender and insurer to investor is skilled and trained to carry out their job.
- Traditional construction practices hardly require any speciality material. Most of the materials used for the construction of traditional buildings are easily available in market. A large quality of materials is locally sourced and produced for traditional construction.
- Masonry construction is one of the most common methods of construction. Masonry materials are very strong and durable with a long life. Additionally, masonry construction is very cost effective as well. Any kind of modification and extension to the existing structure is conveniently possible with this type of construction. A good level of heat and sound insulation can be achieved with the use of masonry and on top of this masonry provides good fire protection (Ramamurthy and Kunhanandan Nambiar, 2004).
- Traditionally built structures show good thermal performance. As most of the construction is based on masonry and masonry has high thermal mass with the ability to absorb heat. This property of masonry keeps the building cold during the summer and heated during the winters. During winter the heat stored inside gradually releases into the house during night time (Ramamurthy and Kunhanandan Nambiar, 2004).

- At the time a traditionally constructed building reaches end of its life, almost the whole building can be fully recycled. Most of the construction materials including the steel, concrete and masonry employed in the traditional building system are recyclable (Lawson et al., 2009).

2.4.4 Issues with Traditional Building System

Like any other construction approach, the traditional building system faces many challenges. Construction activities contribute largely to the emission of carbon dioxide, and in New Zealand 35 percent of carbon emission to the atmosphere is due to construction activities (Burgess et al., 2013). In the United States one third of carbon dioxide emissions are produced as a result of traditional construction practices (Larsen et al., 2011). Other reported statistics of raw material consumption reveal that 60 percent of all raw materials used in United States is consumed in the construction industry and in New Zealand this value is 40 percent which is similar for many other comparable countries (Larsen et al., 2011, Bell, 2009).

Burgess et al. (2013) continue to observe that 40 percent of New Zealand's energy consumption and a similar amount of waste generation is associated with the activities of the construction industry.

Traditional construction methods are labour intensive and most of the labour work under harsh and unsheltered conditions (MBI, 2010). At project sites workers are exposed to certain risks, for example, injuries, falls, harsh weather, noise and dust pollution and so on.

The traditional construction process suffers delays due to unavoidable weather conditions, such as, rain, flood and snow. Construction materials also need to be stored at construction sites and need to be protected from the weather. It is very difficult to completely protect all the construction material stored at site. A lot of material goes to waste due to inadequate storage facilities (Gibb, 1999).

2.5 Comparison of Prefabrication and Traditional Building System

Prefabrication and traditional building systems are two entirely different construction approaches and the choice between the use of the prefabrication and the traditional building system is usually made based on the productivity outcomes of these construction approaches, for example, the development cost rather than the life cycle value of the project. Goodier and Gibb (2007) note that the decision to choose between these two construction approaches is usually made based on the project development cost. Clients tend to prefer the low cost building options. Another most appreciated productivity focused advantage of using prefabrication technology over other methods of construction is in relation to the speed of the construction. Despite the long project design phase, prefabrication technology remarkably shrinks the project completion time compared to the traditional construction approach.

Prefabrication technology is regarded as a very sustainable and very environmentally friendly construction approach. Barret and Weidmann (2007) argue that when compared to traditional building systems, prefabrication technology clearly outperforms the traditional construction approach in terms of greenhouse gas emissions, waste generation and carbon footprint. And construction workers on a typical construction site work in unsheltered conditions and are exposed to these elements.

The Modular Building Institute Report (2010) provides a detailed comparison between prefabrication and the traditional building system. The comparative analysis of prefabrication and traditional building system is summarized as follows: Prefabrication technology carries the potential of optimizing the use of construction materials, minimizing the amount of waste generated and providing a high quality product for the clients; whereas a large amount of construction material is wasted on the site of the traditionally built project. The quality of construction is also hampered due to the uncontrolled conditions at the project site. Further to this in a prefabrication yard, all the materials and supplies are kept in a controlled storage environment. This eliminates the chances of any moisture being trapped in the fabric of the new construction material.

Contrary to this the material stored at a traditional project site gets deteriorated throughout the time it is kept in the on-site storage areas.

Prefabricated construction makes use of lightweight construction materials, so the overall weight of prefabricated components is lighter compared to the traditional masonry and steel construction. These components are easy to handle, move and install. Goodturn et al. (2009) document that labour productivity significantly improves when the construction process makes use of lightweight and easy to move components.

The site of the traditional construction project is very congested due to the material stacking on the project site and the machinery used on the site. In the case of prefabricated construction the majority of components/modules are manufactured in a factory which reduces the congestion at the project site. Also the requirement of machinery and equipment is reduced on the project site when the bulk of building components arrive at the project site, ready to be installed (MBI, 2010).

Construction workers at a site of a traditionally built project are exposed to extreme weather conditions; temperature, rain and winds. Workers are also exposed to the potential of being injured due to material falling off and other site risks. Whereas, in factory conditions, a safe and sheltered workplace is provided where the workers are fully equipped with the required tools and materials (Bell, 2009).

Due to parallel construction activities taking place on and off the project site, the prefabricated construction project can be completed in much less time compared to traditional construction approach. The use of prefabrication saves 50 to 60 percent of the project completion time (Bell and Southcombe, 2012, CRC, 2007, Page and Norman, 2014).

Yau (2006) observed circumstances in the UK and noted the fringe benefits of employing the prefabrication technology of construction over the traditional building system. He recorded that with the application of prefabrication technology the overall productivity of the UK construction industry has increased by at least 2.5 times. Prefabrication technology makes use of improved planning and coordination in terms of the construction process, which in turn reduces the project delays and enhances the productivity of the construction industry by 12 percent onsite and 2 percent offsite. Yau continues to record that prefabrication technology usually has huge cost benefits, although cost benefits are not easy to evaluate particularly considering the high initial set up cost required for establishing the prefabrication production yard.

In another study (Jailon and Poon, 2009) conducted in Honk Kong, researchers compared the use of prefabrication technology with the traditional building system and observed that the use of prefabrication technology substantially improves the quality of the construction. They also reported that prefabrication reduces the project completion time by at least 20 percent compared to the traditional building system. Furthermore, the amount of waste generated on a prefabricated building project is reduced by 56 percent.

Prefabrication manufacturers in New Zealand regard prefabrication technology to have an upper hand on the traditional building system due to the various benefits of prefabrication including but not limited to earlier returns on project investment, easier planning and coordination of the construction process, control of material theft, ability to work under harsh weather conditions and convenient monitoring of the process (StanleyGroup, 2011, Degeest, 2011).

2.6 Global Trend of Prefabrication Use

Prefabricated construction is globally acknowledged as the future of the construction industry for sustainable and more productive construction practices. Almost all of the developed countries are motivated to shift from the traditional construction practices into the more socially and economically beneficial prefabricated construction technology. Many countries including New Zealand, United Kingdom, United States, Australia, Malaysia and China are already focused on overcoming the prevailing construction industry issues by replacing the existing construction practices with prefabrication technology.

2.6.1 Prefabrication in United Kingdom

The United Kingdom was first to realize the importance of prefabrication and took the lead in the adoption of prefabrication. A business organization "Buildoffsite" was established in the UK in 2003, with the aim of promoting significant improvements in the quality, value and productivity in the UK construction industry. The UK construction industry stakeholders, consultants, clients, contractors, builders, suppliers and manufacturers are working together under the umbrella of Buildoffsite. Ever since its establishment "Buildoffsite" is promoting the greater use of prefabrication in the UK construction sector and it has very successfully contributed to the improved perception and uptake of prefabrication in the UK. Buildoffsite is now launching in Australasia to work in collaboration with the key players in the Australia and New Zealand prefabrication industry (Buildoffsite, 2015).

Phillipson (2003) observed the trends of the application of prefabrication in the UK and recorded the various benefits of prefabrication in the UK construction industry, The benefits include the improved quality of the construction products and the fast track delivery of the project to the clients. This results in the enhanced productivity of the construction process and higher profits to the contractors. He also observed that although the prefabrication technology is widely adopted in UK, there are certain factors that are limiting the full potential of prefabrication in UK. Phillipson (2003) further reports that the UK housing market is most affected by the negative perceptions about this technology. Most of all the negative stigma associated with the poor quality construction constrains the use of prefabrication technology in UK.

National statistics (2005) observed the prefabrication trend of the UK construction industry and noted that the uptake of prefabrication technology is continuously increasing. Pan et al. (2005) reported that the current application of prefabrication in the UK construction industry is not just limited to the use in individual houses but a large number of high rise residential buildings are also being constructed using prefabrication technology. In the following years it was observed that prefabricated construction represented around 2.1 percent of all the construction and 3.6 percent of all new buildings constructed in the UK

(Goodier and Gibb, 2007). Taylor (2009) observed an increase of 25 percent market share in terms of prefabricated construction each year in the UK.

There have been many recent successes in the near past. The new district of St. Petersburg was developed using prefabrication technology, where 15,000 dwellings were constructed to provide accommodation for 22,500 people. The £800 million landmark project saved 20 percent construction time and 25 percent project cost. A school project ‘Piggott School, Foremans’ was completed while achieving a 70 percent savings in project schedule. Similarly, a Sainsbury store in London, with a floor area of 1100 m^2 was constructed in just 13 days resulting in a savings of four weeks of the total project programme (Buildoffsite, 2015).

2.6.2 Prefabrication in USA

The USA is also among the first few countries to realize the potential of prefabrication technology. The Modular Building Institutes (MBI) of USA is actively involved in promoting the uptake of prefabrication through research, publications, seminars and exhibitions. The USA construction industry also faced certain challenges, for example, cost over runs, quality issues and inappropriate usage of resources. Lu (2009) observed that clients were more and more concerned about the fast track completion of projects, without having to compromise on the quality of project and health and safety of workers. They further noted that clients are looking into the means of completing projects without having to deal with cost over runs and unexpected delays in completion. MBI report (2010) documented that USA construction industry is currently dealing with a shortage of skilled labour and workers.

The Modular Building Institute believes that the properly coordinated demand based uptake of prefabrication in the USA construction industry is the need of the hour. This way the construction industry can deliver more productive, fast track, better quality and low cost projects. At this stage prefabrication is regarded as to be the most suitable construction approach for the commercial and infrastructure project (Azman et al., 2010).

And it is very likely that with the efforts made by MBI, the uptake of prefabrication will no longer be limited to one or a few sectors of construction (CACPUCI, 2009).

A very recent example of prefabrication success in the USA is the Exempla Saint Joseph replacement hospital that was completed in 2014. This is one of the largest hospitals in the United States and was completed in less than three years, resulting 18 percent reduction in terms of the scheduled completion time. The hospital project comprising 831,327 square feet area was operational in just 30.5 months after its inception. The project was designed to incorporate 446 prefabricated bathrooms, 400 prefabricated headwalls and 250 prefabricated exterior panels (Exempla Saint Joseph Hospital, 2014).

2.6.3 Prefabrication in Australia

Australia also recognized prefabrication technology as the key strategy to improve the productivity of the local construction industry (Hampson and Brandon, 2004). Blismas and Wakefield (2007) pointed out that similar to many other comparable developed countries, Australia was quick to realize the potential of prefabrication technology and the benefits that could be obtained with the use of this technology. Despite this realization the uptake of prefabrication is not up to the mark (Blismas and Wakefield, 2007).

A research based organization "Cooperative Research Centre (CRC)" was founded in 2001 with the aim of encouraging innovation in construction practices. The CRC took the initiative to develop a vision 'Construction 2020'. The focus of this vision was to identify the future targets of the construction industry and investigate the barriers that limit the ability of the construction industry to achieve these targets. After its establishment a CRC report (2007) acknowledged the various benefits of prefabrication technology for the Australian construction industry. The report stated that the benefits include: reduced construction time, cost savings, ease of construction, enhanced quality, improved health and safety, efficient resource utilization, waste minimization and improved life cycle value and energy performance. This evidence was enough to encourage more uptake of prefabrication.

Recognizing the prefabrication benefits, Blismas and Wakefield (2007) substantiated that similar to other countries the Australian construction sector needs to undertake a change in its operating mechanism. Prefabrication requires an entirely different work approach and culture or the complete benefits of prefabrication will not be able to be achieved without having an understanding of prefabrication principles. Blismas et al. (2009) observed that prefabrication holds a great potential to meet the housing shortage of Australia. Another positive indication in most recent years is the establishment of the prefabrication organization 'PrefabAUS' in 2013. PrefabAUS works with government agencies, regulatory bodies, local councils, architects, manufacturers, designers, engineers, project managers and other construction stakeholders to promote the use of prefabrication technology in Australian construction. PrefabAUS is also committed to promote research and development of prefabrication technology and also to act as a hub of quality information about the prefabrication technology.

2.6.4 Prefabrication in China

Construction industry in various parts of China worked in isolation until two decades ago when construction industry was unified and the same laws were made applicable to the entire construction industry throughout China. It was after the unification of the Chinese construction industry in 1996 that more development was observed in the construction sector including the adoption of innovation, international investment and new reforms (Arif and Egbu, 2010).

China is considered as the manufacturing powerhouse in today's world. Tax relaxations, low cost labour, huge production capacity can provide an excellent platform for prefabricated construction in China. The prefabrication industry in China needs government support to compete in the global market place. China still has to make the huge shift from traditional practices to prefabrication, which is only possible with the support of the key stakeholders in the construction industry, and government and leaders at the municipal level(Arif and Egbu, 2010).

Notwithstanding, in few parts of China potential of prefabrication technology was researched and explored. A few projects have been carried out using prefabrication in Hong Kong with the aim of achieving sustainability (Yau, 2006). Tam (2002) documented that the construction industry of Hong Kong is labour intensive employing more than 300,000 construction workers. The construction industry in Hong Kong largely depends on the traditional construction practices which are primarily labour intensive, dangerous from health and safety point of view, environmentally polluting and of low quality (Jaillon and Poon, 2008). Wilson (2006) confirmed that the labour intensive construction industry in Hong Kong, lacks the uptake of prefabrication. Tam (2002) investigated the factors that limit the uptake of prefabrication in Hong Kong and observed three main constraints in terms of the adoption of prefabrication in Hong Kong. These include the town planning regulations of Hong Kong does not have the flexibility to accept the uniform design patterns of prefabrication, it is hard to interface the prefabricated buildings with the already constructed high-rise buildings of Hong Kong and lastly, prefabrication does not seem to be the right choice to meet the water tightness requirements for buildings constructed in Hong Kong.

Hong Kong is a densely populated city, comprising high-rise buildings. In 2005, the construction industry in Hong Kong produced 21.5 million tonnes of waste (Jaillon et al., 2009). Any waste in Hong Kong is disposed of in landfill and these landfills are filling up at a very high speed. The amount of construction and demolition waste is particularly very high. It is recorded that more than 25 percent of the solid waste disposed off in the landfill areas of Hong Kong comes from the construction industry (RSE, 2009). One of the significant advantages of prefabrication is the reduction in waste generation and hence this makes prefabrication a good choice for Hong Kong. Yau (2006) confirms that the use of prefabrication reduces the amount of waste generated and it also improves the health and safety standards of dangerous construction sites by enabling a clean and tidy environment.

In the years to come, Jaillon and Poon (2008) observed a few case study projects in Hong Kong and documented evidence of success including an average reduction of construction waste of 65 percent, a reduction in the requirement of on-site labour by 16 percent, a savings in construction time by 15 percent and a 63 percent reduction in accident rates. It is a common belief that the widespread adoption of prefabrication in the entire country of China can greatly benefit the construction industry to boost the 6.5 percent share of GDP (Egbu, 2006).

2.6.5 Prefabrication in New Zealand

Prefabrication has a long history in New Zealand. Bell and Southcombe (2012) summarised the history of prefabrication in New Zealand and documented that prefabricated kit set homes were first imported in New Zealand as early as 1833. In 1833 ‘Treaty House, one of the most famous colonial houses, was brought to New Zealand by James Busby, as pre-cut frames and materials. In the mid-1800s the prefabrication industry was established in the Bay of Islands where kauri cottages were made and shipped to Australia and to the United States. In the early 1900s New Zealand’s Department of Railway turned out to be the largest producer of prefabricated houses. The Department of Railway produced 1,600 houses in six years (Scofield et al., 2009a). Keith Hay Homes, McRaeway Homes and Lockwood Group pioneered the development of prefabricated housing in the late 1900s. In the 1950s the post-world war shortage further triggered the use of prefabricated housing.

Despite the long history of prefabrication in New Zealand, the current uptake of prefabrication is not very widespread. At the same time the construction industry in New Zealand is regarded as less efficient and least productive (Scofield et al., 2009b). Scofield *et al.* (2009b) explained that the New Zealand construction industry is inclined to use the traditional building system and construction approach to meet the market demands. The construction industry is not willing to try innovative methods of construction and therefore prefers following the tried and tested traditional methods that appear to be less risky. Becker (2005) recorded that despite the low uptake of prefabrication in New Zealand, there is a huge potential for prefabrication in the construction industry in New Zealand. He further reports that the New Zealand building regulations are based on performance and that these regulations are very flexible to adopt innovative alternatives to achieve project targets. Realizing the potential of prefabrication and the need to improve its uptake in the New Zealand construction industry, an industry organization ‘PrefabNZ’ was established in 2010. PrefabNZ is the umbrella organization for prefabrication in New Zealand. The aim of PrefabNZ is to double the current uptake of prefabrication in New Zealand to 20 percent by year 2020. Ever since its inception PrefabNZ has immensely contributed to the research, promotion and uptake of prefabrication technology in New Zealand.

The uptake of prefabrication is very critical to improve the declining productivity of the New Zealand construction sector. The Building and Construction Sector Productivity Taskforce has recognised the uptake of prefabrication as a breakthrough technology to enhance the productivity of the New Zealand construction sector. Multiple evidence exists that prefabrication technology is essential to address the prevailing productivity issues of the New Zealand construction industry (Bell, 2009, BCSPT, 2012, Shahzad, 2011).

The redevelopment of Canterbury after the deadly earthquake of Canterbury in 2010 has further increased the potential of prefabrication uptake in New Zealand. In addition to this, the housing shortage in Auckland also holds great potential for prefabrication in New Zealand. Auckland and Canterbury are current focus points of New Zealand construction industry and a great opportunity to make use of prefabrication (PrefabNZ, 2013). The Canterbury earthquake damaged 17,000 dwellings beyond a point of repair, while another 15,000 damaged dwellings were repairable (Ryan and Nick, 2012). As for Auckland, the current housing demand is 10,000 dwellings per year for the next decade, whereas the current house delivery rate is 3,500 dwellings per year. According to calculations Auckland will be short of 90,000 houses in the next 20 years. To fulfil the housing demands in Canterbury and Auckland prefabricated construction has been identified as a key strategy (PrefabNZ, 2013).

Recently many successful prefabricated projects have taken place in New Zealand, paving the way to more prefabrication in New Zealand. Completed in 2011, Elam Hall (University of Auckland’s hall of residence), is a landmark prefabricated project and the first of its kind in New Zealand (Stanley, 2013). The 14-story accommodation building, consisting of 468 modules was completed in less than a year’s time. The project was a joint venture of the Stanley Group and Hawkins Construction. The Stanley Group manufactured the modular units in their factory in Matamata under controlled settings and close monitoring and the modules were transported to project site, just in time for their installation. Hawkins was responsible for the construction of the base structure to place the modules and installation of modules (Burgess et al., 2013). Each of the factory-built modules was completely finished with carpets, cabinets, joinery and electrical fittings. Careful planning was carried out to safely transport the modules and to minimize the number of trips to the project site (Stanley, 2013). The project resulted in an immense reduction in project completion time and overall project cost. The Elam Hall project was completed nine months earlier compared to the traditional building system (Bell and Southcombe, 2012). This project is an example of a large size construction project where cost, quality and time benefits were achieved with a high degree of repetition and just in time delivery of modules to avoid disruption on project site. Other success projects of Stanley Group include Albany Senior High School project, which was completed in the short time of eight months to accommodate 300 high school kids. Many prefabricators in New Zealand have excelled in the skill of manufacturing prefabricated houses in New Zealand. To mention a few, Christchurch based Liang Homes has the capacity to manufacture 6 – 12 custom designed houses in their yard, which takes approximately 8 – 10 weeks for completion. Liang Homes claim that their manufactured houses are 40 percent more affordable than traditionally built houses while saving almost half the construction time (Bell and Southcombe, 2012). Keith Hay Homes is a very old provider of housing in New Zealand. Keith Hay has many house plans in place that can be manufactured and delivered to a project site in 8 – 10 weeks, in two sections that can be joined together at the project site. Lockwood Homes, another established provider of prefabricated homes, has a large variety of house plans ranging from an area of $51m^2$ to $300m^2$.

2.7 Summary of Review of Literature

The productivity performance of the construction industry is vital for determining the sector's ability and efficiency and it is equally important for country's economy. The productivity performance of the construction industry in New Zealand is continuously declining. To improve the declining productivity trend, the use of prefabrication technology has been identified as a breakthrough technology. For the measurement of productivity there are three key productivity measures – cost savings, time savings and productivity improvement and use of prefabrication can contribute to the achievement of these productivity measures.

The benefits of prefabrication technology to improve the productivity performance of construction projects have been widely documented. Regardless of the various known benefits of prefabrication, the stakeholders generally prefer traditional building systems instead of using prefabrication technology. This might be due to the major gap observed in the existing research, since a lack exists in terms of the evidence-based benefits of prefabrication system compared to the traditional construction methods. For an evaluation of productivity gains that are achievable with the use of prefabrication technology, there is a need to identify and disseminate the quantified benefits achievable by the use of prefabrication in place of the traditional building system.

2.8 Gaps in Knowledge

From a comprehensive and in depth review of the literature that exists on prefabrication two major gaps have been identified. One significant gap observed in the literature is the lack of evidence-based support for the various claimed benefits of prefabrication technology. No doubt extensive research has been conducted on the benefits of the prefabricated construction approach, in many countries across the globe. Yet, unfortunately not much attention has been focused on quantifying the claimed benefits of prefabrication that can encourage the clients to adopt the prefabricated construction approach in place of the traditional construction methods. It is the lack of quantifiable benefits that is limiting the uptake of prefabrication technology, although on the other hand the existence of sufficient evidence-based benefits can drive a greater uptake of prefabrication. The necessity to measure the quantifiable benefits of prefabrication based on rigorous data instead of anecdotal evidence is a critical challenge to improve the uptake of prefabrication in New Zealand. Without the presence of quantifiable benefits, stakeholders will not have enough confidence in the technology to invest in it.

The other critical gap identified in the existing literature is the absence of a meticulous method of measuring the construction productivity at the project level. Construction productivity is generally measured at the national level and the various methods of productivity measurement that exist do not comply with the requirements and goals of construction projects.

The aim of this research is to contribute by providing the answers to the questions outlined in the research objectives section by filling in the gaps in knowledge that have been identified.

CHAPTER 3: METHODOLOGY

3.1 Overview

This chapter presents an insight into the methodology adopted to carry out this research. The research is divided into two distinct phases: Investigation of case study building projects and a survey of industry stakeholders' views on the key subject matter. The chapter starts with the presentation of the research strategy employed in the study. This is followed by a discussion of the key elements of the research methodology employed for the case study of the building projects including the data collection, sampling methods and data analysis.

In the next section the methodology adopted for conducting the questionnaire survey is presented in detail. It discusses the key elements of the questionnaire survey including the data collection, the sampling method, the pre-testing and, circulation of the questionnaire and an analysis of the collected data. This chapter also discusses the ethical approval sought from and granted by Massey University's Human Ethics Committee (MUHEC) to conduct this research following the ethical principles set forth by the University.

3.2 Research Methodology

Research is a process for critically investigating the facts leading to the development of knowledge (Saunders et al., 2007). Hughes (2009) argues that, generally a piece of research should either develop new theory or test existing theory; a 'research' work that does neither will not add to the existing body of knowledge and therefore is not 'research' in the true sense of the word.

On the other hand, research methodology is a comprehensive plan to craft research activities and involves deciding the research approach, the method of data collection, data analysis and hypothesis testing (Brannen, 2005). Byman and Bell (2015) define research methodology as a structured approach that guides the entire process of research by defining the methods of data collection and analysis of data in order to explore and find answers to the research questions.

Various factors govern the choice of research design formulated to guide in the gathering of the data and the data analysis in relation to accomplishing the research objectives or specific research questions. These factors include the research philosophy, the nature of the research objectives, the nature and distribution of the primary data, and the number of variables to be analysed (Yin, 2003, Saunders et al., 2007). These are discussed in the following sections.

3.3 Research Philosophy

The research philosophy forms the basis for the choice of the appropriate research design. The use of the appropriate research philosophy ensures a form of reference or standpoint of argument and leads to a smooth research process and reliable findings (Easterby-Smith et al., 2012). Easterby-Smith et al. (2012) further explained that the research philosophy helps to clarify the research design and enable the researcher to understand which research design is more suitable to achieve the research objectives. Collis and Hussey (2013) also argued that the research philosophy governs the way the research is conducted. Classification of various philosophical approaches is discussed in following section.

3.3.1 Positivism/Deductive Approach

This research philosophy places emphasis on the generalizability of the research findings beyond the study scope of a piece of research. It therefore requires having a representation of the data from a defined population and would generally involve a statistical test of significance to accord some measure of confidence in the results and the conclusions that are drawn from them (Tan, 2008). While the focus of positivism is based on measuring facts through observations, positivists make use of the quantitative methods of research that are bound to a strict set of the rules of logic. Research governed by positivism place emphasis on testing and refining the existing theories and laws (Amaratunga et al., 2002, Easterby-Smith et al., 2012). The viewpoint of positivists that reality has a pre-determined nature and structure is defined as realism and objectivism (Saunders et al., 2007, Johnson and Duberley, 2000). Positivitism also believe that any theory, phenomenon or law is only regarded as knowledge if and only if it is observable and measurable (Collis and Hussey, 2013). This approach minimises the bias in research outcomes as it allows minimum amendments to the collected data (Crossan, 2003). Owing to the methodological approach of positivitism, the quantitative research approach is regarded as the most suitable approach (Crossan, 2003).

3.3.2 Interpretivism/Inductive Approach

The philosophical approach of interpretivism research is focused on understanding phenomenon as it is, since it advocates and supports the idea that reality depends on the perceptions of the person (Cormack, 2000, Fellows and Liu, 2003). Interpretivism also sometimes known as 'Phenomenology', is a paradigm which recognizes that individuals and world are interdependent and hence research objectives are affected by the research process (Collis and Hussey, 2013). The focus of this research philosophy is to reduce the gap between the researcher and research objectives (Bailey, 2007, Collis and Hussey, 2013). Interpretivism usually adopts qualitative research methods, which enables the researcher to carry out extensive discussions with a group of participants to examine the issues.

3.3.3 Pragmatism

Pragmatism provides a reasonably flexible research approach. Pragmatism has the potential to link theory with practice, while selecting a research method that is most suitable to achieve the research objectives. The key focus of pragmatism is towards the research outcome and the key concern is towards applications and finding a solution to the research problems (Patton, 2003). Pragmatic researchers have the freedom to employ the research methods and techniques associated with qualitative and quantitative research approaches. Pragmatic researchers realize that every research method has some shortcomings or limitations and that they can use different research techniques at the same time or alternatively.

3.3.4 Research Philosophy Adopted in this Study

This study has adopted the pragmatism research philosophy for two reasons. First, it links theory to the practice and second, it is a flexible approach that not only satisfies the interpretivist and positivist philosophical viewpoints by adopting the deductive-hypothetical standpoints but also provides freedom to researchers for using multiple methods of data collection and analysis (Patton, 2003, Fellows and Liu, 2003). Following deductive reasoning, the benefits of prefabrication in case study projects were studied and used as a basis to formulate the hypothesis regarding the potential benefits of the technology in terms of the time and cost savings and productivity improvements. Following the hypothetical standpoint, the hypotheses are tested for validity and reliability in quantitative surveys. This combined approach helps to minimize the shortcoming of the individual philosophical approaches and provides the benefits of both worlds (Creswell, 2009, Vogt, 2005).

3.4 Research Design

The research design helps a researcher to develop a suitable research implementation plan and process to suit the philosophical position adopted for the study. It helps to link the research questions/objectives to the nature of data required, data sources, and appropriate data collection and analysis methods (Easterby-Smith et al., 2012).

Based on the data collection and data analysis method, the research methods are classified in three categories which include the qualitative, quantitative and mixed research methods (Tashakkori and Creswell, 2008). These research methods offer different choices of data collection, data analysis and a level of flexibility that is required for various research approaches (Williams, 2007). A brief discussion on different research approaches is presented in the following section.

3.4.1 Exploratory/Qualitative Method

Qualitative research methods are spontaneous, which encourage the interaction between the researchers and the participants. Qualitative research methods use data collection techniques, for example, interviews and the open-ended survey questionnaire, which provide freedom to participants to respond in the way they want to respond (Mack et al., 2005). The data collection procedure adopted for qualitative research, for categorizing data such as thematic analysis generates text data or non-numeric data. Qualitative research methods are less formal which enable the researchers to gain detailed insight into the research query from the participants (Creswell, 2009).

The above views about qualitative research method appear to relate solely to surveys and lack criterion around the purpose of the research. In a different context, Zikmund (2012) provides a more succinct explanation by identifying qualitative research from the perspectives of theory building. Qualitative research in this context is focused on generating data – whether objectively or subjectively provided – for the purpose of developing hypothesis, proposition or theory. The emphasis here is not on robust statistical analysis or obtaining representation from target populations. However, the problem with qualitative research is that it lacks representation from the target population hence it is heavily criticized by researchers from the positivist school of thought (Patton, 2003).

3.4.2 Confirmatory/Quantitative Method

Quantitative research methods refer to any data collection technique like close-ended questionnaires and unlike qualitative research methods, quantitative research methods are generally inflexible. Data analysis techniques such as statistical analysis generate numerical data (Mack et al., 2005). In this method of research, all participants are given a similar set of questions and the choices to be made are in the same order. With quantitative research methods, participants cannot have the flexibility to express their point of view beyond the limited choices offered to them. In this research method, participants are required to have a good understanding of the research questions and the ability to present a range of possible responses (Creswell, 2009). One of the key benefits of this approach is that researchers are allowed to carry out comparisons of the viewpoints of the participants from different backgrounds.

In a different context, Zikmund (2012) identified quantitative research from the perspective of theory testing. Quantitative research in this context is aimed at testing existing theory using robust statistical tests. The emphasis will be on using representative samples from the target populations in quantitative data analysis that involves a rigorous statistical test of significance, which could lead to confirmation, or disconfirmation of the initial theory or hypothesis.

The interpretivists have critiqued the quantitative research approach. This is because it involves the imposition of unfounded theory on the population that defines a given phenomenon without an attempt to align with the peculiarities of the population context (Creswell, 2009).

3.4.3 Mixed Method

Mixed method research as the name explains is a mix of both qualitative and quantitative research methods. Mixed method of research is a combination of both approaches and consists of qualitative and quantitative data collection and data analysis techniques (Creswell, 2009). The various advantages of mixed method have been identified to meet the requirements of positivists and interpretivists in the research process and as a result is increasingly becoming a preferred choice for obtaining better and more reliable research findings (Johnson and Duberley, 2000). The mixed method approach has been recognised as a research method that addresses the weaknesses of both the qualitative and quantitative research method by conducting them separately and by balancing them with the strengths of either method (Amaratunga et al., 2002). For example, close-ended survey questionnaires aimed at quantitative data gathering have a disadvantage of eliciting very limited responses and limited views of survey participants (Oppermann, 2000). This shortcoming of close-ended questions can be minimised by the use of open-ended questions or interviews to explore further constructs not included in the close-ended questionnaire. Qualitative and quantitative data can be collected at the same time in the mixed method approach using close-ended questionnaire (Tashakkori and Creswell, 2008).

3.4.4 Research Method Adopted for the Study

Having discussed the scope of qualitative research method (section 3.4.1), quantitative research method (section 3.4.2) and mixed method (section 3.4.3) and considering the pragmatic philosophical position of research, mixed method has been adopted for this research. The mixed-research method is hinged on its deductive-hypothetical focus (Patton, 2003). The choice of this method was also necessitated by the nature of the research questions and objectives which require both qualitative and quantitative data. The lack of quantifiable benefits of prefabrication technology in New Zealand required qualitative data exploration of case study projects. Whereas, for the purpose of triangulation a questionnaire survey was needed.

3.5 Research Strategy

Research strategy is defined as the manner in which research will be carried out including the methods used for data collection and analysis to obtain the answers to the research questions (Bryman and Bell, 2015, Tan, 2008). The research strategy provides a framework for understanding the research. A number of factors govern the choice of research strategy including the research objectives, research questions, research philosophy, time and resources available for the research (Saunders et al., 2007). Some other researchers argue that the research strategy should instead be governed by the research problem, the researcher's personal experience and on the research participants as well (Tashakkori and Creswell, 2008). Yin (2003) considers the amount of control researchers want to have over events as the main driver of the research strategy. Further to this, Yin (2003) categorizes the research strategies as experiment, survey, archival analysis, history study and case study. Whereas, Saunders et al. (2007) categorize the research categories as experiment, survey, case study, action research, grounded theory, ethnography and archival research. A brief description of these research strategies is presented in the following sections.

3.5.1 Survey

Survey is a systematic approach for collecting primary data for research from the sample population (Tan, 2008). Survey is regarded as the most suitable method of data collection when a large amount of data is required from a large population (Saunders et al., 2007). This is the most commonly used method of data collection as this approach is suitable for both qualitative and quantitative data collection and data can be collected using various tools like questionnaires, observations and interviews (Saunders et al., 2007). This method has some shortcomings including the truthfulness and accuracy of the data acquired and only a limited amount of data can be collected using this approach (Cooper and Emroy., 2009, Saunders et al., 2007).

3.5.2 Experiment

This research approach is used to determine the relationship between various variables of a population within a controlled environment. Experiment is defined as a scientific method of investigation used for formulating and testing hypothesis (Bailey, 2007). The limitations of experimental research were documented by Saunders et al. (2007) to be the high cost of experiments, the requirements of certain conditions required for experiments, the willingness of people to participate in research and the hurdles of arriving at a representative sample.

3.5.3 Archival Analysis

For exploratory, explanatory and descriptive research, archival research is regarded to be a suitable approach (Yin, 2003). Saunders et al. (2007) define archival analysis as the method of data collection from archives, records and documents both recent and old. This approach is employed to draw a comparison between past and present scenarios and other comparable situations. Archival analysis has some short comings, for example, access to data, availability of data and precise nature of data (Tan, 2008).

3.5.4 History

Since this research approach is employed to explore the historical events, it is an exploratory method of research which helps to find the answers to how and why questions (Yin, 2003). The focus of this research strategy is to collect data on past occurrences and hence investigate and report the events that occurred in the past.

3.5.5 Case Study

Case study research method is an empirical method of investigation involving contemporary phenomenon in the context of a real-life situation (Saunders et al., 2007, Yin, 2003). Creswell (2009) recommended the case study research method as applicable where it is necessary to explore any occurrence in detail. From a posteriori perspective, Tan (2008) noted that the case study method is used to test theories, guided by a hypothesis from an apriori perspective, whilst Fellow and Liu (2003) recommended it for exploring constructs for theory-building. In addition to this, the case study research method offers the flexibility of utilising various observational techniques including interviews, observations, archival records and visual inspections (Saunders et al., 2007). Case studies can be single cases or multiple cases and it is always recommended to have multiple case studies which yield generalized research outcomes (Yin, 2003, Williams, 2007).

3.5.6 Action Research

If the action researcher works together with members of a social setting for the analysis of a problem which leads to development of a solution, the adopted research strategy is called action research (Williams, 2007). Saunders et al. (2007) define action research as the approach which is usually adopted by academic researchers to develop new theories. Bryman (2015) defines action research as a process which analyses the facts to discover new theories that can be employed practically in the future. In regard to the limitations of action research, they were also recorded to be lack of rigour and a possible tendency to be biased.

3.5.7 Grounded Theory

Grounded theory is developed through a series of data collection and a subsequent series of analysis. This involves a repetitive process of data collection and analysis, which repeats one after another (Bryman and Bell, 2015, Saunders et al., 2007). The application of the grounded theory is regarded as appropriate when it is desired to develop a theory of process which is grounded in the opinions of the research participants (Creswell, 2009, Fellows and Liu, 2003).

3.5.8 Ethnography

Ethnography is the research in which researchers involve a group of participants from a common culture and this type of research is conducted to understand a group of people by involving them in the observation process (Leedy, 2000). Creswell (2009) describes ethnography as a research approach in which the researcher immerses himself in a natural setting to understand the inhabitants of that setting.

3.5.9 Research Strategies Suitable for this Study

A combination of archival research (in the context of the case study) and questionnaire survey were found most appropriate for realising the research objectives, given the mixed method nature of the inquiries set forth. Two stages of qualitative and quantitative data collection approaches were adopted. In order to derive the evidence based cost and time saving and productivity improvement benefits of prefabrication technology, the case study research method was adopted during the first phase of the study to investigate buildings constructed using prefabrication technology. The case-study method was also deemed to be appropriate because it enabled an exploratory investigation or limited observations in order to obtain data for theory building without the strict requirement of the representative sampling of the project data.

During the second phase of the study, the prefabrication benefits were triangulated through the feedback from the respondents responding to the questionnaire survey. The essence at this stage is to test the theories or hypotheses developed from the first phase of the qualitative data gathering. With the first phase focused on objectively quantifiable data, there was no room for subjectively defined data. However, in the second phase, wider constructs were explored over and above the quantitatively defined data of the first phase. This helped to improve the reliability and validity of the findings and to ensure that they could be generalized in a wider setting beyond the scope of the study data.

3.6 Reliability and Validity

The success of any research is counted in terms of its validity which in turns determines the application of research in the future (Fellows and Liu, 2003). The reliability and validity of every research study is important either in terms of its qualitative research or quantitative research (Malhotra and Birks, 2007). There are various measures of reliability and validity, which are discussed in the following sections. Golafshani (2004) models the key differences between reliability and validity in Figure 3.1 with four outcomes as follows.

1. Unreliable and invalid: This is where there is inconsistency in the outcomes and a clear departure from the intended result.

2. Unreliable, but valid: This is where there is inconsistency in the outcomes, but the average result lies at the intended outcome.

3. Reliable, but not valid: This is where there is consistency in the outcomes but there is a clear departure from the intended result.

4. Reliable and valid: This where there is consistency in the outcomes as well as alignment with the intended result.

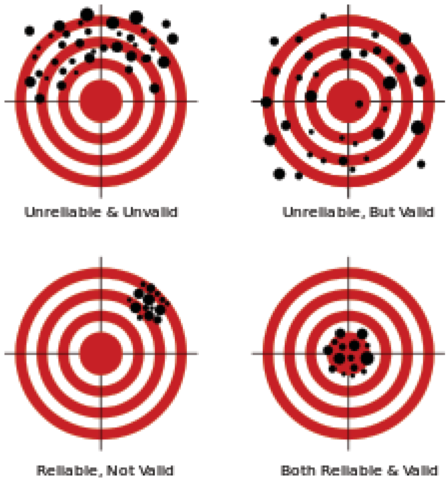

Figure 3.1: Modelling reliability and validity in research [(Adapted from: Golafshani, 2003]

It should be noted that reliability and validity are associated with the research design, measuring instrument or the overall research findings. Saunders et al. (2007) argue that all three perspectives point to the same purpose, namely, to provide a measure of quality, certainty or assurance in the outcome of the research. As a result, in this study, reliability and validity in regard to the research findings and research instrument are treated as similar.

3.6.1 Validity

Saunders et al. (2007) identify two main types of validity, namely, external and internal validity.

3.6.1.1 External Validity

Research findings are said to be externally valid if they can be generalized beyond the scope of the data to different settings and context (Saunders et al., 2007).

The requirement for external validity was met in the sampling design through the following approaches:

- Ensuring that representative samples of the prospective respondents in the survey were randomly sampled from their various trade and professional organisations that represent the sampling frames. This helped to ensure that each respondent in a given sampling frame had an equal chance of being selected to participate in the survey;
- The required sampling sizes were calculated using appropriate statistical expressions to ensure representation.
- Where sampling frames were not able to be accessed due to privacy reasons, a census survey was conducted through the secretariats of the various associations extending invitations to all their members so everyone was given the opportunity to participate, thereby eliminating bias in the process.

3.6.1.2 Internal Validity

Saunders et al. (2007) define internal validity as the ability of a scale or measuring instrument to measure what is intended to be measured. Gill and Johnson (2002) discuss three forms of internal validity, namely, content, criterion-related and construct internal validity.

The content validity of a measuring instrument is the extent to which it provides sufficient depth of coverage of the topic under study (Gill and Johnson, 2002).

Measures taken to ensure good content validity in the current research include the following:

- Adequate depth of coverage of the problem investigated. This is reflected in the in-depth treatment given to the topic, which includes a critical review of the extant literature as well as gathering the empirical evidence from archived records and opinion surveys.

- Use of pilot surveys to identify relevant constructs or themes, and then validating the constructs through respondents' ratings in the quantitative survey stage.

Saunders et al. (2007) view 'criterion validity' as the ability of some measure to correlate with other measures of the same construct. In this study, criterion validity has been addressed in two ways:

First, by comparing the extra values of time and cost savings and productivity improvement achievable by the use of prefabrication technology analysed from the project records with the corresponding values analysed from the surveys. The student t-test statistic was found most suitable for this comparative analysis.

Secondly, the factors underlying the prefabrication benefits analysed from the records were compared with another set of factors from the surveys. Factor analysis involving the Principal Component Analysis (PCA) technique was used to analyse the key constructs in the survey. Criterion-related validity is achieved if both criteria that underpin the prefabrication benefits are found to be similar or related in some way, such as their relative influences on the identified benefits. Predictive validity was not applicable in the context of the current study since the research was not aimed at developing a model for predicting the prefabrication benefits on the basis of the underlying components or factors.

Construct validity is the degree to which a test measures what it claims to measure (Fellows and Liu, 2003). From a related perspective, it is identified as the ability of a measure to confirm other sources a network of related hypotheses generated from a theory based on the concepts (Zikmund, 2012). Zikmund argues that in construct validity, the empirical evidence is consistent with the theoretical logic about the concepts, and adds that, "if the measure behaves the way it is supposed to, in a pattern of inter-correlation with a variety of other variables, there is evidence for construct validity" (p. 291).

Saunders et al.(2007) see 'criterion validity' in terms of having multiple sources of evidence of the same measure, for example, if two or more results point to the same conclusion, there is a measure of criterion-related validity in the result.

In the study, construct validity is addressed in two ways. First by using Cronbach's Alpha to test whether the identified factors influencing prefabrication benefits were truly good measures of the quantitative benefits as analysed. Secondly, construct validity was tested by obtaining more than one source of evidence of the measure of interest, for example, the benefits achievable by prefabrication in regard to cost and time savings and productivity improvement were sourced from the project records as well as from the respondents' feedback in the surveys and then correlating the two for significance.

3.6.2 Reliability

Reliability could be defined as the degree to which measures of a construct are free from errors and bias. Reliability is inferred by examining whether or not the measures yield consistent results (Zikmund, 2012). Robson (2002) identifies key types of reliability as (1) stability; (2) equivalence and (3) internal consistency. These are discussed in the following subsections.

3.6.2.1 Stability

Stability could be achieved if consistent results are obtained from repeated measurements of the same subject and with the same instrument (Robson, 2002). This approach did not align with the objectives of this study and so it was not used.

3.6.2.2 Equivalence

Another approach to measuring reliability checks the amount of errors that may be introduced by different angles of observations of the same construct (Robson, 2002). Item sample equivalence could be tested by using parallel forms of the same test administered to the same set of respondents simultaneously and then correlating the results of the two tests. Saunders et al. (2007) describe 'equivalence' as 'alternative forms' and argue that they ensure the reliability of questions by comparing the responses to an alternative form of the same question or group of questions. An alternative form of reliability test was not followed in the study because applying it in the survey would have increased the length of the questionnaire. This could have resulted in a low response rate.

3.6.2.3 Internal Consistency

The internal consistency form of reliability uses only one test to assess consistency or homogeneity among the items (Saunders et al., 2007). Cronbach's Alpha was used in the data analysis to test the internal consistency of the scale (or applicable variables) to determine the significant factors that influence the benefits of prefabrication over and above the traditional building system. First, the Cronbach's Alpha helped to determine the overall internal consistency (or reliability) of the set of variables identified as influential factors. Foxcroft et al. (2014) advised that Cronbach's Alpha value of 0.7 is the benchmark for evaluating whether or not there was internal consistency and reliability in the scale that was used. Furthermore, the Cronbach's Alpha score helps to identify those variables in the dataset that should be removed to improve the internal consistency or reliability of the overall scale measure. Foxcroft et al. (2014) advised that these could be identified by examining those variables that resulted in a lower Cronbach's Alpha value, than the initial score obtained for the overall measure.

Overall, attempts were made to improve reliability by minimizing the external sources of variations during measurement. These included the adoption of standardized measurement approaches, minimization of subject bias by ensuring anonymity of responses, and avoidance of 'box-ticking' in the questionnaire through the provision of 'No idea' so respondents could tick this option if they have no idea about some questions in the questionnaire.

Finally, the use of the statistical test of significance in the hypothesis testing helps to accord some measure of confidence in the test results at 95 percent confidence intervals under which the tests were conducted.

3.7 Conceptual Framework for the Study

Gill and Johnson (2002) defined a conceptual framework as a visual image, model or a piece of writing that explains graphically or narratively the key focus of research and the important information to be studied, including the key factors, concepts and variables and the underlying relationships among them. This definition also agrees with a number of other studies in some respects. However, the narrative part is the walk-through presentation of the real conceptual framework that is the graphical part. This is because, the graphical part or picture tells a clearer and better story than a thousand words. Mbachu (2002) corroborated this by arguing that every research should have a conceptual framework that succinctly illustrates in graphical presentation the key thrusts of the research, showing clear linkages between the objectives, research design and data gathering stages. In fact, conceptual framework is a pictorial representation of the abstract or synopsis for a research undertaking (Mbachu, 2002).

As discussed in section 1.3, the principal aim of this study was to quantify the potential added benefits that could be achieved by the use of a framed/panelised prefabrication system in place of the traditional building system on the basis of documented evidence from the case study projects. However, the project records could only provide the objectively quantified benefits in terms of cost and time savings and productivity improvements in relation to the five building types investigated in the case study building projects across the three main cities in New Zealand. The study also aimed to evaluate the key factors influencing the identified benefits. However, building types and locations were the only objectively determinable factors from the project records. To explore a wider range of influencing factors, an industry survey was conducted. Feedback from industry stakeholders provided subjectively determinable factors. Through the use of principal component analysis and statistical test of significance, the objectively determinable results were triangulated with the survey results in order to test the reliability of the findings.

The conceptual framework for the study in Figure 3.2 provides a graphical illustration of the key thrusts of the study in relation to the above issues. It shows the two foci of establishment of the quantum of added benefits of prefabrication and the factors influencing these from both survey and case studies. The triangulation of the results from both sources of evidence was for the sake of reliability and validity tests. The framework also illustrated the two limbs of the mixed method research design adopted in the study, namely, exploratory or qualitative focus via case studies and quantitative focus via industry surveys. The relationship of the key objectives of the study to the research design is also presented.

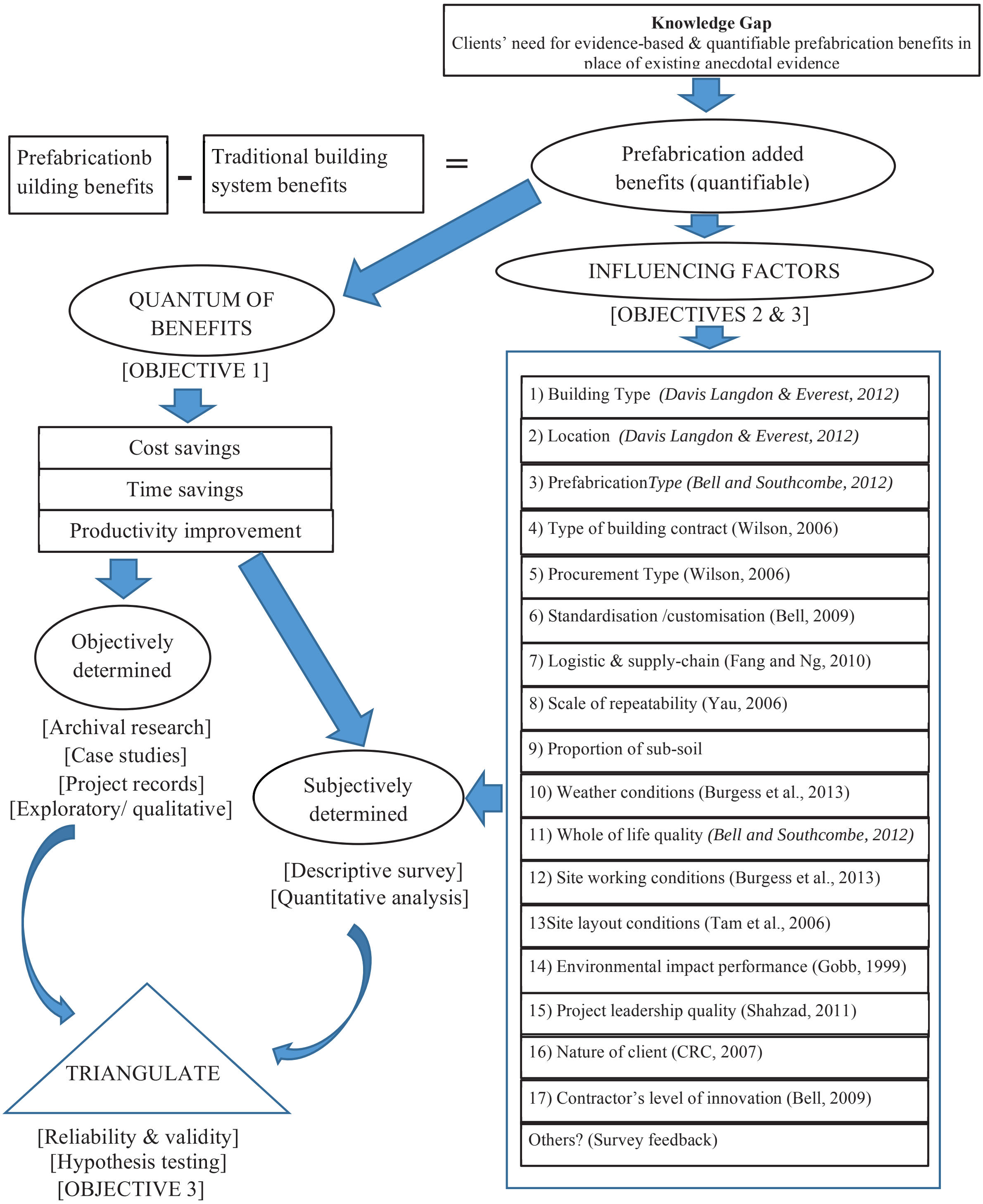

Figure 3.2 : Conceptual framework for the study

3.8 Research Method Adopted for this Study

As discussed in earlier sections, the mixed method of research approach addresses both the positivist and interpretivist's concerns in a research, and hence is increasingly being used in the social sciences and elsewhere (Creswell, 2009). This research adopted the mixed method approach that involved both qualitative and quantitative research in a two-stage data-gathering process. In the first qualitative data-gathering stage, the focus is to develop a theory or hypothesis on the potential benefits of the use of prefabrication technology in place of traditional building systems. Data was collected on the time and cost savings and productivity improvement achieved in some case study projects. In the second stage the theory that was developed was tested by triangulating the results of the first stage with the feedback that was received at the second-stage questionnaire survey. Appropriate tests of significance were employed in the theory evaluation such as t-tests, f-tests and Cronbach's Alpha test of reliability.

The following sections 3.9 and 3.10 provide further discussions on the two stages of this research study.

3.9 Stage 1: Case Study of Building Projects

3.9.1 Research Method

During the first phase of the research, qualitative research using case study was adopted due to the theory-building focus at this stage. The case study research method is described as an empirical investigation on any phenomenon in the context of real life (Yin, 2003). Data required at this stage comprised historical project information on various types of building projects completed in the three main cities of New Zealand namely, Auckland, Christchurch and Wellington. Creswell (2009) noted that case study research method is highly suitable when the researcher has to explore an event or activity in detail. Therefore, the case study research method was adopted as the appropriate research method since it permits the extraction of in-depth information from archived records. Each case study included in the study has been carefully selected to ensure that the information sourced is relevant to the research. In addition, Cooper and Emory (2009) recommend the use of the case study research method where data samples are chosen for relevance to the breadth of the issue under investigation rather than on the basis of how well they represent the target population. This permitted focus on cases where access was granted to project records hence convenience/purposive sampling technique was used in the selection of the units of analysis at this stage (Yin, 2003).

3.9.2 Data Sources

For the first phase of research where the case study research method is utilised, project records/archives of completed building projects served as the main source of required data. Obtaining the data from the project archives required an extensive amount of fieldwork. During the fieldwork, a significant amount of data was sourced from the project diaries and drawings of building projects completed using framed/panelised prefabrication technology. Regarding instances where some of the required information was missing and any other project specific information was needed, contacts were made with the project managers to supply the missing data.

In order to compare the prefabricated buildings with similar buildings completed using traditional construction methods, project information was obtained for similar buildings completed using the traditional construction methods. This information was available in the majority of the projects because comparative analyses were made at the Outline Design Proposal (ODP) phases of the design development during which different alternative design solutions were presented to the building owners to choose the most appropriate solution that met the building owners' preferences in the project with respect to the capital development costs and completion times, and operation and maintenance costs and convenience. Where this information was not available the estimating and quantity surveying departments of the contracting companies involved in the construction of the projects provided it.

Statistics New Zealand (2015) provides a standard building type classification that is modelled in Figure 3.3.

Out of the ten building types provided under the standard building classification framework (shown in Figure 3.3), five were delineated for this study for two reasons. First, they are the most common types of buildings frequently procured in New Zealand. Secondly, their cumulative value accounts for over 80 percent of the total value of building work put in place annually (Statistics, 2015). Therefore, focusing on the samples of these buildings may provide a fair representation of the buildings in New Zealand.

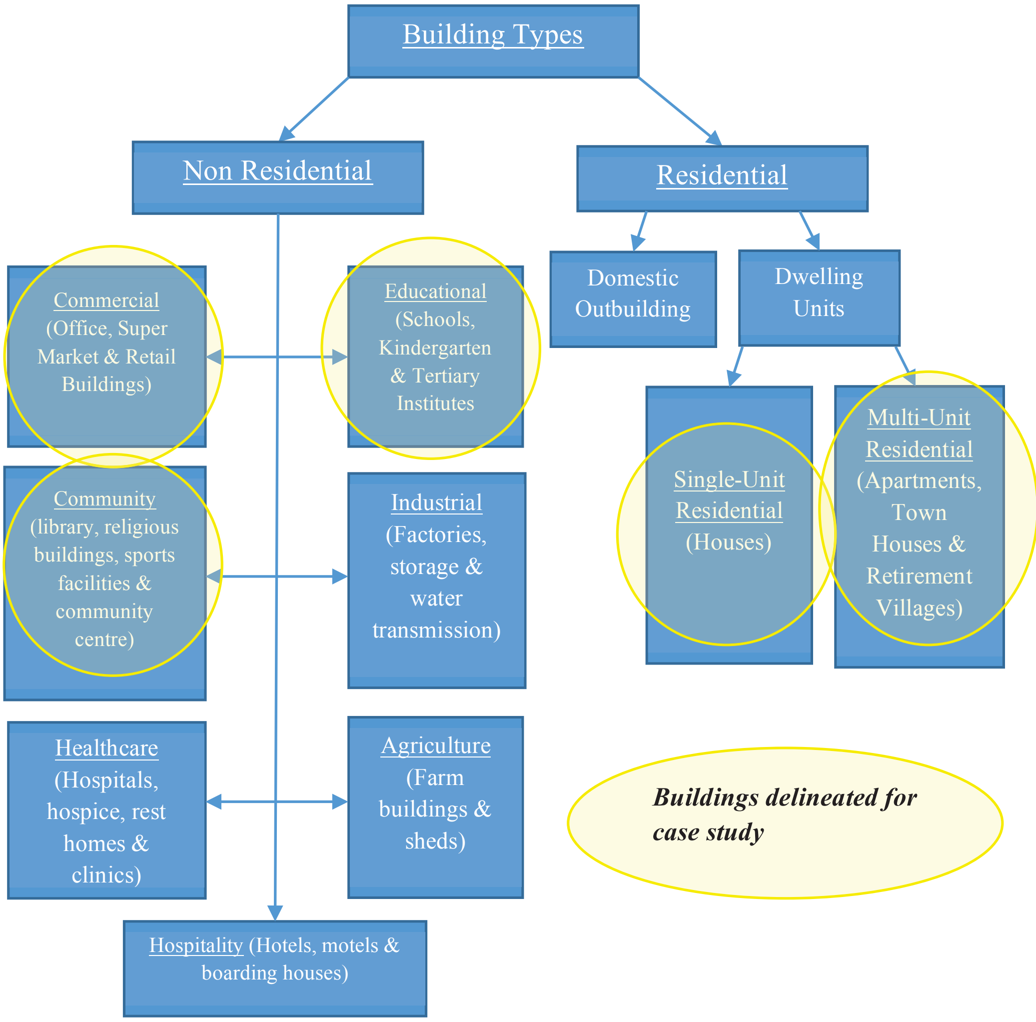

Figure 3.3 : Standard building classification [Source: (Statistics NZ, 2015)]

3.9.3 Data Collection

Five different types of buildings were targeted in Auckland, Christchurch and Wellington including commercial, educational, community, apartment and house buildings.

The data collected for each of the five building types included final costs and durations at completion, and building features such as gross floor area (GFA), number of floors, type of construction, and level of complexity. The contractors provided three categories of complexity of each building – basic, medium and high – based on the following criteria: type and complexity of crainage required, nature of the site, whether sloping or level or requiring to be de-watered, number of stories, and the complexity of the foundation design, e.g., requiring heavy civil engineering works. Other information was extracted from project diaries and drawings.

3.9.4 Sampling Method

In order to capture the empirical data required for this study, the purposive sampling method (Saunders et al., 2007) was employed. As there was not an existing database from which sample projects could be acquired, purposive sampling was deemed to be the best suitable sampling approach. This also aligned with the qualitative nature of this stage of the research to develop theory from some observed data without being emphatic about representation from a defined population/sampling frame (Creswell, 2009). Through the assistance of the Registered Masters Builders Federation of New Zealand (RMBF) and PrefabNZ, various contractors and prefabrication manufacturers were contacted who were willing to assist in the research by providing access to records of their completed projects and any missing information required. The participating contractors and prefabrication manufacturers were assured that their feedback and information provided would be treated in strict confidence. They were assured that the provided data would only be used for the purpose of academic research without revealing any details about their projects, companies and clients. Through this strategy, access was obtained to a total of 151 projects, 75 projects were located in Auckland, 40 in Christchurch and 36 in Wellington.

3.10 Stage 2: Questionnaire Survey

This stage involved quantitative data collection through questionnaire surveys. A countrywide questionnaire survey was conducted of construction industry stakeholders, between July 2015 and October 2015. The aim of this exercise was to triangulate the benefits of prefabrication technology with a view to obtaining reliable and representative feedback of construction representatives that could be generalized across the industry. The survey was also used to gain feedback from industry stakeholders regarding the various factors that influence the benefits of prefabrication.

3.10.1 Research Method

During this second phase of the study an industry wide questionnaire survey was carried out. Berends (2006) advocates that survey is an effective tool to learn about and know the trends and opinions of concerned patrons. Survey is recognized as systematic approach of collecting data from a particular sample (Tan, 2008). Saunders et al. (2007) describe the questionnaire survey as a well liked and popular approach that facilitates the collection of a large amount of data from a large size population. The choice of conducting an industry survey was made for two reasons. The first reason took into account the triangulation of data collected during the first phase of research. The evidence collected from multiple sources is considered to be more robust and compelling (Yin, 2003). Keeping this in view, one of the focuses of the questionnaire survey was to seek the agreement/disagreement of industry stakeholders on the outcomes of the first phase of the research. The other focus of the survey was to extend the knowledge gained from the first phase of the data collection, namely, gathering the feedback from industry members regarding the significance of various factors that have an impact on the benefits of prefabrication. The following sections explain the target population, the sampling methods and the design and analysis of the survey in detail.

3.10.2 Target Population

In terms of the population of the respondents, ideally it includes all of the relevant stakeholders to generalize the outcomes while avoiding any bias (Fowler and Floyd, 2013). In order to source data from the questionnaire survey that is representative of the New Zealand construction industry, a target population was selected that can be useful in gathering accurate information. The population of targeted respondents consisted of the major building industry and prefabrication organizations. The key construction professionals include architects, building officials, contractors, engineers, project managers and quantity surveyors. The target populations are registered members of the various construction industry associations of New Zealand and are representatives of contractors, consultants, designers, manufacturers, quantity surveyors and suppliers.

The industry organizations that participated in the study included:

- ACENZ - Association of Consulting Engineers New Zealand
- NZIA - New Zealand Institute of Architects
- NZIOB - New Zealand Institute of Buildings
- NZIQS - New Zealand Institute of Quantity Surveyors
- PrefabNZ (Hub of prefabrication in New Zealand)

3.10.3 Sampling Frame

The sampling frame for the questionnaire survey in this case consists of fully registered practising members of construction industry organizations in New Zealand, listed in section 3.10.2. Those members of organizations who participated in the questionnaire pre-test were excluded from the current sampling frames. The selection of the sampling frame was made to canvas the opinions of key stakeholders in the building industry.

3.10.4 Sampling Method

After a careful selection of the sampling frame, the next step was to choose a sampling method that could canvas the representative views of clients, contractors and prefabrication manufacturers. These are the main groups in the construction industry who would benefit the most from the prefabrication technology. As the sample survey was mainly to be drawn from the sampling frame, industry organizations included in the sampling frame were contacted.

Membership directories of two organizations were not accessible due to privacy issues related to the Privacy Act 1993. These organizations include the New Zealand Institute of Quantity Surveyors (NZIQS) and the New Zealand Institute of Building (NZIOB). The secretaries of these organizations suggested sending out the electronic link for the survey to the registered members through the secretariats of the organizations. The NZIQS included a request for their members to participate in the research survey in their monthly e-bulletin (Appendix B1). NZIOB hosted a similar request for participation in the research survey on their website (Appendix B2) and circulated an email notifying the members about the availability of the survey on the website. The Institution of Professional Engineers New Zealand (IPENZ) acknowledged the inability to provide any support to circulate and publish the survey link. Registered Master Builders Federation and Certified Builders of New Zealand (RMBF) did not respond to the request to participate in this research. PrefabNZ extended their cooperation to conduct research and provided the complete list of their members' along with their contact details including e-mail addresses. The researcher contacted the members of PrefabNZ (excluding the student members) individually to request their participation in the survey. New Zealand Institute of Architecture (NZIA) and Association of Consulting Engineers New Zealand (ACENZ) have open access membership directories available online. The researcher approached both of these organizations and they further supported the research by including a request to participate in the survey in their monthly newsletters (Appendix B3& B4).

Foregoing the situation, no sampling method was used for sending survey participation request to the members of NZIQS and NZIOB. However, the selection of participants from the membership directories of ACENZ, NZIA and PrefabNZ was conducted using a simple random sampling method. Feedback acquired through the random sampling method is regarded as the most authentic sampling method as each member of the sampling frame gets an equal opportunity to participate in the study (Leedy, 2000).

Opinions gathered using the random sampling method represent the purest form of probability sampling. The random sampling method provides each member of the population an equal and known chance of qualifying to be selected. However, when the population size is very large, it becomes very difficult to identify every member of the population, so the group of available subjects becomes biased.

3.10.5 Minimum and Adjusted Minimum Sample Size

Minimum sample size is the population that can provide representative feedback in terms of the entire population. Minimum sample size is determined and applied to research when it is not possible to include the entire population in the research. Kotrlik and Higgins (2001) documented the usefulness of Cochran's formula for the computation of the sample size. Cochran's formula (Equation 3.1) was used to calculate the minimum sample size for each organization included in the sampling frame. The calculation was carried out to represent the characteristics of the population at a 95 percent level of confidence and considering only a 5 percent margin of error. Whilst level of confidence is the measure of how accurately the sample size reflects the entire population, margin of error reflects how close the responses of the participants are to be the true values.

$$N = (t^2 \times s^2) / d^2 \qquad \text{Equation 3.1}$$

Where:

N = Minimum sample size

t = t-value (1.96 for the alpha level of 0.05)

s = Standard deviation in the population

d = Acceptable margin of error

Adjusted minimum sample size is a smaller sample size that can be used for the purpose of data collection, without affecting the accuracy of the sampling for the entire population. Saunders *et al*. (2007) recommend the use of 'adjusted minimum sample size', for the target populations, if the total size of population is less than 1000. The adjusted minimum sample size was computed using Equation 3.2 provided by Saunders et al. (2007).

$$N' = N / 1 + (N / N_T) \qquad \text{Equation 3.2}$$

Where:

N = Minimum sample size

N' = Adjusted minimum sample size

N_T = Total population

3.10.6 Design and Development of Questionnaire

The questionnaire used in this phase of research was developed with a focus on research objectives, for example, the need to triangulate the findings of the first research phase and acquiring the industry feedback related to the factors that have an influence on the benefits of prefabrication. The questionnaire began with an introduction of the research and its main objectives. The questionnaire was divided into three sections and every question in each of these sections was crafted to capture the feedback and attributes of respondents. Each section was prefaced with the statement of purpose and how to respond to the questions.

The questions included in the first section of the survey questionnaire were in line with the focus of triangulating the outcomes of the first research phase, the investigation of case studies. The questions were randomly arranged in the following order: cost saving, time saving and productivity improvements. For each of these benefits of prefabrication technology, respondents were asked to nominate a percentage improvement value; they believe can be achieved for each of five building types investigated in this research. All the questions in this section were close-ended with multiple-choice answers. In addition to the listed options, the option of selecting "other" with a space for feedback was also provided with each question. This was to facilitate the respondents to make a choice of their own if they did not agree with the listed options.

The second section of the questionnaire was focused on the research objective aimed at exploring the factors that influence the benefits of prefabrication technology. The questions in this section were developed based on the findings of the literature review, other studies conducted on the subject matter and feedback gained from New Zealand practitioners. The developed questions were arranged in a logical order to ensure a smooth flow of ideas while facilitating the understanding of the respondents.

Respondents were asked to indicate the relative level of influence through a five-point Likert scale. Saunders et al. (2007) documents a 5 point scale to be a preferred and reasonable choice over the much limited 3 point scale and unnecessarily huge 7 or 9 point scale. The multi-choice answers comprised ratings from 5 to 1, on the level of influence each of the listed factors has on the benefits of prefabrication technology as follows.

1. Very High = 5 (transcribes to a very high level of influence)
2. High = 4 (transcribes to a high level of influence)
3. Average = 3 (transcribes to a moderate level of influence)
4. Low = 2 (transcribes to a low level of influence)
5. Very Low = 1 (transcribes to a very low level of influence)

To avoid and minimize the bias and improve the reliability of responses a "No Idea" option was also provided in addition to the 5-point ratings. This option was provided for the respondents who might not have knowledge about the questions. At the end of this section, an open-ended text box was provided for the respondents to add further factors they might consider have an influence on prefabrication benefits.

The third and last section of the questionnaire was strategically kept for the demographic background of the respondents. List type close-ended questions were developed to seek information about the profile of the respondents. These questions captured the information on the professional affiliations, designations in their respective companies, professional roles and experience level. The demographic profile helped to screen the responses to ensure that usable responses were obtained only from the target populations and from those who could provide authentic feedback on the research area from experienced professionals with important positions in their respective organizations.

The questionnaire ended with a note of appreciation to the participants and a disclaimer statement coordinating with the ethical requirements of the Massey University Human Ethics Committee (MUHEC).

A covering letter (Appendix C1) and participant information sheet (Appendix C2) accompanied the questionnaire (Appendix C3). The cover letter provided the introduction of the research and a request to participate in the survey. The participant information sheet provided information about the researcher, the objectives of the research study, the importance of the research outcomes, the importance of participation, ethical concerns, how to complete questionnaire and the contact details for the researcher.

The participants were also provided an opportunity to be informed about the research outcomes after the completion of the research, subject to their willingness and interest in receiving a summary of the research findings (Appendix C4).

3.10.7 Pretesting of Questionnaire

The researcher finalized the questionnaire used for this survey after a number of brainstorming sessions with the research supervisor, industry practitioners and other research colleagues. The final version of the questionnaire was pre-tested by industry members, before sending it out to the potential survey participants. During the pre-testing of the questionnaire, feedback on the questionnaire was sought from at least one member of each construction industry organization included in the sampling frame. The main purpose of pre-testing the questionnaire was to test the relevance of the survey in relation to the research objectives and to the factors that influence the benefits of prefabrication technology in the New Zealand context. One of the purposes of pre-testing was to identify any other factors that were not captured from the secondary sources. In addition to this, pre-testing also assured the clarity and relevance of the questions to improve the appeal of the questionnaire and the response rate.

The survey questionnaire was pre-tested by six industry members drawn from the target population of the study. Responses revealed a need to improve the clarity of a few questions and the use of simple English for easy understanding of the participants to avoid any misinterpretation. The questionnaire was revised based on the feedback received from participants, few question statements were revised to ensure the use of clear sentences using simple English. More details were added to Participant Information Sheet regarding the study to provide a robust understanding of research project to the potential participants.

3.10.8 Questionnaire Administration

There are various ways to administer a questionnaire survey. Questionnaire administration is broadly classified into two main categories, namely, the self-administered questionnaire and the interviewer administered questionnaire (Saunders et al., 2007). For the selection of the most appropriate manner of questionnaire administration Saunders et al. (2007) suggest that while making a choice for administration approach, there is a need to consider the factors that govern the process.

The factors that govern the selection of the appropriate method of questionnaire administration include:

- Characteristic of respondents;
- Importance of reaching certain people as respondents;
- Importance of respondent's feedback
- Required sample size
- Number and type of questions to be asked.

The benefits of prefabrication technology affect the New Zealand construction industry on the whole and directly involve clients, consultants, contractors and manufacturers as major stakeholders. Therefore, the sample of this survey was diverse and covered a large geographical area. Self-administered internet based questionnaire survey was selected as the administration strategy. Otherwise it was not possible to cover this type of sample though administrated questionnaires by interviewers.

Saunders et al. (2007) document that the self-administrated internet based questionnaire ensures that targeted respondents participate in the questionnaire. They further document that the chance of data distortion by the participants is very low with this approach of questionnaire administration. Alongside the benefits of this administration approach, there is also a disadvantage of this strategy, which is low response rate.

The questionnaire was made available online on the Survey Monkey website (Appendix C5). Survey Monkey is a free web portal that can collect the responses of the participants and also facilitate the importing of the collected data into statistical packages for the purpose of analysis. The web link to the questionnaire was sent to the target population utilising the sampling methods discussed in section 3.10.2 of this chapter. Questionnaire link was sent to the members of ACENZ, NZIA and PrefabNZ, directly via emails and follow up reminders (emails/telephonic) were also sent out within the next few weeks. The survey requests were sent out to the members of NZIQS and NZIOB through newsletters of both organisations. No follow up with NZIQS and NZIOB members was possible as access to membership directories was not available and the questionnaire itself was circulated among the members by the secretariat though their newsletters.

3.10.9 Bias

Bias is defined as any influence on the research process that distorts research outcomes, this influence can arise from a single source or multiple set of conditions (Leedy, 2000). It is critically important for a researcher to understand the importance of addressing in advance any potential for bias in the research design. While the potential for bias exists in all forms of data collection, in particular, descriptive surveys are more vulnerable to bias (Saunders et al., 2007). A potential source of bias in the survey method is respondent's bias. Respondent's bias can arise from respondent's unwillingness to answer the questions truthfully or the inability of the respondents to understand the question in its true sense. Another source of bias is bias on the part of the researcher. This could happen when there is a flaw in the survey design, for example, a lack of properly defined sampling frame, a lack of clarity of questions, a failure to provide background and understanding of the research objectives to the participants and so forth.

To minimize the bias arising from the survey design, pre-testing of the survey questionnaire was carried out to acquire the feedback of industry practitioners in regard to the clarity, length and structure of the questionnaire. A cover letter and participant information sheet accompanied each questionnaire request to enable the survey participants to have a clear understanding of the research goals and the importance of their honest contribution.

3.11 Method of Data Analysis for Realizing Research Objectives

Mbachu (2002) argued that data analysis in research is geared towards achieving two aims as illustrated in Figure 3.2; namely, a) to provide answers to the research questions or objectives; b) to evaluate the reliability and validity of the research findings. The last set of analysis is accomplished through proposition/hypothesis testing.

Guidance in terms of the appropriate choice of data analysis technique is aggregated from different sources as shown in Figure 3.4. The framework modelled in Figure 3.5 was followed in this study to choose the appropriate data analysis techniques based on six criteria that underpin the appropriate choice of the following: a) the nature of the research questions/objectives (Patton, 2003); b) the nature of the primary/empirical data (Brannen, 2005); c) the measurement scale of data (Mack et al., 2005); d) the nature of dataset distribution (Fellows and Liu, 2003); e) the number of variables to be analysed (Zikmund, 2012); and f) the relationship and dependency among the variables (Fellows and Liu, 2003; Gill and Johnson, 2002). These are discussed in the following subsections.

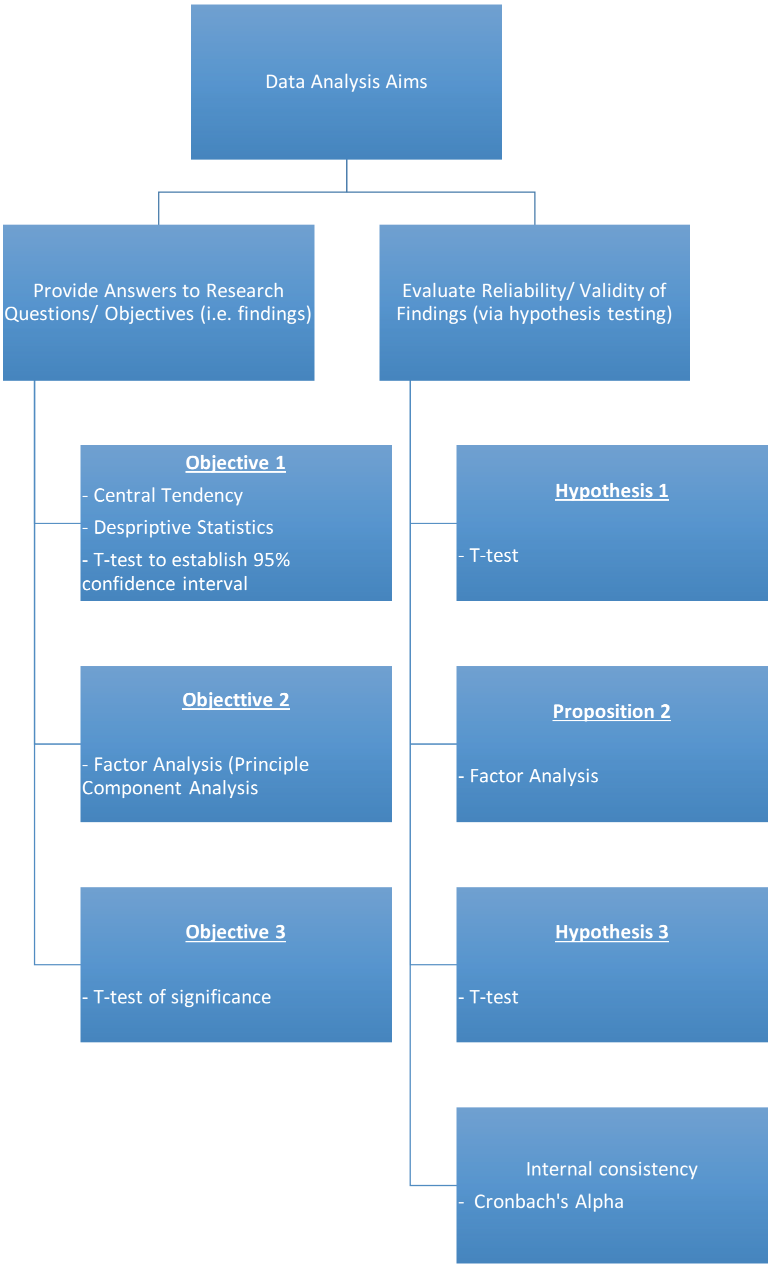

Figure 3.4 : Aims of data analysis in research

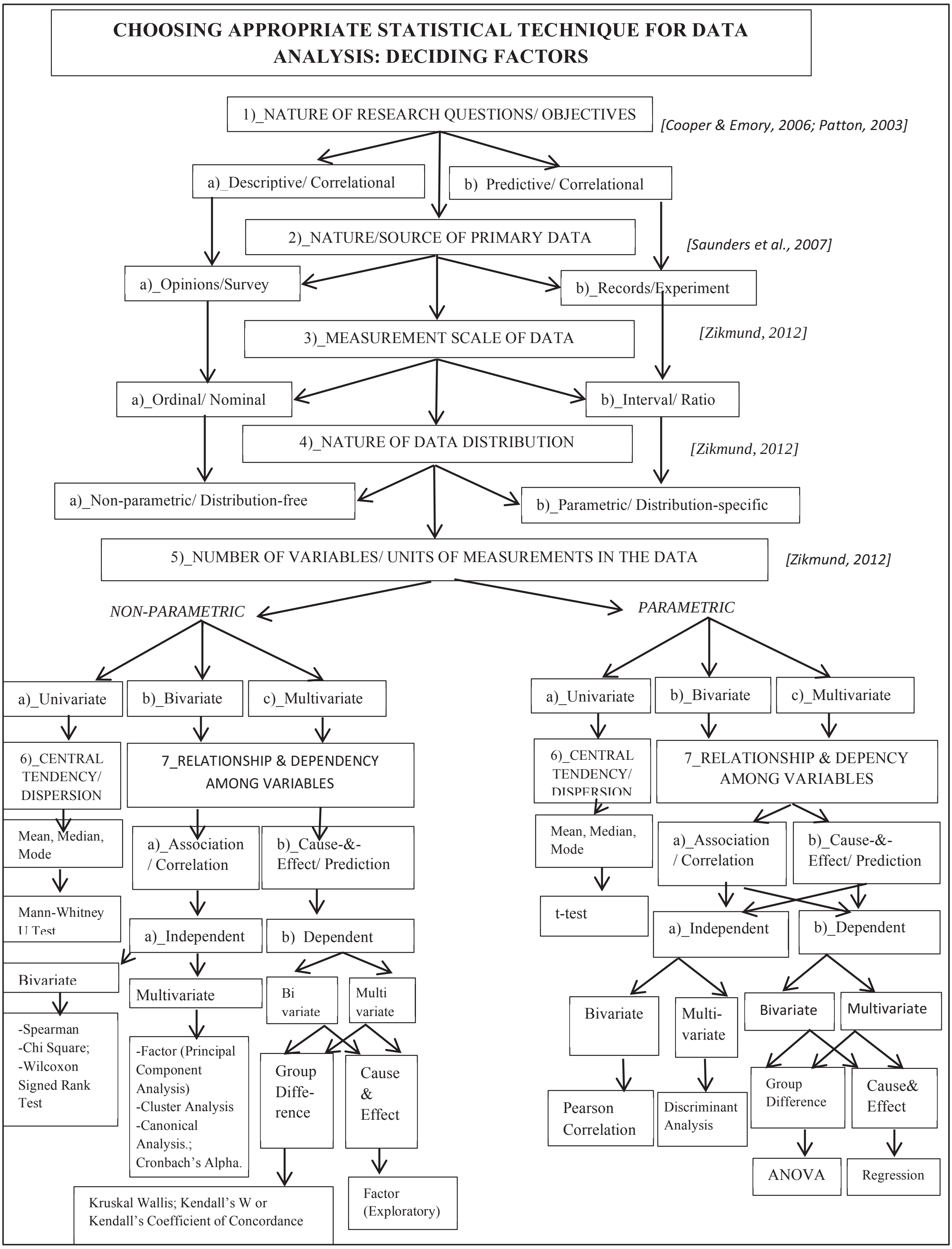

Figure 3.5 : Framework for choosing appropriate research method and analysis

3.11.1 Nature of Research Questions/Objectives

Cooper and Emory (2006) argued that the nature of the research questions or objectives is the first criterion that gives insights into the nature of the data required to address those questions or objectives and by implication, the nature of the research design. Zikmund (2012) further argues that there are three types of research questions or objectives. The first is the descriptive research question. Here the aim is to establish the parameters for gaining understanding into the nature of a particular phenomenon under study.

Patton (2003) outlines the key parameters that underpin the descriptive statistics for a given dataset to include measures of central tendency (requiring the measurement of the mean, median and mode of the dataset) in order to ascertain the nature of the underlying data distribution, which may fit into known distributions such as normal and beta distributions. In this case, the underlying data are said to be parametric. Where the underlying data distribution does not fit into standard distributions, it is regarded as non-parametric or distribution-free. The type of test statistic for conducting statistical test of significance to be carried out to examine the reliability of the test outcome depends on whether the dataset is parametric or non-parametric.

As could be seen in Figure 3.5, the Student t-test is most commonly used for this purpose for parametric dataset, hence its adoption in the research analysis in this context.

3.11.2 Nature of the Primary/Empirical Data

The nature of the primary data required in the study could assist in determining the appropriate research method that fits the dataset. Patton (2003) identifies the three key primary data as opinions captured through surveys or interviews, archived data obtained from records and data recorded from experiments or simulation.

In this study, the mixed method approach was adopted which required archived data from case study project records as well as opinions from triangulation/validation surveys.

3.11.3 Measurement Scale of Data

Zikmund (2012) identified two key categories of measurement scale for empirical data as ordinal/nominal and ratio or interval scales. The ordinal scale is used for rating or ranking items in a given order of relativity such as relative importance, frequency of occurrence, severity or impact. The alternative and less frequently used is the nominal or categorical scale which provides categories mostly associated with demographic profiling such as ‘black’ and ‘white’, ‘good’ and ‘bad’, ‘male’ or ‘female’. On the other hand the ratio or interval scale is used to measure items on a continuum, for example, distance data measured in metres or temperature data measured in degrees centigrade. The ratio scale is for proportional measurement such as percentage or fractions.

This study involved both categories of scale measurement. The ordinal scale was used in the 5-point Likert rating of items in the surveys. The interval scale measurement was used to measure the quantitative data on cost and time savings, while productivity improvement was measured on ratio scale in percentages.

3.11.4 Nature of Dataset Distribution

Cooper and Emory (2006) identified two broad categories of distributions for the empirical dataset, namely parametric and non-parametric. The parametric distribution is for empirical dataset that is measured in interval or ratio scale where the underlying distribution could be fitted into standard normal distributions for very large data sizes or beta distributions for small data sizes. Patton (2003) recommends the use of parametric statistics for analysing datasets that meet the conditions for parametric distributions.

On the other hand, the non-parametric or distribution-free datasets are empirical data that are measured on an ordinal/nominal scale. Zikmund (2012) observed that such data do not fit into known statistical distributions hence they are more appropriately analysed using distribution-free statistics where the key assumptions of normality needed in the parametric datasets cannot be sustained.

3.11.5 Number of Variables to be Analysed

Zikmund (2012) identified three key broad categories under the number of variables to be analysed, namely, univariate, bivariate and multivariate analyses. In the univariate analysis, the focus is only on one variable and the objective is to examine important characteristics about the variable such as the mean or standard deviation. On the other hand, the bivariate and multivariate analyses involve a focus on establishing a relationship or dependency among the variables such as measures of association among the variables to be analysed or to establish a cause-and-effect relationship between the two variables (as in bivariate analysis) or among the variables (as in multivariate analysis) (Saunders et al., 2007).

In this study, the nature of the objectives required focus on univariate and multivariate analyses. The univariate analysis was used to determine the means and standard deviations of variables or parameters of interest. The multivariate analysis was used to establish the factors influencing the benefits of prefabrication.

3.12 Key Statistical Techniques Used for the Data Analysis

In this section, brief discussions are provided on the key statistical analyses carried out in the study that were found to be the most appropriate based on the guidelines established in Figure 3.5. These include the Student t-test, factor analysis, principal component analysis, and the Cronbach's alpha tests.

3.12.1 Student t-test

A Student t-test (or simply called 't-test') is a test used in statistical hypothesis testing procedure where the test statistic is dictated by a Student t-distribution (Saunders et al., 2007). Usually, the t-test is adopted where the sample size is not large enough to follow a standard normal distribution. Saunders et al. (2007) identifies 1000 as the minimum sample size for an assumption of standard normal distribution, whereby any sample size less than this may follow a beta distribution that is another name for Student t-distribution.

In such a small sample size situation, the standard deviation and variance of the distribution can only be estimations of the population standard deviation and variance.

Cooper and Emory (2009) added that the t-test can be used to determine if two sets of data are significantly different from each other and is most commonly applied when the test statistic would not follow a normal distribution due to the small sample size.

Saunders et al. (2007) identify the following as different use situations for t-tests.

- One-sample location t-test: Used to test whether or not the mean of a population has a value specified in a null hypothesis.
- Two-sample location t-test: Used to test whether or not the means of two populations are equal.
- Unpaired or independent samples t-tests: Used when the statistical units underlying two paired or unpaired samples being compared are non-overlapping.

In this study, one-sample location t-test is most applicable for testing the first hypothesis since the aim was to examine whether or not the mean values of the time and cost savings and productivity improvement analysed from the questionnaire surveys were within the upper end limit boundaries of the t-test statistic values computed from the case study project data.

Student-t was used in this study to test hypothesis 1, that assumed that there will be no significant differences between the time and cost savings and productivity improvement analysed from project records and the corresponding values analysed from the questionnaire survey. The expression for computing the one-sample location t-test statistic for the purpose of hypothesis testing is given in Equation 3.3.

$$t = (\bar{x} - \mu)/(s/\sqrt{n}) \qquad \text{Equation No. 3.3}$$

Where:

$\bar{x}$ = Sample mean

μ = Mean for which t-test statistic is needed

S = Standard deviation of the sample

n = Sample size

The degrees of freedom are expressed as $n - 1$.

From the above expression for t-test statistic, it could be seen that its upper and lower limit values corresponding to the 95 percent confidence interval for a one-tailed test within which to specify the upper and lower limit values of the sample mean for accepting the null hypothesis testing can be expressed as follows:

$$\bar{x} \pm t\,(\alpha / \sqrt{n}\,) \qquad \text{Equation 3.4}$$

i.e.

$$Xmax = \bar{x} + t\,(\alpha / \sqrt{n}\,) \qquad \text{Equation 3.5}$$

$$Xmin = \bar{x} - t\,(\alpha / \sqrt{n}\,) \qquad \text{Equation 3.6}$$

3.12.2 Factor Analysis and Principal Component Analysis

IBM (2014) observed that factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. Patton (2003) recommended the use of factor analysis where the objective is to establish the relative weights or contributions of underlying factors in bringing about the outcome of a particular phenomenon.

IBM (2014) identified three key categories of factor analysis:

a) Exploratory factor analysis: Here the objective is to determine the number of common factors influencing a set of measures. It could also serve to explore the cause-and-effect relationship between an independent and dependent variable(s).

b) Confirmatory factor analysis: The primary objective of this category of factor analysis is to determine the ability of a pre-defined model to fit an observed set of data. In this context, IBM (2014) argues that factor analysis can also be used to generate hypotheses regarding causal mechanisms or to screen variables for subsequent analysis, for example, to identify collinearity prior to performing a linear regression analysis.

c) Dimension reducing factor analysis: This category of factor analysis is also called principal component analysis (PCA). The objective is to identify a small number of factors that explain most of the variance that is observed in a much larger number of manifest variables.

In this study the exploratory and principal component analysis sub-types of factor analysis were involved in the data analysis to meet the second objective. The confirmatory factor analysis was not used because there no objective on developing a predictive model.

3.12.3 Cronbach's Alpha Analysis

IBM (2014) stated that Cronbach's Alpha is an estimate of the internal consistency associated with the scores that can be derived from a scale or composite score. IBM (2014) further noted that reliability is important because in the absence of it, it is impossible to associate any validity or reliability to any scale or composite score. Gliem and Gliem (2003) argued that the Cronbach's Alpha test helps to determine whether or not it is justifiable to interpret scores that have been aggregated together.

Consequently, Cronbach's Alpha was used in the data analysis to test the internal consistency of the scale (or applicable variables) for determining the significant constructs or factors that influence the benefits prefabrication offers over and above those of traditional building system.

Expression-wise, IBM (2014) stated that the computation of Cronbach's alpha is based on the number of items on the survey (k) and the ratio of the average inter-item covariance to the average item variance (see equation 3.7).

$$\alpha = k\frac{\left(\frac{cov}{var}\right)}{(1+(k-1)(\frac{cov}{var})}$$ Equation 3.7

Where:

k	=	Number of items
cov	=	Inter-item covariance
var	=	Item variance

3.12.4 Data Analysis for Realising the First Research Objective

The first research objective aimed to establish the unbiased estimate of the prefabrication benefits over and above those of the traditional building systems in terms of cost savings, time savings and productivity improvement in projects. This requires data analysis that is focused on measure of central tendency, involving the computation of the mean/average, the standard deviations/variance, the mode and the median of the dataset. Descriptive statistic technique was used for this purpose (Cooper and Emroy., 2009). To provide a measure of confidence in the established results, t-test of significance was carried out on the data at 95 percent confidence and alpha level of 5 percent.

The subsections below provide further details of the mathematical expressions used for obtaining the average values of the time and cost savings and productivity improvement in the case study projects.

In sum, the data analysis was focused on computing the cost savings, time savings and resulting improvement in productivity performance for each case study building project when traditional building systems were replaced by the panelised prefabricated construction. The data analysis involved the computation of these parameters for a particular city 'k', and for a particular building type 'i', in the 'jth' project of the set of buildings for the building type delineated for case study:

3.12.4.1 Cost Saving (CSkij)

One of the key advantages of using prefabrication technology is the saving in total project cost. Cost savings achievable with the use of prefabrication technology in place of traditional construction approaches were computed as the difference between the final cost of the prefabricated building and the corresponding cost for a similar building erected using the traditional building system, expressed as a percentage of the later. Equation 3.8 provides the expression for the CS_{kij}.

$$CS_{kij} = \left(\frac{C_{TRADkij} - C_{PREFABkij}}{C_{TRADkij}} \right) \quad \text{Equation 3.8}$$

Where:

CS_{kij} = Cost saving achieved in the jth project within the set of buildings for the particular building type 'i'' delineated for the case study, in a particular city 'k'.

$C_{PREFABkij}$ = Final cost of the jth prefabricated building.

$C_{TRADkij}$ = Corresponding final cost of a similar building completed using the traditional building system.

3.12.4.2 Average Cost Saving (ACSki)

Average saving in cost achieved with the use of prefabrication technology in place of traditional building system, across the building types in different cities was computed as the average of the cost savings (CS) for all the case study projects for a particular building type. Equation 3.9 provides the expression for evaluating the ACS_{ki}.

$$ACS_{ki} = \left(\frac{\sum_{j=1}^{n} CS_{kij}}{n} \right) \qquad \text{Equation 3.9}$$

Where:

ACS_{ki} = Average cost savings achieved in all the case study buildings for the building type 'i', in a particular city 'k'.

n = Number of buildings.

3.12.4.3 Time Saving (TSkij)

Use of prefabrication technology significantly reduces project completion time due to the parallel construction activities taking place in manufacturing yard and project site. Reduction in project completion time i.e. time savings achieved with the use of prefabrication technology in place of traditional building system were computed as the difference between the completion time of prefabricated building and the corresponding time required for a similar building built using traditional construction methods, expressed a percentage of later. Equation 3.10 provides the expression for the TS_{ki}

$$TS_{kij} = \left(\frac{T_{TRADkij} - T_{PREFABkij}}{T_{TRADkij}} \right) \qquad \text{Equation 3.10}$$

Where:

TS_{kij} = Time Saving achieved in the jth project within the set of buildings for the particular building type 'i' delineated for the case study, in a particular city 'k'.

$T_{PREFABkij}$ = Completion time for the jth prefabricated building.

$T_{TRADkij}$ = Corresponding completion time for a similar building completed using the traditional building system.

3.12.4.4 Average Time Saving (ATSki)

The average time savings achieved with the use of prefabrication in place of the traditional building system was computed as the average of the time-savings (TS) for all of the case study projects for a particular building type in a particular city. Equation 3.11 provides the expression for calculating the average time savings.

$$ATS_{ki} = \left(\frac{\sum_{j=1}^{n} TS_{kij}}{n} \right) \quad \text{Equation 3.11}$$

Where:

ATS_{ki} = Average Time Savings achieved in all the case study buildings for the building type 'i', in a particular city 'k'.

n = Number of buildings.

3.12.4.5 Productivity Improvement (PIki)

Productivity improvement achieved in the construction process with the use of prefabrication technology in place of the traditional building system was computed for each project. Productivity improvement was computed as the product of the cost savings and time savings achieved in each of the case study building projects included in this research. Similarly, average productivity improvement for each building type i in particular city k was also computed.

The rationale for computing the productivity improvement as a product of time and cost savings draws upon two streams of thought. First, in the construction industry context, productivity performance depends largely on the cost and schedule performance of the project under consideration (Takim and Akintoye, 2002). This strategic perspective of the concept of productivity differs to some extent from the economist's perspective of productivity which is solely based on the ratios of output resources versus input resources, featuring variants such as labour, material, capital and multi-factor productivity measures. Abbot and Carson (2012) clearly pointed out this distinction.

The mathematical expression for an integrated productivity measurement based on the two key parameters of cost and time savings draws from the fact that productivity is directly proportional to the cost and schedule performance as follows.

$$P \propto (S_p, C_P) \qquad \text{Equation 3.12}$$

$$P = \beta(S_P \times C_P) \qquad \text{Equation 3.13}$$

Where:

P = Productivity performance achieved in a project,

β = Empirically determinable constant of proportionality that depends on the dynamics of the operational environment. The constant could be taken as unity (i.e. value of 1) for projects executed under normal operating conditions as assumed in the study.

Sp = Schedule performance computed using equation 3.10,

Cp = Cost performance computed using equation 3.8.

Equation 3.14 was used to compute the productivity improvement achieved at the individual project level.

$$PI_{kij} = MCS_{kij} \times MTS_{kij} \qquad \text{Equation 3.14}$$

Where:

PI_{kij} = Productivity improvement achieved in the jth project for the building type i in city k.

CS_{kij} = Cost Saving achieved in the jth project for the building type i in city k.

TS_{kij} = Time Savings achieved in the jth project for the building type i in city k.

3.12.4.6 Average Productivity Improvement (API)

Average productivity improvement (API) was computed on two levels, namely, the city level average productivity improvement was computed using Equation No. 3.15, for each city as the average of the productivity improvement achieved across all building types. The average productivity improvement for building type was computed using Equation No. 3.16, as the average of the productivity improvement achieved for the particular building types across all cities.

$$API_k = \left(\frac{\sum_{i=1}^{m} PI_i}{m} \right) \qquad \text{Equation 3.15}$$

Where:

API_k = Average productivity improvement achieved in all the m building types in a particular city.

$$API_i = \left(\frac{\sum_{i=1}^{g} PI_k}{g} \right) \qquad \text{Equation 3.16}$$

Where:

API_i = Average productivity improvement achieved in all the g cities for a particular building type i.

3.12.5 Data Analysis for Realising the Second Research Objective

The second objective of the study aimed to ascertain the principal factors accounting for the level of benefits achievable by the use of the prefabrication building technique in place of the traditional technique. Given that this research objective requires exploring the dependency among variables, and that since the data source was from the questionnaire survey it involved an ordinal scale of measurement. This is in addition to the fact that the data distribution associated with the questionnaire survey is often non-parametric or distribution free statistics (Saunders et al., 2007), the appropriate statistical analysis approach was found to be factor analysis involving principal component analysis (PCA). The step-wise elimination process followed to isolate or choose this analytical technique among many competing alternatives is shown in Figure 3.5.

3.12.6 Data Analysis for Realising the Third Research Objective

The third objective of the study aimed to ascertain how the benefits analysed from the records of the case study projects compared to the corresponding benefits analysed from the feedback from the stakeholders who answered the questionnaire survey. The key focus of this objective was to triangulate the results obtained in the first objective of the study from the case study project and the corresponding results obtained from the average values analysed in the survey feedback. The triangulation of the result was on the basis of examining whether the average time and cost savings and productivity improvements analysed from the surveys would fit into the confidence intervals established in the first objective using t-tests. The data analysis therefore involved the t-test of significance.

3.12.7 Data Analysis for Reliability and Validity Evaluations of Study Findings

Data analysis, regarding the reliability and validity evaluations of the study findings, is detailed in Chapter 6.

3.13 Ethical Approval

While working towards the achievement of research objectives, a researcher's main focus should remain on research ethics (Mack et al., 2005). Research ethics have been defined as the study and practice of making good and precise decisions while engaging in a research study (McMurray et al., 2004). Saunders et al. (2007) defines research ethics as the behaviour of a researcher towards the research participants or the people affected by the research.

Prior to commencing the data collection process for research, ethical approval was sought from the Massey University Human Ethics Committee (MUHEC) and application was submitted to MUHEC for its approval, accompanied by supporting documents. The committee declared the study as low-risk and granted permission to advance the process of data collection (See copy of the Low Risk Notification in Appendix A). As a part of the ethical compliance requirement a disclaimer statement was added in the last section of the survey questionnaire and correspondence with the research participants.

Massey University has a structured policy and a code of ethical conduct for researchers that are involved with human participation. The Massey University Human Ethics Committee's (MUHEC) code of ethical conduct assures respect in terms of the privacy and confidentiality of research participants and the collected data.

The major ethical principles of MUHEC include: a) respect for persons; b) minimisation of harm to participants, researchers, institutions and groups; c) informed and voluntary consent; d) respect for privacy and confidentiality; e) the avoidance of unnecessary deception; f) avoidance of conflict of interest; g) social and cultural sensitivity to the age, gender, culture, religion, social class of the participants and h) justice.

Compliance of ethical principles was ensured by the researcher through out the research process. All the study participants were treated with due respect. Participants were informed about the background and benefits of this study by providing a participant information sheet. They were clearly informed that the sole purpose of their involvement in the study is to benefit from their knowledge and experience. Prior consent to participate in the study was obtained from each of the study participant.

CHAPTER 4: DATA ANALYSIS, RESULTS AND DISCUSSION - CASE STUDIES

4.1 Overview

This chapter presents the data obtained from the historical project reports of the case study on building projects and the subsequent analysis of the collected data. The chapter also presents discussions on the results of the data analysis in relation to the research objective, which sought to examine the extent to which prefabrication technology can deliver superior value in terms of cost and time savings and improvement in productivity, when used in place of traditional building system.

4.2 Case Study Projects

As discussed in section 3.3.2, the case study project data was collected from building contracting companies in Auckland, Wellington and Christchurch. A total of 151 framed/panelised prefabricated buildings were investigated. The building types included 32 commercial (21 percent), 21 community (14 percent), 26 educational (17 percent), 21 apartment (14 percent) and 51 house (34 percent) buildings. Information was sourced from the project diaries and drawings of the case study building project. A summary of case study building project types used for Stage-I data analysis is presented in Table 4.1.

Data collected for each of the five building types included final costs and durations at completion, and building features such as gross floor area (GFA), number of floors, type of construction, and level of complexity. As indicated earlier (section 3.9.3), contractors provided three categories in terms of the complexity of each building – basic, medium and high – based on the following criteria: type and complexity of crane work required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories, and the complexity of the foundation design, e.g. requiring heavy civil engineering work. Other information was extracted from project diaries and drawings.

Table 4.1: Summary of case study building projects

Case Study Project Types, Number and Locations					
	Building Types				
City	**Commercial Buildings**	**Community Buildings**	**Educational Buildings**	**Apartment Buildings**	**Houses**
Auckland	16	7	12	7	33
Christchurch	8	7	7	7	11
Wellington	8	7	7	7	7
Sub Total	32	21	26	21	51
Total	151				
Sub Total as %age of Total	21%	14%	17%	14%	34%

4.3 Prefabrication Added Benefits

The main focus of this study is on exploring the potential added benefits of prefabrication technology. The first research objective is to quantify the benefits that panelised prefabrication technology can offer in terms of the cost savings, time savings and productivity improvements, over and above the corresponding benefits achievable with the use of the traditional building system. As detailed above, the research was based on the case studies of 151 framed/panelised prefabricated buildings in three cities of New Zealand including Auckland, Christchurch and Wellington involving five building types, commercial, community, educational, apartment, and house buildings. Cost savings, time savings and productivity improvement were calculated based on the final contract value of the project and project completion time. These project details were acquired from the project records of case study projects.

The following sections provide the results of the analysis of the benefits for each of the three cities as found in the case study projects.

4.4 Cost Savings

In regard to the overall savings in terms of the project cost, it is regarded as one of the most significant benefits and drivers of prefabrication uptake (Bell, 2009). For this research, comparisons were made between the cost required for the completion of panelised prefabricated projects and traditionally built projects. The cost saving (CS) achieved by the use of the prefabrication system in place of the traditional building system is obtained first by deducting the cost of the prefabricated project from the cost of the equivalent traditional project and then expressing this cost difference as the percentage of the latter. Equation 3.8 provides the expression for the computation of the cost savings. Cost savings were computed for each and every case study building project included in this research. Following the computation of cost savings for individual case study projects, the average cost savings were computed for all five types of buildings, in three cities in New Zealand. In terms of cost savings, average values were computed using the equation 3.9. The summary of the results for the cost savings that were analysed for the five building types, across the three cities included in this research is in table 4.2. The results show that an average cost saving of 21.3 percent is observed across all the building types across the three cities. An analysis of the cost savings for commercial, community, educational, residential and apartment buildings is shown below:

Table 4.2: Cost savings achievable using prefabrication over traditional building systems across building types and locations

	Percentage Cost Savings Achieved by the use of Panelised Prefabrication in place of Traditional Building System for Building Categories						
City	**Commercial Buildings**	**Community Buildings**	**Educational Buildings**	**Houses**	**Apartment Buildings**	**Average**	***SD**
Auckland	22.71	22.66	6.89	20.19	20.58	18.60	5.9
Christchurch	20.30	37.17	22.21	13.17	12.70	21.11	9.9
Wellington	12.90	31.14	35.56	6.84	30.47	23.38	12.7
Average	18.63	30.32	21.55	13.40	21.25	21.03	9.5
***SD**	4.2	5.95	11.7	5.5	7.3	6.9	

Notes: Percentage cost savings were calculated using equation (3.8); *Standard Deviation

4.4.1 Cost Savings for Commercial Buildings

For the 32 commercial building projects investigated in the three cities in New Zealand, it is observed that an overall average cost saving of 18.63 percent was achieved for prefabricated construction over and above the traditional building system. For the 16 commercial building projects located in Auckland, the average cost savings achieved with the use of prefabrication technology is 22.71 percent. The results of cost saving analysis for Auckland commercial projects are presented in Appendix D1.1 of this report. Almost a similar value of 20.30 percent average cost saving was observed by the use of prefabrication technology for commercial building projects in the city of Christchurch (Appendix D1.2. Selected case studies of commercial buildings projects located in Wellington yielded a 12.90 percent cost savings (Appendix D1.3) with the use of prefabrication technology in place of the traditional building system.

4.4.2 Cost Savings for Community Buildings

Among all of the five building types investigated in this research, community buildings delivered the highest amount of cost savings in all of the three cities. The twenty one (21) community building projects selected from Auckland, Christchurch and Wellington yielded a 30.32 percent average cost saving. Use of panelised prefabrication technology in place of traditional building system for community buildings resulted in a 22.66 percent cost savings for seven Auckland projects. The results are presented at Appendix D2.1. Christchurch community projects yielded a very high 37.17 percent of cost saving. The Wellington community projects observed in this research also yielded a reasonably high amount of 31.14 percent cost saving (Appendix D2.2 & D2.3).

4.4.3 Cost Savings for Educational Buildings

A total of twenty-six (26) educational projects located in Auckland, Christchurch and Wellington were investigated in this research. The results of the cost analysis show that in the case study the educational projects delivered a 21.55 percent of average cost savings across the three cities. The twelve educational projects of Auckland investigated in this study reveal a cost savings of 6.89 percent (Appendix D3.1) for panelised prefabricated buildings compared to the traditional construction approach. Educational projects of Christchurch and Wellington resulted in a substantial amount of cost savings of 22.21 percent and 35.56 percent, respectively. The cost saving analysis of the Christchurch educational buildings is presented at (Appendix D3.2) and the cost analysis for the Wellington projects is presented at (Appendix D3.3).

4.4.4 Cost Savings for Houses

The use of prefabrication technology is most common for residential buildings in New Zealand (Bell and Southcombe, 2012). A total of 51 houses were investigated in Auckland, Christchurch and Wellington and these houses yielded an average 13.40 percent of cost savings. Out of these house projects, 33 of the houses located in Auckland delivered a 20.19 percent of cost savings (Appendix D4.1) with the use of prefabrication technology compared to the traditional building system. Whereas in the Christchurch and Wellington houses investigated in this study they yielded a 17 percent (Appendix D4.2) and 6.84 percent (Appendix D4.3) cost savings, respectively. The overall average cost saving for residential houses turned out to the lowest among all the building types investigated.

4.4.5 Cost Savings for Apartment Buildings

Apartment buildings included in this study showed an average 21.25 percent of cost savings and 21 apartment buildings were investigated in Auckland, Christchurch and Wellington. The Auckland buildings revealed a 20.58 percent of cost savings with the use of prefabrication technology (Appendix D5.1). The case study buildings observed in Christchurch yielded a 12.70 percent of cost savings (Appendix D5.2) and the Wellington projects yielded a 30.47 percent cost savings (Appendix D5.3).

4.4.6 Discussion on Cost Saving Results

A cost comparison comparing prefabricated buildings and buildings built using the traditional building system for five types of buildings located in Auckland, Christchurch and Wellington is represented in Table 4.2.

The range of added cost savings achieved for various building types across different cities of New Zealand provides an evidence for the superior cost benefits of prefabrication technology compared to the traditional building system. The minimum cost saving observed in this research is for building houses, i.e. 13.40 percent. Commercial buildings revealed more cost saving than residential houses at around 18.63 percent. Educational and apartment buildings showed similar cost savings of 21 percent. The maximum cost saving of 30 percent was observed for community buildings projects. Perhaps, the relatively simpler design nature of community buildings (Rouce, 1998) might have contributed to this result because this attribute aligns with the key features of prefabrication for an optimised economy (Bell, 2009).

The observed cost savings in New Zealand corroborate the findings of previous studies. For instance, Bradsher (2013) observed that the use of prefabricated modules resulted in halving the overall capital construction costs for the Sky City building project to $1.5 billion.

Winter et al. (2006) recorded a 25 percent cost saving in construction projects with the use of prefabrication technology. Winter et al. (2006) maintained that reduction of cost is a direct result of reduced timeframe in respect to managing the entire construction process. Further to this, the ability to responsibly use the construction material also contributes to the savings of project cost. Another case study research (Hamilton, 2007) conducted in USA recorded a 40 percent cost saving in school projects, in addition to substantially reducing the duration of the completion of the project.

Bell (2009) indicated that the use of prefabrication can result in as much as a 65 percent decrease in the project cost due to the potential of this construction approach to decrease the amount of waste. It is estimated that while prefabrication technology can reduce the amount of waste generation up to 77 percent, this saving of material eventually reduces the project completion cost (Bell, 2009). Bradsher (2013) notes that the use of prefabrication technology would result in a huge initial cost savings due to the reduced on-site material wastages, safer work environment and shrinking the duration of the time-related aspects of the preliminary and general items, as well as a reduction in the cost of project finance. However, a number of researchers do not agree with these findings, they believe that prefabrication very seldom results in large initial cost savings. This perception might be driven by two facts. First, since they are of higher quality, prefabricated components are generally more expensive than components produced onsite. Secondly, the time-cost relationship in the execution of a project with the conventional system means that if the duration is reduced, the initial cost is increased, depending on the cost slope of critical activities on the critical path (Fewings, 2013).

4.5 Time Savings

The reduction in project completion time is also a very significant benefit of prefabrication technology, which could translate to a reduction in the project completion cost (Bradsher, 2013). A comparison was made between the project completion time for a panelised prefabricated project and a traditionally built project in the case study projects. Time saving (TS) was calculated by deducting the time duration required to complete the prefabricated project compared with the duration of an equivalent traditional project and expressing this difference as a percentage of the latter. Equation 3.10 provides the expression for the computation of the time savings. The use of prefabrication in place of the traditional building system for the case study projects showed an average time saving of 46.77 percent in the five building types included in this study. Table 4.3 represents the summary of results across the five building project types and three cities of New Zealand included as the focussed of this study.

Table 4.3: Time savings achievable using prefabrication over traditional building systems across building types and locations

City	Percentage Time Savings Achieved by the use of Panelised Prefabrication in place of Traditional Building System for Building Categories						
	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartments	Average	*SD
Auckland	36.59	29.72	33.29	49.82	22.43	34.37	9.0
Christchurch	60.01	53.69	47.97	71.79	45.98	55.89	10.4
Wellington	39.57	51.43	43.16	74.05	42.04	50.05	14.1
Average	45.39	44.95	41.47	65.22	36.82	46.77	11.2
***SD**	10.4	10.80	6.1	10.9	10.3	9.7	

Notes: Percentage time savings were calculated using equation (3.10); *Standard Deviation

4.5.1 Time Savings for Commercial Buildings

In relation to individual building types, results showed that commercial building projects saved 45.39 percent of project duration. The time savings for this building type observed in Auckland, Christchurch and Wellington were 36.59 percent, 60.01 percent and 39.57 percent, respectively. The full results are presented in Appendix E1.

4.5.2 Time Savings for Community Buildings

Community building projects across the three cities were found to deliver an average time saving of 44.95 percent. Of the total community buildings projects, the projects located in Auckland city showed the least time saving of 29.72 percent (Appendix E2.1) when traditional construction methods were replaced by prefabrication technology. The time saving analysis for the Christchurch projects showed the highest value of 53.69 percent. The time saving observed for the Wellington based community projects was 51.43 percent. The detailed results in terms of the time saving analysis for community projects in Christchurch and Wellington are provided at Appendix E2.2 and Appendix E2.3 respectively.

4.5.3 Time Savings for Educational Projects

Table 4.3 showed that an overall average time saving of 41.47 percent was observed for all of the educational projects in the three cities. The educational buildings in Auckland achieved a 33.29 percent time saving (Appendix E3.1) with the use of prefabrication technology. Similarly, reasonably high levels of time saving were observed for the educational building projects in Christchurch and Wellington with figures of 47.97 percent (Appendix E3.2) and 43.16 percent (Appendix E3.3), respectively.

4.5.4 Time Savings for Houses

As shown in Table 4.3, the use of prefabrication in place of the traditional building system for housing projects resulted in an average time saving of 65.22 percent in the five building types across the three cities selected for the study. Auckland showed an average time saving of 49.82 percent (Appendix E4.1). Even higher values of time saving were observed for the residential projects in the other two cities: 71.79 percent for the Christchurch projects (Appendix E4.2) and 74.05 percent for the Wellington projects (Appendix E4.3).

4.5.5 Time Savings for Apartment Buildings

Apartment projects showed the least average time saving of 36.82 percent in Table 4.3. Apartment buildings located in the three cities showed an average time saving of 22.43 percent in Auckland (Appendix E5.1), 45.98 percent in Christchurch (Appendix E5.2) and 42.04 percent in Wellington (Appendix E5.3).

4.5.6 Discussion on Time Saving Results

Table 4.3 reveal that time savings in a range between 37 percent and 65 percent were achieved in different types of buildings across New Zealand when prefabrication technology is used in place of traditional building system. The maximum time saving of 65 percent was achieved for residential houses. This result could be due to the fact that a majority of the houses were developed off standard plans provided by the group home builders (Mbachu and Seadon, 2014). Mbachu and Seadon (2014) observed that such the plans and building of these houses readily lend to the standardisation of components, which contributes to faster manufacturing and installation, thereby enhancing the speed of construction. Standard house plans save time required to plan and design individual unique houses. Also the consenting process becomes much quicker when the project is built off standard plans.

These findings are in agreement with the results of previous studies. For instance, Lawson et al. (2012) investigated the efficiency gains of prefabrication technology and found a 50 percent reduction in completion time of projects where prefabrication system was employed. Lawson et al. (2012) argued that this result could be due to a number of factors including the fact that the bulk of the construction work was shifted from the project site to an off-site location where faster construction processes are achieved on account of the conducive factory environment as opposed to the risky and less conducive onsite construction environment. The authors observed an 80 percent gain in the productivity performance of construction workers, when working in a controlled factory setting compared to the onsite setting. In another study that reported on a prefabrication success in Spain, a four story building was constructed and put to use in just 15 days (Gunawardena et al., 2015). Similarly a 25 storey prefabricated student accommodation project located in Wolverhampton, UK was completed in 27 weeks resulting in a 50 percent saving in completion time compared to the traditional building system (Lawson et al., 2012).

4.6 Productivity Improvement

Analysis of productivity improvement in the case study projects in Table 4.4 showed an average 10 percent level of improvement with the use of prefabrication in place of the traditional building system. These results were consistent across the five building types and across the three cities delineated for the study. The highest productivity improvement value of 14.97 percent was achieved in community building projects, while the least values of 8.5 percent and 8.87 percent were achieved in the residential houses and commercial

Table 4.4: Productivity improvement achievable using prefabrication over traditional systems across building types and locations

	Percentage Productivity Improvement Achieved by the use of Panelised Prefabrication in Place of Traditional Building System for Building Categories						
City	**Commercial Buildings**	**Community Buildings**	**Educational Buildings**	**Houses**	**Apartments**	**Average**	***SD**
Auckland	8.76	8.17	2.46	11.07	5.30	7.15	3.0
Christchurch	12.10	21.33	10.62	9.39	6.62	12.01	5.6
Wellington	5.74	15.40	14.02	5.05	17.39	11.52	5.7
Average	8.87	14.97	9.03	8.50	9.77	10.23	4.8
***SD**	2.6	5.38	4.9	2.5	5.4	4.2	

Notes: Percentage productivity improvement were calculated using equation (3.13); *Standard Deviation

buildings, respectively. Mid-range productivity improvement levels of 9.03 percent and 9.77 percent were recorded for apartment buildings and educational buildings, respectively.

4.6.1 Discussion on Productivity Improvement Results

The highest productivity improvement levels achieved by the use of prefabrication in place of the traditional building system in the apartment, community and educational building projects across the three cities delineated for the study might be due to the cost-conscious nature of the clients of these project types. Mbachu and Nkadu (2006) observed that cost-conscious construction clients are usually faced with limited availability of funds and that they have strong preferences for the functionality of their buildings over and above the aesthetics and other design complexities. These are ideal attributes for prefabrication solutions (Bell, 2009). Overall, the use of prefabrication technology should result in a higher level of productivity than could be achieved by the use of the traditional building system because of other factors. For instance, prefabricated construction readily lends to the use of the just-in-time (JIT) procurement method, which obviates the requirement for the costly onsite storage of materials and improves the efficiency of site layout planning (Fewings, 2013). Fewings (2013) further argued that improving the site layout efficiency through the use of the JIT procurement system could bolster onsite labour productivity. This is in addition to safer working environment and reduced number of onsite operatives which have been found to improve onsite productivity by 30-40 percent (Illingworth, 2002). Egan (2002) identified certain further advantages with respect to the use of prefabrication technology that include speed of construction, lower cost, reduced need for skilled labour and achievement of zero defects, all of which could have a significant impact on the on-site level of productivity.

CHAPTER 5: DATA ANALYSIS, RESULTS AND DISCUSSION - QUESTIONNAIRE SURVEY

5.1 Introduction

This chapter presents the results of an industry wide survey of construction practitioners in New Zealand. The essence of the chapter is to triangulate the results obtained from the case study and to explore further constructs surrounding the subject under study; these subjectively defined constructs were not obtainable from project records, yet they have profound influence on the outcome. The results are presented in two streams including the survey responses and demographic information of the participants, and the results related to the research objectives.

5.2 Survey Responses

A total of 96 survey responses were received by the cut-off date set for the survey. After the initial screening, three non-responsive surveys were excluded from the analysis. To obtain the findings the responses from the remaining 93 useable survey responses were analysed. The 93 responses were from architects, building officials, contractors, engineers, project managers and quantity surveyors. The survey responses from construction industry stakeholders provided balanced viewpoint of various construction industry professionals. However, the majority of survey respondents were architects (25 percent), which meant that the survey findings are influenced more by the architects' viewpoints than from other construction industry stakeholders. This should be expected, given that architects, as the key designers have a significant influence on the choice of design solutions and specifications regarding how performance downstream should be measured.

Minimum sample size and adjusted minimum sample size for each of the participating professional organisation was calculated using Equation 3.1 and Equation 3.2 respectively. Based on the sample size response rate for each organisation was calculated. Table 5.1 represents the computations for sample sizes and corresponding response rates of professional organisation involved in this study.

Table 5.1: Sample Size and Corresponding Response Rate of Professional Organisations

Organi-zation	No of Members	*Min Sample Size	**Adj Min Sample Size	*** Request Sent	Responses Received	Sample Representation	Response Rate
Prefab NZ	221	141	86	86	16	7%	17%
NZIA	300	169	108	108	23	8%	25%
ACENZ	99	79	44	44	22	22%	24%
NZIQS	900	270	208	900	15	2%	16%
NZIOB	449	208	142	449	17	4%	18%
					Total	93	100%
					Average Response Rate	**9%**	20%

Min sample Size: Minimum sample size calculated using equation 3.1, **Adj Min Sample size: Adjusted minimum sample size calculated using equation 3.2,*Request sent: Questionnaire survey via organisation's secretariat internal circulars were used for NZIQS and NZIOB due to unavailability of membership directories and direct contact information*

The maximum response rate was 25 percent for NZIA followed by 24 percent response rate of ACENZ members. NZIOB, PrefabNZ and NZIQS response rate was 18 percent, 17 percent and 16 percent respectively.

5.3 Demographic Profiles of Survey Participants

5.3.1 Professional Affiliations

The professional affiliation of the survey respondents to construction industry organizations included in the sampling frames of this research study is presented in the graph (Figure 5.1). It shows that 24 percent of the survey respondents were members of the Association of Consulting Engineers New Zealand (ACENZ); 25 percent were registered architects of New Zealand Institute of Architects. The survey responses from New Zealand Institute of Quantity Surveyors (NZIQS) and the New Zealand Institute of Building (NZIOB) were 16 percent and 17 percent respectively. The participation of PrefabNZ members represented 18 percent of the total survey responses.

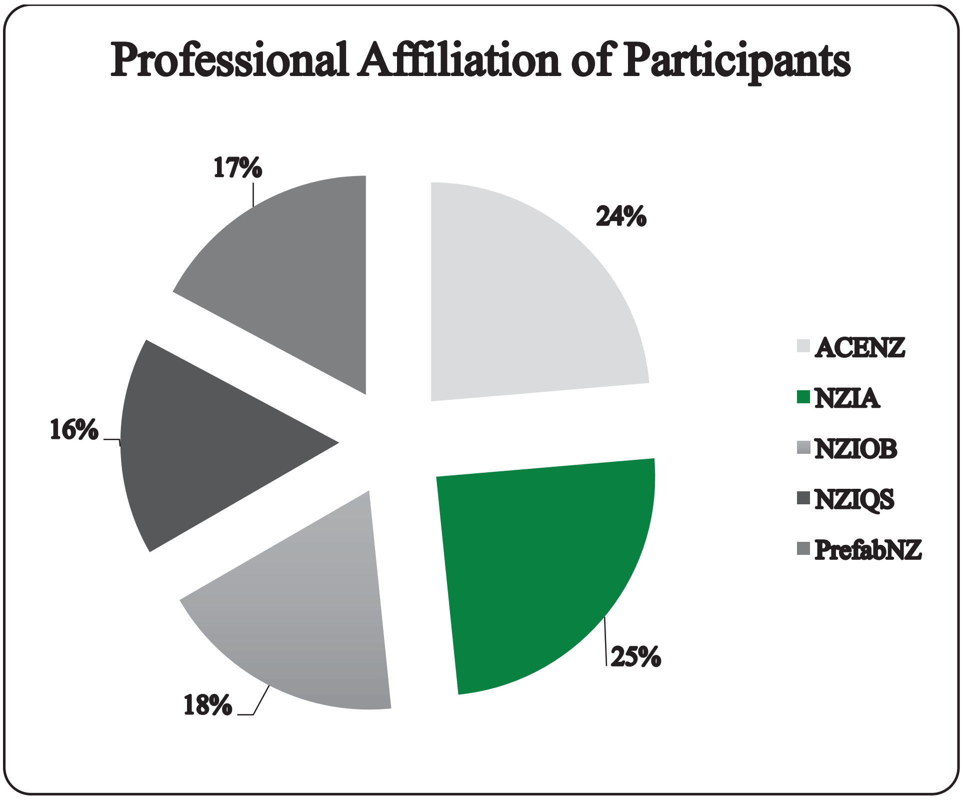

Figure 5.1: Professional affiliation of survey participants

Figure 5.1 shows that the findings of this study were influenced largely by the opinions of NZIA members since they contributed the greatest proportion of the responses i.e. 25 percent. This should be expected given that architects set the scene with the design solutions and specifications.

5.3.2 Position in Organisations

Figure 5.2 presents the position of survey respondents in their respective organizations. Majority of respondent hold high-level positions in their organizations. Greatest amount of respondents (48 percent) work as managers while another 45 percent respondents hold the position of managing director or equivalent. Survey respondents also included 5 percent supervisors and 1 percent trainees.

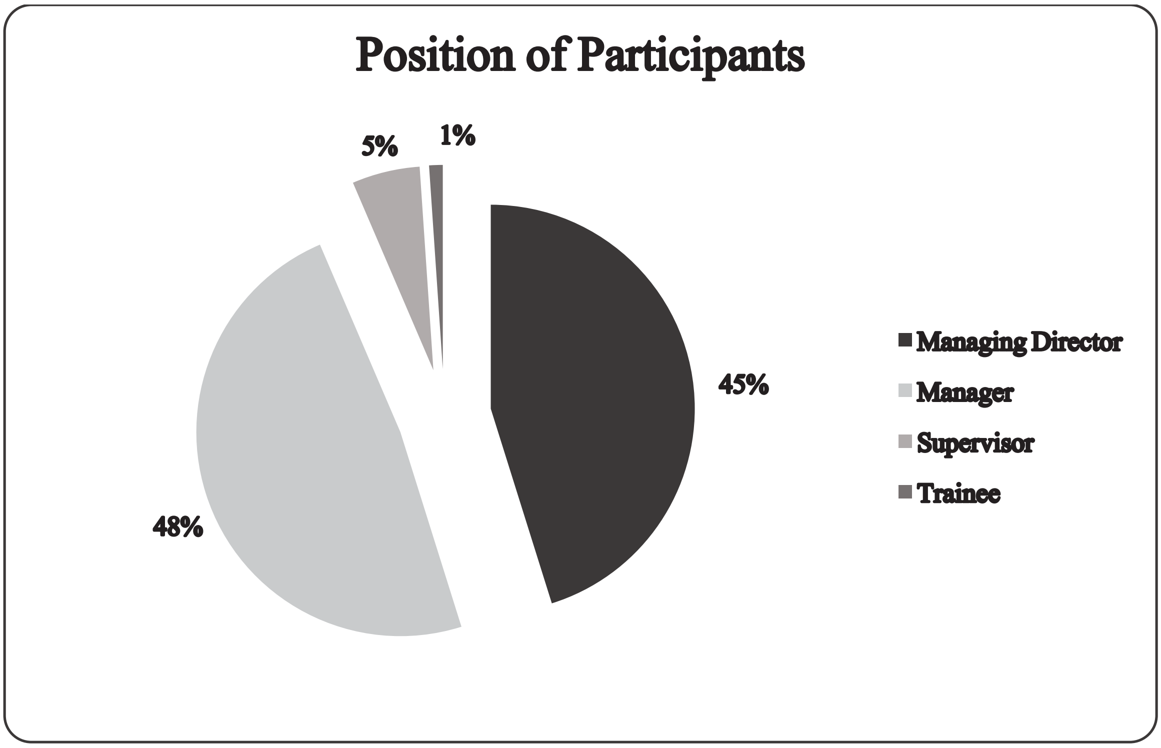

Figure 5.2 : Position of survey participants in their organization

5.3.3 Professional Role

The professional role of survey respondents is presented in figure 5.3. The 93 usable survey responses comprised feedback from architects (26 percent), building officials (15 percent), contractors (13 percent), engineers (23 percent), project managers (14 percent) and quantity surveyors (10 percent). As mentioned the greatest amount of feedback received was mainly from architects in the New Zealand construction industry. Though not significantly skewed as to introduce critical bias the findings of the study and the conclusions could be influenced by the majority of responses from architects, to their own credit. The findings and conclusions can be interpreted in this context.

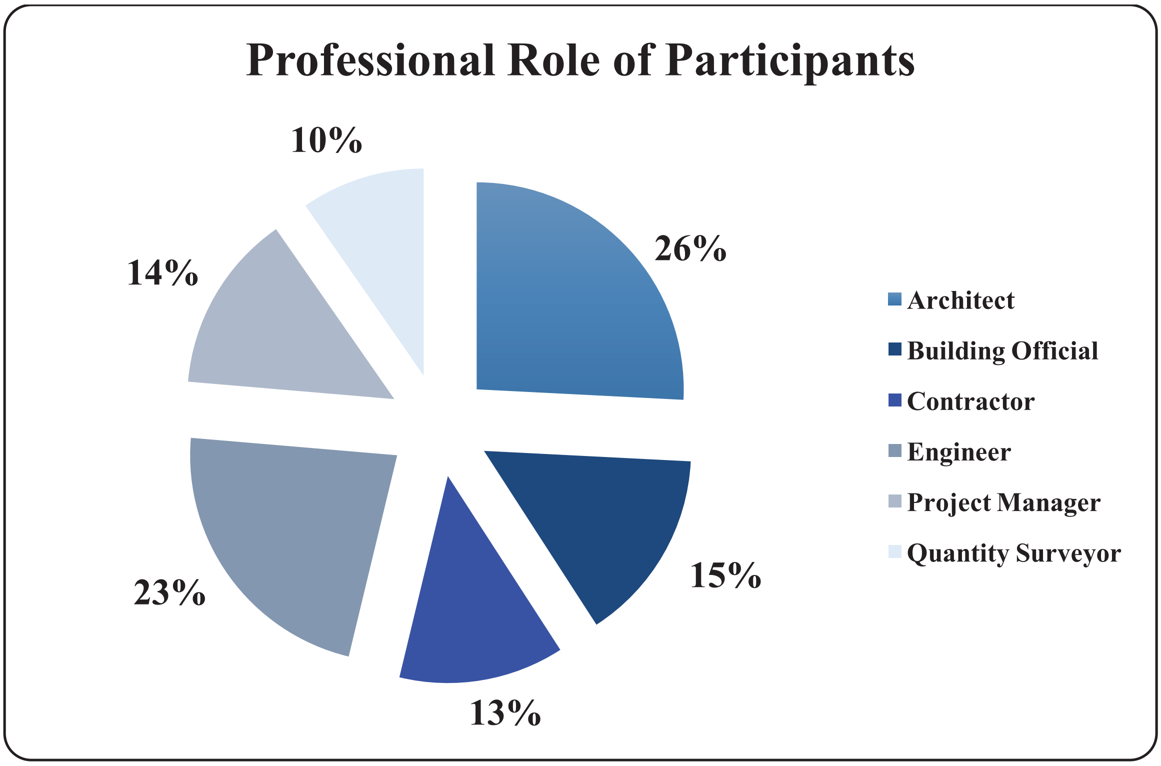

Figure 5.3 : Professional role of survey participants

5.3.4 Professional Experience

The years of experience of the survey respondents in their respective professional roles is summarized in figure 5.4. It is apparent from the chart that the majority of the survey respondents (29 percent) had professional work experience in the construction industry for 21 to 25 years. This figure validates the quality of the feedback and the results of the findings, since the greatest number of responses were from highly experienced industry key players, who on account of their vast experience, knew much about the needs and issues of the industry and therefore could provide authoritative feedback on the subject matter.

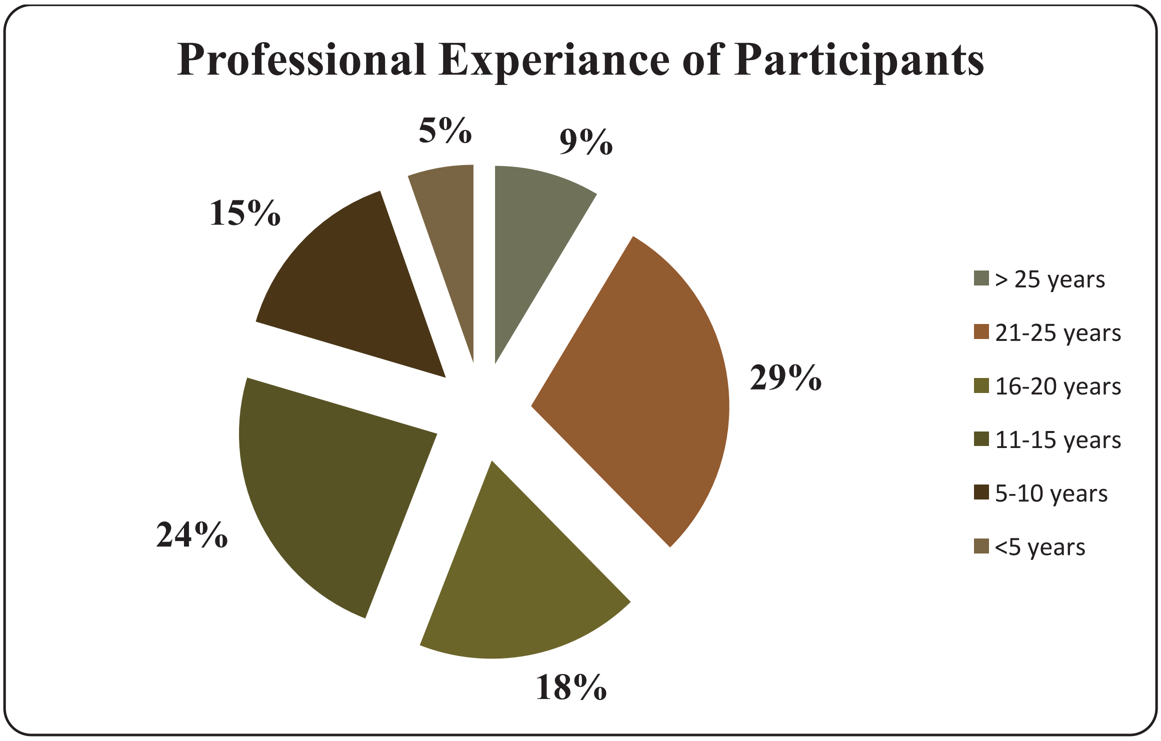

Figure 5.4 : Length of professional experience of survey participants

5.3.5 Implications of Demographic Profile on Research Quality

The above respondents' demographic profiles show that majority of the respondents (65 percent) had 21-25 years of experience, occupied high managerial positions (as managing directors), and occupied influential roles as designers. These demographic profiles showed that the respondents were highly experienced, occupied top positions in their organisations, and are key decision-makers in relation to the issue under study. Their quality feedback should therefore contribute to the reliability and validity of the research findings. However, the responses were below the required minimum samples from the various stakeholder groupings targeted in the research. These responses therefore were not representations of the corresponding stakeholder groupings. The overall implication of the poor response rates in regard to the research is that the findings may not be generalised beyond the data sampling scope of this study.

5.4 Benefits Achievable by the use of Prefabrication (Survey Responses)

The third and last objective of this research is "to examine how the findings analysed from the case studies of the completed project records compare to those from the industry stakeholder's feedback with a view to ascertaining the implications of the outcome of this comparison on the reliability and validity of the research findings and their ability to be generalised beyond the study scope". Stakeholder's feedback was collected on cost savings, time savings and productivity improvement for different building types included in this research, using close-ended questions in the survey. The following subsections present the data and analyses, and discussions of results in relation to the research objectives.

5.4.1 Cost Savings

The typical analysis of the survey responses for cost savings achievable using prefabrication in place of the traditional building system is presented for the case of educational buildings as demonstration (Figure 5.2). The full analysis across building types is presented in Appendix G1. The overall results are presented in Table 5.3. The results showed that highest cost savings are associated with community and educational building projects, with an average cost saving of 23.2 percent and 22.9 percent, respectively. In terms of the analysis of the average overall cost saving across all five building types it was 22.2 percent.

Table 5.2: Analysis of Prefabrication Cost Savings for Educational Buildings (Survey Results)

Rating interval	0.26 - 0.30	0.21 - 0.25	0.16 - 0.20	0. 10 - 0.15	Other (open-ended)
Ave Cost Saving	0.28	0.23	0.18	0.125	0.08
No. of Responses	32	35	16	7	1
				Total Participants	91
				Average	0.23
				Standard Deviation	0.002
				Mode	0.23

5.4.2 Time Savings

In regard to the analysis of the typical time savings according to the survey responses, it is presented in Appendix G2. The results of this analysis showed that the maximum time saving was associated with residential houses and community buildings while prefabrication was used in place of traditional building system. Residential houses and community buildings yielded a time saving of 46.9 percent and 46.6 percent, respectively. An average overall time saving of 45 percent (Table 5.3.) was observed for all the building types.

5.4.3 Productivity Improvement

With respect to the analysis of the survey responses for the typical productivity improvement achievable using prefabrication in place of the traditional building system across five building types, it is presented in Appendix G3. The overall results presented in Table 5.3 showed that the highest productivity improvement was associated with community and residential building projects, with an average improvement value of 8.4 percent for both. In regard to the overall productivity improvement across the five building types, the average was 8.2 percent.

5.4.4 Summary of Cost Savings, Time Savings and Productivity Improvement

Table 5.3 summarises the cost savings, time savings and productivity improvement across the five building types as analysed from respondent's ratings. The table shows that, on average, the use of prefabrication in place of the traditional building system could result in a 22.2 percent savings in cost, a 45.2 percent savings in completion time and 8.2 percent improvement in productivity. These results are fairly consistent with the findings of other studies. For instance, Winter et al. (2006) reported 25 percent average cost savings, for construction projects where prefabrication is used in place of traditional construction practices. Lawson et al. (2012) observed a similar value of overall time savings (for a student accommodation project). No literature exists on the quantitative value of productivity improvement other than anecdotal evidence. Shahzad et al. (2015) associated a number of reasons for the added benefits for the use of prefabrication in place of the traditional building system, such as, a reduction in the amount of construction material wastage, no delays owing to bad weather, a safe and hassle free environment for workers and no interference and disturbance to workers due to materials coming in and being stored on site.

Table 5.3: Summary of Cost Savings, Time Savings and Productivity Improvement Across the Building Types (Survey Responses)

		Commercial	Educational	Community	Apartments	Houses
Cost Savings	Mean Value	21.8%	22.9%	23.2%	21.8%	21.4%
	*SD	4.1%	0.2%	0.3%	4.3%	4.3%
	Mode	18%	23%	28%	23%	28%
Time Savings	Mean Value	42.5%	45.4%	46.6%	44.7%	46.9%
	*SD	1.67%	1.85%	1.93%	1.79%	1.84%
	Mode	43%	48%	53%	48%	53%
Productivity Improvement	Mean Value	7.8%	8.2%	8.4%	8.0%	8.4%
	*SD	0.51%	0.57%	0.59%	0.52%	0.60%
	Mode	9%	9%	9%	9%	9%

** Standard Deviation*

5.5 Factor Influencing Prefabrication Benefits

The second objective of this research is to identify and prioritise the factors that can significantly influence the benefits achievable by the use of prefabrication technology. In order to achieve this research objective, the relative levels of influence of the factors impacting on the benefits accruable from the use of panelised prefabrication technology were determined from the survey responses. In total 17 factors were determined as recurring constructs during the pilot interviews. These were used to design the questionnaires and the respondents rated their relative levels of influence on the added benefits of prefabrication over and above those of the traditional building system. The survey responses were analysed using the Statistical Package for the Social Sciences (SPSS) based factor analysis in order to establish the relative levels of influence of the 17 factors on the prefabrication benefits/outcomes. The descriptive statistics output of the SPSS factor analysis is presented in Table 5.4.

Table 5.4 : Factors Influencing Prefabrication Added Benefits (Survey Responses)

Factors	Mean Rating	*SD	**Remark
1) Building Type	4.9	0.301	Very high
2) Location	4.71	0.461	Very high
3) Logistics	4.58	0.502	Very high
4) Prefabrication Type	4.55	0.506	Very high
5) Scale/Repeatability	4.42	0.502	Very high
6) Standardisation/Customisation	4.39	0.495	Very high
7) Contractor's Innovation	4.29	0.461	Very high
8) Environmental Impact	3.81	0.792	High
9) Project Leadership	3.68	0.832	High
10) Procurement Type	3.61	0.715	High
11) Whole of life Quality	3.61	0.715	High
12) Site Conditions	3.52	0.677	High
13) Site Layout	3.52	0.811	High
14) Client nature	3.48	0.769	High
15) Contract Type	3.39	0.615	Moderate
16) Weather Condition	3.39	0.558	Moderate
17) Subsoil Proportion	3.03	0.875	Moderate

**Standard Deviation **Remark: "Very high" = 4.201 ≤ Mean ≤ 5; "High" = 3.401 ≤ mean ≤ 4.2; "Moderate" = 2.601 ≤ mean ≤ 3.4; "Low" = 1.801 ≤ mean ≤ 2.6; "Very low" = 1.00 ≤ mean ≤ 1.8*

The results showed that all 17 factors were rated moderate to very high in influence on the 5-point Likert rating scale used. No factor was rated low or very low. Additional factors supplied by the respondents in the open-ended section of the questionnaire were rewordings of the factors already included in the list. This meant that no new factors were suggested during the survey.

Of the 17 factors, three were rated 'moderate' in influence, with contract type occupying the top of this group. Seven factors were rated 'high' in influence, with environmental impact topping the group. Factors with 'very high' influence rating comprise building type and location as the most influential of all of the 17 factors. The lowest standard deviations associated with these two factors relative to the others showed that the respondents were more consistent in their ratings than for the others. This indicated a strong consensus among the respondents concerning the high influence of these factors on the potential benefits prefabrication provides.

'Building type' as the most influential factor means that the amount of benefit the technology can offer could vary significantly depending on the type of building. This finding is supported by the research study of Langdon and Everest (2004). Their study documented that prefabrication technology offers more benefits when used for high-rise buildings. Similarly, Bell (2009) documented that in the New Zealand context, prefabrication offers maximum productivity benefits when used for housing projects. This however is in contrast with a number of studies (Hamilton, 2007, Lusby-Taylor et al., 2004) that had reported prefabrication benefits across the board without qualifying the benefits in relation to the purpose in terms of the group or type of building.

With respect to 'location' as the second most influential factor in terms of the potential prefabrication benefits, it is understandable and is in agreement with the popular buzzword in the property circle that the three most important underpinnings of the attractiveness and value of a residential property value are 'location', 'location' and 'location'. Burgess et al. (2013), observed the relationship of the prefabrication benefits and location and documented that the benefits of prefabrication will be limited mainly to seven main cities throughout New Zealand which include: Auckland, Christchurch, Dunedin, Hamilton, Napier, Tauranga and Wellington. And 'logistics', the third most influential factor, impacts heavily on the potential benefits of prefabrication technology depending on the distance between the construction site and the prefabrication factory site, as well as the logistics and other challenges involved in transporting the prefabrication components. Fang and Ng (2010) reported that where the construction site is remote from the prefabrication factory location, the cost of transportation, traffic challenges and risks of delay in supply make the use of prefabrication a less preferred alternative to the traditional construction methods.

The type of prefabrication is also listed as having a very high influence on prefabrication benefits. Some studies have associated the type of prefabrication with the building purpose. For instance, Jaillon and Poon (2009) noted that whole building prefabrication is most suitable for portable buildings and motels. On the other hand, Langdon and Everest (2004) reported that modular prefabrication is a highly suitable option for multi-storey buildings. This is largely due to the opportunity for repeatability and standardisation in regard to the prefabricated components, which help to maximise the benefits of prefabrication. Yau (2006) corroborated Langdon and Everest's (2004) statement by noting that superior cost and time savings are optimised in the repeated manufacturing of the standardized prefabrication components.

5.6 Reducing Number of Influential Factors

Based on the descriptive statistics output of the SPSS-based factor analysis, the 17 factors identified during the pilot interviews have been evaluated to know their relative levels of influence on the potential benefits of prefabrication. This was made possible by interpreting the mean rating of each factor in the re-scaled five-band Likert range. The results in Table 5.4 showed that the 17 factors were rated to be of moderate to very high influence.

However, there is a need to reduce the 17 factors further for succinctness and for resource efficiency. This is mainly so that the inter-correlations that may exist among the factors may justify their partitioning into lesser number of representative broader groupings. This way, factors that show high inter-correlations may be grouped under one broader category.

Principal component analysis (PCA) is an ideal statistical technique for achieving this purpose (IBM, 2014). The PCA also helps to accord some measure of reliability and validity to the analysis beyond what the descriptive analysis could offer. The Varimax rotation option was used, as this is the most appropriate form of PCA (IBM, 2014).

The choice of PCA as the most appropriate statistical analysis for the second research objective was on the basis of the nature of the research question, the nature of the data and the scale of the measurement and other underpinning variables. Table 5.5 was used for this purpose.

The following sections present the SPSS output of the PCA for the analysis of the survey responses of the factors influencing the benefits of prefabrication. These consist of the scree plot, Table of Total Variances Explained, Table of Communalities, KMO and Bartlett’s Test of Sphericity.

5.6.1 Scree Plot

The first SPSS output of the principal component analysis to consider is the scree plot. IBM (2014) explained that the scree plot is a plot of the ‘Eigenvalues’ of the variables under study. The Eigenvalue provides information about the relative efficacy of each discriminant function or principal component in explaining the total variations among the variables being loaded on the principal components. In the PCA, each variable that is analysed is initially regarded as a component; the eigenvalue helps to identify the variable(s) that can represent a significant number of the rest of the variables and hence serve as a good proxy for the variables that are represented. In the Scree Plot, the number of principal components to be extracted are shown as those with eigenvalues of 1 or above (see Figure 5.5). So the principal components that are high on the ‘cliff’ of the scree plot have a higher propensity to explain the variations among a greater number of other variables. Those components on the gentle sloping part of the plot have so many inter-correlations hence do not have a distinctive or unique contribution with respect to the phenomenon that is the subject of the study.

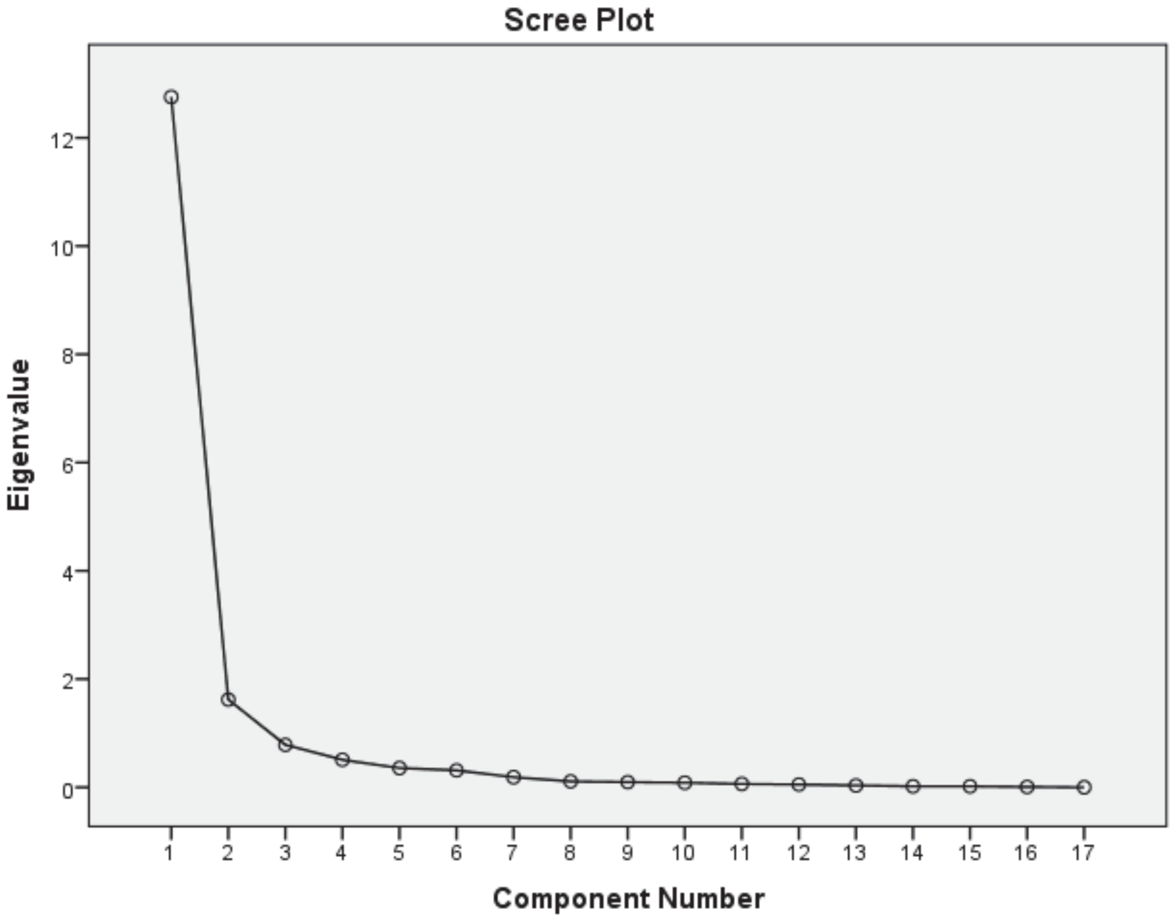

Figure 5.5 : Scree plot of the Eigenvalues against the 17 variables influencing prefabrication benefits

The scree plot of Figure 5.5 shows that two components have eigenvalues above 1. The scree plot that has a point of inflexion or 'elbow' also confirms the appropriateness of the use of the principal component of the analysis for this analysis.

5.6.2 Total Variance Explained

Having established the number of principal components to be extracted from the underlying variables as good proxy for the variable sets, the SPSS outputs a Table of Variance Explained to show the relative contributions of the principal components in explaining the total variations among the variables in the set (see Table 5.5).

Table 5.5 :: Total variance explained (SPSS-PCA)

Components	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	%age of Variance	Cumulative %	Total	%age of Variance	Cumulative %	Total	%age of Variance	Cumulative %
1	12.754	75.024	75.024	12.754	75.024	75.024	10.060	59.179	59.179
2	1.621	9.532	84.557	1.621	9.532	84.557	4.314	25.378	84.557
3	.784	4.613	89.169						
4	.509	2.993	92.162						
5	.355	2.091	94.253						
6	.312	1.838	96.091						
7	.186	1.095	97.186						
8	.109	.639	97.825						
9	.097	.570	98.396						
10	.084	.496	98.891						
11	.062	.363	99.254						
12	.050	.293	99.547						
13	.035	.204	99.752						
14	.018	.108	99.859						
15	.017	.100	99.959						
16	.007	.041	100.00						
17	-3.090E-18	-1.818E-17	100.00						

Extraction Method: Principal Component Analysis.

Table 5.5 confirms the scree plot result that only two components could be extracted from the 17 variables by providing loadings of extraction sums of squared and rotation sums of squared values only for these two components as shown. The table also shows that the first component with an eigenvalue of 12.754 explains 75 percent of the variance among the 17 variables, while the second component with an eigenvalue of 1.621 explains 9.6 percent of the variance. In combination, these two components explain 85 percent of the variance among the 17 variables.

The first of the two components relates with the first of the 17 variables. This means that this first variable – Building Type – is the most significant contributor to this component hence it draws upon it. The second component relates with the second of the 17 variables. This also means that the second variable – Location – is the most significant contributor to this second component. Together, both component results confirm that building type and location are the most significant contributors to the prefabrication added benefits and so justify the focus on these two objectively quantifiable variables in the first stage of the case in terms of the study research.

5.6.3 KMO and Bartlett's Test of Sphericity

The Kaiser Meyer Olkin' (KMO) value is a measure of sampling adequacy. IBM (2014) explains that the KMO score helps to test the first assumption that underlies the principal component analysis - that there are significant inter-correlations among the underlying variables to justify reducing their number to fewer and broader subsets (i.e. principal components), which provide unique and distinctive contributions to the phenomenon that is the subject of the research study. The SPPS outputs the table of Kaiser Meyer Olkin's (KMO) and Bartlett's Test of Sphericity for the principal component analysis. Patton (2003) explains that a KMO value of 0.7 is the threshold to assess whether or not this first assumption has been satisfied. Result in Table 5.6 shows a KMO value of 0.925, which shows a very high inter-correlation among the variables and so a good satisfaction of the first underlying assumption of PCA.

The Bartlett's Test of Sphericity provides a test of the second assumption of the PCA – that there is no correlation or an insignificant correlation among the principal components as a confirmation of their ability to provide unique and distinct contributions to the phenomenon under study. The SPSS uses an F-test involving Chi Square test statistics to test the null hypothesis of significant correlations among the principal components.

Result in Table 5.6 shows pi value of 0.0001 for the Bartlett's Test of Sphericity. Since this value is less than 0.05 alpha level of the test it shows a rejection of the null hypothesis and acceptance of the alternative hypothesis of insignificant correlations among the two principal components extracted from the 17 variables, and hence a satisfaction of the second underlying assumption of the PCA.

Table 5.6 : KMO Measure and Bartlett's Test of Sphericity

KMO Measure of Sampling Adequacy.		.925
Bartlett's Test of Sphericity	Approx. Chi-Square	3301.703
	df	136
	Sig.	0.0001

5.6.4 Rotated Component Matrix

In order to segregate the variables into the principal components, SPSS outputs the table of rotated component matrix to show how the variables are loaded on the principal components on the basis of their Kaiser Normalisation Coefficient (KNC) values; with each variable segregated into a principal component where it has a higher loading of the Kaiser Normalisation coefficient. Clear segregation of the factors influencing prefabrication added benefits in the 'Component – Segregated' column of Table 5.7 were achieved by restricting the loading of the factors having Kaiser Normalisation Coefficient of 0.2 or less on the principal components.

From the table 5.7, it could be seen that 10 out of the 17 factors loaded more on component 1, while the remaining 7 factors loaded more on component 2. Component 1 has building type as the highest contributing factor with a KNC value of 0.943. On the other hand, component 2 has location as the highest contributing factor with a KNC value of 0.789.

IBM (2014) and Patton (2003) noted that how a principal component is named is a subjective exercise, but draws closely to the nature of the underlying subcomponents. Based on this rule, an appropriate name for component 1 is "strategic, operational and technical issues relating to design, planning and construction of a project" while component 2 is "strategic, operational and technical issues relating to location and site conditions".

Table 5.7 : Rotated Component Matrix

Factors Influencing Prefabrication Added Benefits	Components (Mixed)		Components (Segregated)	
	1	2	1	2
Building Type	.943	.175	0.943	
Prefabrication Type	.651	.152	0.651	
Contract Type	.632	.151	0.632	
Procurement Type	.621	.148	0.621	
Standardisation / Customisation	.615	.143	0.615	
Scale / Repeatability	.605	.142	0.605	
Whole of life Quality	.580	.138	0.580	
Project Leadership	.570	.137	0.570	
Client Nature	.565	.134	0.565	
Contractor's Innovation	.561	.133	0.561	
Location	.130	.789		0.789
Logistics	.125	.743		0.743
Subsoil Proportion	.123	.735		0.735
Weather Condition	.118	.248		0.248
Site Conditions	.116	.451		0.451
Site Layout	.114	.514		0.514
Environmental Impact	.120	.325		0.325

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]

CHAPTER 6: RELIABILITY AND VALIDITY TESTING

6.1 Overview

In Section 3.11, two streams of data analysis were discussed. One focuses on finding the answers to the research questions/objectives and the other focuses on the reliability and validity of the research findings using statistical tests related to the hypotheses. This was shown in Figure 3.4.

This chapter presents and discusses the reliability and validity of the evaluations in terms of the research design and findings as highlighted in Section 3.6. Overall, Section 3.6 presents a discussion on the reliability and validity of the research and the specific actions to achieve them in this study. Figure 3.4 shows three key hypotheses/propositions that aligned with the three research objectives and the test statistics utilised to test them. In regard to the choice of the test of statistics it was guided by the framework in Figure 3.5, which as discussed in Section 3.7, is a flowchart for choosing the appropriate research design and analysis procedure.

The following subsections present the hypotheses/propositions, the testing, and a discussion of the results. In addition, with respect to the reliability and validity of the research findings the implications of the results are also highlighted.

6.2 Research Propositions

In general, propositions are proposed to keep research investigations focused on the particular areas of inquiry. They assist in the design and implementation of the appropriate research strategy and data collection to achieve the research objectives (Saunders et al., 2007).

Different statistical tests of significance were carried out to establish a reasonable measure of confidence in the conclusions achieved. It is pertinent to mention here that when a statistical test of significance is employed 'propositions' are termed as 'hypothesis' (Cooper and Emroy., 2009). The hypothesis is defined as predictive statements in which the researcher predicts the various outcomes of the research (Creswell, 2009). The research hypothesis narrows the research objectives to specific predictions. Creswell (2009) further defines a structured step by step approach in regard to the testing hypothesis. The first step is to identify a null hypothesis and an alternative hypothesis. The establishing the level of significance follows the identification of hypothesis, which governs the third step of the data collection process. The sample statistics are calculated using the collected data. The last step is making a decision about rejecting or accepting the null hypothesis.

The choice of an appropriate analytical technique adopted in each test was guided by Cooper and Emory's (2009) recommendations. Figure 3.3 illustrates the research objectives, the related propositions and the analytical techniques adopted in testing the propositions.

6.3 Test of Proposition 1

The first objective of this research is to quantify the benefits of the panelised prefabrication system over and above the corresponding benefits of the traditional building system.

Proposition 1 was postulated to help in achieving the first objective. The proposition assumed that the use of the panelised prefabrication system in place of the traditional building system does not offer a significant level of benefits in terms of cost savings, time savings and overall productivity improvement across the building types and locations. This proposition was informed by insights from a review of the literature (Taylor, 2009, Kelly, 2009) which provided mixed results in regard to saving time and cost via the use of the technology.

Since the benefits of prefabrication technology consist of cost savings, time saving and productivity improvement, proposition 1 is split into three subgroups to determine the benefits of prefabrication technology in each case.

Proposition 1.1 focused on cost savings and assumed that the use of the panelised prefabrication system in place of the traditional building system does not offer significant cost savings across building types and locations.

Proposition 1.2 assumed that the use of the panelised prefabrication system in place of the traditional building system does not offer significant time savings across building types and locations.

Proposition 1.3 assumed that the use of the panelised prefabrication system in place of the traditional building system does not offer significant productivity improvement across building types and locations.

The tests of the sub-propositions and the discussions of the results are presented in the following sub-sections. The propositions were first re-stated as hypotheses to enable a statistical test of significance to be conducted at an alpha level of 5 percent, which is mostly used in statistical tests (Patton, 2003). Guided by Figure 3.5, the Student t-test was found to be the most appropriate test statistic to use and since the nature of the objective to be achieved is descriptive, the scale of the measurement of the data is interval (i.e., percentage values) and the underlying distribution of the dataset as analysed using the SPSS is parametric.

6.3.1 Sub-proposition 1.1

This sub-proposition tests whether or not prefabrication technology offers cost saving benefits and how these cost savings vary across a range of building types and locations.

The null and alternative hypotheses for testing sub-proposition 1.1 under the t test statistic are stated as follows:

The null hypothesis assumes that the use of panelised prefabrication system in place of the traditional building system does not offer significant cost savings across building types and locations. The expression for the test procedure is based on the student t-test statistic which was defined in Equation 3.3. The null and alternative hypotheses are stated as follows.

H_o: x - t*s/sqrt(n) > 0 (Region of acceptance of $H_{o)}$) Equation 6.1

H_A: x - t*s/sqrt(n) $\leq$ 0 (Region of rejection of $H_{o,}$ Accept H_A) Equation 6.2

Where:

x = Mean of the cost savings computed from the case study projects across locations & building types.

s = Standard deviation computed from the case study projects across locations & building types.

n = Number of data points involved in the analysis.

t = Student t-test statistic computed from Equation 3.3.

The results of the test of hypothesis 1.1 are presented in Table 6.1 for the test across building types and Table 6.2 presents the results for the test across locations.

Percentage Cost Savings

Table 6.1: Cost savings achievable using prefabrication over traditional building systems across building types

	Percentage Cost Savings Achieved by the use of Panelised Prefabrication in place of Traditional Building System				
	Commercial Buildings	**Community Buildings**	**Educational Buildings**	**Houses**	**Apartment**
Average Cost Savings	18.63	30.32	21.55	13.40	21.25
Standard Deviation	4.2	5.95	11.7	5.5	7.3
Degree of Freedom n-1	2.0	2.0	2.0	2.0	2.0
t-value	4.3	4.3	4.3	4.3	4.3
t*s/sqr(n)	10.37	14.78	29.10	13.55	18.06
μ - t*s/sqr(n)	8.27	15.54	-7.55	-0.15	3.19
Range of Cost Savings at 95% Confidence					
Max Value	29.00	45.11	50.66	26.94	39.31
Min Value	8.27	15.54	-7.55	-0.15	3.19

Table 6.2 : Cost savings achievable using prefabrication over traditional building systems across locations

Percentage Cost Savings Achieved by the use of Panelised Prefabrication in place of Traditional Building System			
	Auckland	**Christchurch**	**Wellington**
Average Cost Saving	34.37	55.89	50.05
Standard Deviation	9.04	10.43	14.13
Degree of Freedom n-1	4.00	4.00	4.00
t-value:	2.78	2.78	2.78
t*s/sqr(n)	12.55	14.49	19.62
μ - t*s/sqr(n)	21.81	41.40	30.43
Range of Cost at 95% confidence			
Max Value	46.92	70.37	69.67
Min Value	21.81	41.40	30.43

6.3.2 Sub-proposition 1.2

Following the sub-proposition 1.1, this sub-proposition tests whether or not prefabrication technology offers time saving benefits and how these time savings vary across a range of building types and locations.

A similar t-test was employed to test sub-proposition 1.2. The time savings achieved with the use of prefabrication technology were computed and the mean values for time savings were established for all of the five building types in each city and for each building type in all of the three cities. The mean values were compared to the hypothesized mean.

H_o: μ > t*s/sqrt(n) (Region of Acceptance of $H_{o)}$) Equation 6.3

H_A: μ < t*s/sqrt(n) (Region of Rejection of $H_{o,}$ Accept H_A) Equation 6.4

Where:

x = Mean of the time savings computed from the case study projects across locations & building types.

s = Standard deviation computed from the case study projects across locations & building types.

n = Number of data points involved in the analysis.

t = Student t-test statistic computed from Equation 3.3.

Percentage Time Savings

Table 6.3 : Time savings achievable using prefabrication over traditional building systems across building types

	Percentage time savings achieved by the use of panelised prefabrication in place of traditional building system				
	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartment
Average Time Saving	45.39	44.95	41.47	65.22	36.82
Standard Deviation	10.4	10.80	6.1	10.9	10.3
Degree of Freedom n-1	2.0	2.0	2.0	2.0	2.0
t-value:	4.3	4.3	4.3	4.3	4.3
t*s/sqr(n)	25.86	26.84	15.18	27.15	25.59
μ - t*s/sqr(n)	19.53	18.11	26.29	38.07	11.23
Range of time savings at 95% confidence					
Max Value	71.25	71.79	56.65	92.36	62.41
Min Value	19.53	18.11	26.29	38.07	11.23

The results of the test of hypothesis 1.2 are presented in Table 6.3 for the test across building types and Table 6.4 presents the results for the test across locations.

Table 6.4 : Time savings achievable using prefabrication over traditional building systems across locations using t-test

Percentage Time Savings Achieved by the use of Panelised Prefabrication in place of Traditional Building System			
	Auckland	**Christchurch**	**Wellington**
Average Time Saving	34.37	12.01	11.52
Standard Deviation	9.04	5.58	5.72
Degree of Freedom n-1	4.00	4.00	4.00
t-value:	2.78	2.78	2.78
t*s/sqr(n)	12.55	7.75	7.95
μ - t*s/sqr(n)	21.81	4.26	3.58
Range of time saving at 95% confidence			
Max Value	46.92	19.76	19.47
Min Value	21.81	4.26	3.58

6.3.3 Sub-proposition 1.3

Sub-proposition 1.3 tests whether or not prefabrication technology offers productivity improvement benefits and how this productivity improvement varies across a range of building types and locations.

To test sub-proposition 1.3 a similar t-test was employed. The productivity improvement achieved with the use of prefabrication technology was computed and the mean values for productivity improvement were established for all of the five building types in each city and for each building type in all of the three cities. The mean values were compared to the hypothesized mean.

Percentage Productivity Improvement

Table 6.5 : Productivity improvement achievable using prefabrication over traditional building systems across building types

	Percentage Productivity Improvement Achieved by the use of Panelised Prefabrication in place of Traditional Building System				
	Commercial Buildings	**Community Buildings**	**Educational Buildings**	**Houses**	**Apartment**
Average Productivity Improvement	8.87	14.97	9.03	8.50	9.77
Standard Deviation	2.6	5.38	4.9	2.5	5.4
Degree of Freedom n-1	2.0	2.0	2.0	2.0	2.0
t-value:	4.3	4.3	4.3	4.3	4.3
t*s/sqr(n)	6.45	13.37	12.06	6.30	13.45
μ - t*s/sqr(n)	2.42	1.60	-3.02	2.20	-3.68
Range of productivity improvement at 95% confidence					
Max value	15.32	28.33	21.09	14.80	23.23
Min value	2.42	1.60	-3.02	2.20	-3.68

H_o: $\mu > t*s/sqrt(n)$ (Region of Acceptance of $H_{o)}$) Equation 6.5

H_A: $\mu < t*s/sqrt(n)$ (Region of Rejection of $H_{o,}$ Accept H_A) Equation 6.6

Where:

x = Mean of the productivity improvement computed from the case study projects across locations & building types.

s = Standard deviation computed from the case study projects across locations & building types.

n = Number of data points involved in the analysis.

t = Student t-test statistic computed from Equation 3.3.

The results of the test of hypothesis 1.3 are presented in Table 6.5 for the test across building types and Table 6.6 presents the results for test across locations.

Table 6.6 : Productivity improvement achievable using prefabrication over traditional building systems across locations

Percentage Productivity Improvement Achieved by the use of Panelised Prefabrication in place of Traditional Building System			
	Auckland	**Christchurch**	**Wellington**
Average Productivity Improvement	7.15	12.01	11.52
Standard Deviation	2.98	5.58	5.72
Degree of Freedom n-1	4.00	4.00	4.00
t-value:	2.78	2.78	2.78
t*s/sqr(n)	4.14	7.75	7.95
μ - t*s/sqr(n)	3.01	4.26	3.58
Range of productivity improvement at 95% confidence			
Max Value	11.29	19.76	19.47
Min Value	3.01	4.26	3.58

6.3.4 Conclusion on the Tests of Proposition 1

Table 6.7 presents the summarised results for the tests of the three subcomponents of Proposition 1.

The table shows that the null hypotheses were accepted in all but two of the six sets of tests carried out in Tables 6.1 – 6.2. This suggests that prefabrication offers significant positive benefits across building types and locations only in relation to time savings across locations and building types. No statistical evidence exists to support the significant positive benefits in cost savings and productivity improvement across building types, even though significant positive benefits exist across locations. Overall, proposition 1 is therefore rejected due to not being true in all six instances.

The finding that prefabrication offers significant positive benefits across building types and locations in relation to time savings is supported by the similar findings of Page and Norman (2014) and Lu (2009). This result might be due to the focus of prefabrication on taking as much as possible of the construction activities away from the site to factory controlled conditions where the work environment is more conducive for a faster rate of construction with a lesser incidence of defective work (Bell, 2009).

Table 6.7 : Summary of tests of Proposition 1

Sr. No.	Sub-proposition:	Acceptance Criteria	Observation	Conclusion
	Prefabrication is superior compared to traditional building system in terms of providing:			
1	Cost savings across building types (i.e. positive difference)	μ - t*s/sqrt(n) > 0	FALSE	Reject H_0
2	Cost savings across locations (i.e. positive difference)	μ - t*s/sqrt(n) > 0	TRUE	Accept H_0
3	Time savings across building types (i.e. positive difference)	μ - t*s/sqrt(n) > 0	TRUE	Accept H_0
4	Time savings across locations (i.e. positive difference)	μ - t*s/sqrt(n) > 0	TRUE	Accept H_0
5	Productivity improvement across building types (i.e. positive difference)	μ - t*s/sqrt(n) > 0	FALSE	Reject H_0
6	Productivity improvement across locations (i.e. positive difference)	μ - t*s/sqrt(n) > 0	TRUE	Accept H_0
		OVERALL	**FALSE**	**Reject H0; Accept HA**

While the finding that no statistical evidence exists to support significant positive benefits in cost savings and productivity improvement across building types is consistent with a number of studies, it is inconsistent with some other studies. For instance, while Page (2014) found a considerable amount of cost savings (45 percent), Lange (2013) argued that the use of the technology is more expensive for the capital development part of the total building life cycle costs. It should be noted that earlier studies did not rely on large sample sizes in their analyses and did not compare the results across buildings and locations. This shortcoming in the previous studies might have given rise to the conflicting reports about the potential benefits of the technology. Hence this study presents a more holistic picture and clears the ambiguities resulting from the lopsided view of the subject in the previous studies.

6.4 Test of Proposition 2

Proposition 2 assumed that 'building type' and 'location' are not the factors that have the most significant impact on the productivity benefits offered by the prefabrication technology. To test this proposition, the ratings of respondents in the questionnaire survey were analysed using the principal component analysis (PCA) form of factor analysis. The choice of this method of analysis was guided by the framework for choosing appropriate statistical technique for the data analysis modelled in Figure 3.5 and explained in detail in Section 3.7 of the Methodology Chapter.

The SPSS output of the result of the PCA analysis is presented in Table 5.4. The table shows that out of the 17 factors identified as the constructs that influence the added benefits of prefabrication, building type and location received the highest mean component weightings of 4.90 and 4.71, respectively. The least values of standard deviations computed by the SPSS for these two factors were also the least in the whole set of variables – 0.301 and 0.461 for building type and location, respectively. The small values of standard deviations for these variables – relative to the others – are indications of low variability and therefore high reliability and certainty in the result (Saunders et al., 2007).

On the basis of the above results, there is no empirical evidence to support proposition 2. It could therefore be concluded that 'building type' and 'location' are the objectively quantifiable factors that have the most significant impact on the productivity benefits prefabrication technology offers.

The finding that location has a profound influence on the added benefits of prefabrication for a building project is consistent with a number of studies. For instance, Langdon and Everest (2004) observed that Burgess et al. (2013) claimed that the benefits of prefabrication are mainly limited to the main cities (of New Zealand), with less than the desired results experienced in remote locations, ostensibly due to the uneconomic logistical issues, such as, the high transportation costs. One of the conclusions related to this is that prefabrication benefits could be maximised in situations where the site location does not present costly transportation and logistics arrangements since otherwise the benefits could be eroded and the use of the traditional building system may well be more economical in this circumstance.

The finding that building type has the most profound influence on the added benefits of prefabrication for a building project is also consistent with a number of studies. For instance, Langdon and Everest (2004) observed that prefabrication is more suited to high-rise buildings. This may be because the prefabrication benefits are optimised where the design and construction of the building permit replication of the components and elements on a sufficient scale that offers substantial economy. The conclusion in relation to this finding is therefore that the benefits of prefabrication can be maximised for buildings with simple designs and replication of walling, flooring and structural frames, such as, in industrial buildings, warehouses and retail shops. On the negative side, the benefits of prefabrication will be undermined if the technology is used for buildings with complex designs that do not have the flexibility for the replication of parts and components, for example, residential buildings for lifestyle living that involve highly bespoke designs, hotels and historic buildings. In these situations, the traditional building system may be more economical.

6.5 Test of Proposition 3

Proposition 3 assumed that the benefits of prefabrication technology analysed from the completed project records are not significantly different from those analysed from the feedback from industry stakeholders. The strategic importance of this proposition is to provide the opportunity to test the external construct validity of the study findings by comparing the benefits of prefabrication established in the case study with the corresponding benefits analysed from the feedback from the survey.

As discussed in Section 2.3.3 and modelled in Figure 2.3, the benefits of prefabrication that are the focus in this study are the objectively determinable or evidence-based added benefits of the technology which could be measured on the hard data interval or ratio scale. This contrasts with the subjectively determined benefits widely reported on in the literature that were measured on an ordinal or nominal scale.

The objectively determinable or evidence-based added benefits sourced from the project records in the case studies were the time and cost savings and the associated productivity improvement the technology offers over and above the corresponding benefits the traditional building system offers.

As shown in Figure 3.5, the Student t-test was found to be the most appropriate statistical technique to test this proposition, given the comparison of the means of groups of data, which the measurement scale was based on, utilizing the interval/ratio scale in both the case study data and survey ratings. The choice of this method of analysis was also guided by the framework for choosing the appropriate statistical technique for data analysis modelled in Figure 3.5 and explained in detail in Section 3.7 of the Methodology Chapter.

Essentially, the test involved examining whether or not the average values of time and cost savings and productivity improvement that were analysed from the survey ratings would fit into the value ranges established for these benefits in the case study results.

6.5.1 Hypothesis Testing Procedure

Prior to conducting the Student t-test, Proposition 3 was re-stated as a hypothesis to enable a statistical test of significance to be carried out at a confidence interval of 95 percent (i.e., at an alpha level of 5 percent). The associated null and alternative hypotheses to this effect are stated as follows:

The null hypothesis (Ho) assumed that the average values of the time and cost savings and the productivity improvements offered by prefabrication as analysed from the surveys would fit into their corresponding confidence interval ranges that were established in the case study results. The null hypothesis Ho could be broken into three subcomponents to test for the time savings, cost savings and productivity improvement using the following expressions:

$H_{o(Time)}$: $X - t*s/\sqrt{n} \leq X_s \leq X + t*s/\sqrt{n}$ Equation 6.7

Where:

$H_{o(Time)}$ = Null hypothesis for time savings

X = Average value of time saving established in the case study results

t = Student T-test statistic computed for the time saving data of the case study projects

s = Standard deviation computed for the time saving data of the case study projects

n = Number of data points involved in the case study data analysis.

X_s = Average value of time saving analysed from the survey ratings

Similar expressions for the cost savings and productivity improvement are as follows:

$H_{o(Cost)}$: $X - t*s/\sqrt{n} \leq X_s \leq X + t*s/\sqrt{n}$ Equation 6.8

$H_{o(Productivity)}$: $X - t*s/\sqrt{n} \leq X_s \leq X + t*s/\sqrt{n}$ Equation 6.9

Where:

$H_{o(Cost)}$: = Null hypothesis for cost savings

$H_{o(Productivity)}$ = Null hypothesis for productivity improvement

To enable sub-component testing, Proposition 3 was split into three for cost saving, time saving and productivity improvement in the following subsections.

6.5.2 Sub-proposition 3.1: Cost Savings

The null hypothesis (Ho) for this sub-proposition assumed that the average values of the cost savings offered by prefabrication as analysed from the surveys would fit into their corresponding confidence interval ranges established in the case study results. The results of the analysis of the case study and the survey data results in relation to this hypothesis testing are presented in Table 6.8. To enable a better visual appreciation of the results, Figure 6.1 presents the graphical plots of the fit of the average cost savings analysed from the survey responses within the upper and lower confidence interval (CI) values of the cost savings analysed from the case study.

Table 6.8 : Comparison of cost savings benefits analysed from case studies and survey feedback

Building type:	**Commercial Buildings**	**Community Buildings**	**Educational Buildings**	**Houses**	**Apartment**
Case study analysis:					
Average Cost Savings	18.63	30.32	21.55	13.40	21.25
t-value:	4.2	5.95	11.7	5.5	7.3
Maximum Cost Saving Value	29.00	45.11	50.66	26.94	39.31
Minimum Cost Saving Value	8.27	15.54	-7.55	-0.15	3.19
Survey Analysis:					
Average Cost Savings	21.80	23.20	22.90	21.40	21.80
Result: Survey Average versus Case Study Interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval

Results in Table 6.8 and Figure 6.1 show that the added benefits of prefabrication in terms of the average percentage cost savings analysed from the survey responses fitted within the upper and lower confidence intervals of the case study results. There is therefore no statistical evidence for not accepting this null hypothesis for this sub-proposition.

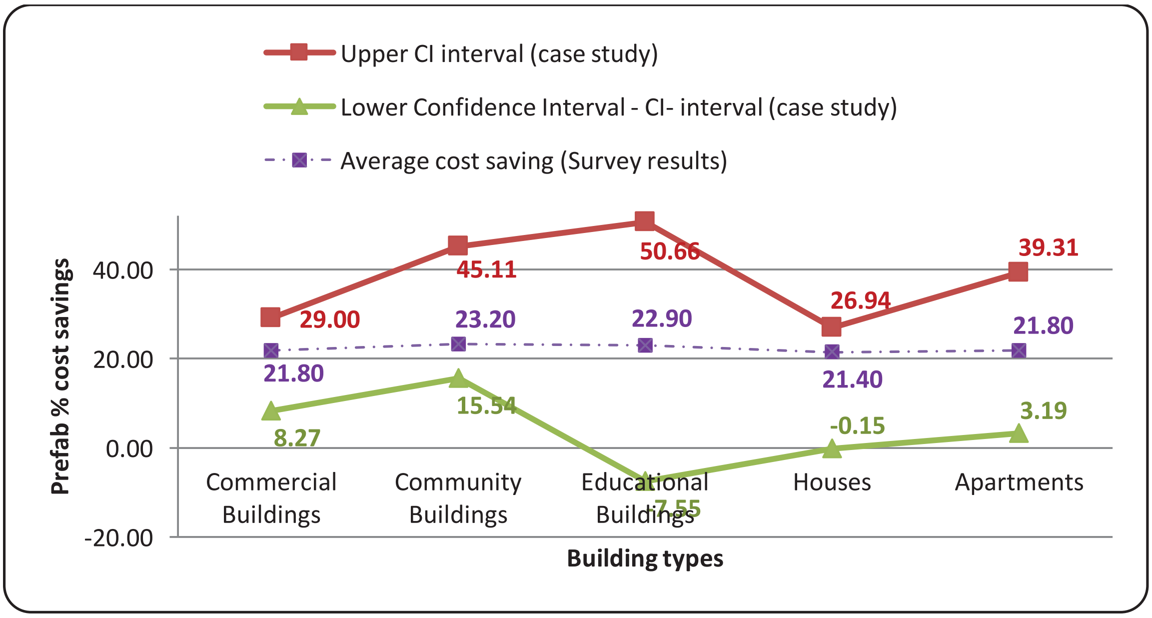

Figure 6.1: Visual check of fit of average survey cost saving benefits within the confidence intervals of case study average results

6.5.3 Sub-proposition 3.2: Time Savings

The null hypothesis (Ho) for this sub-proposition assumed that the average values of the time savings offered by prefabrication as analysed from the surveys would fit into their corresponding confidence interval ranges established in the case study results. The results of the analysis of the case study and survey data results in relation to this hypothesis testing are presented in Table 6.9. Again, to enable a better visual appreciation of the results, Figure 6.2 presents the graphical plots of the fit of the average time savings analysed from the survey responses within the upper and lower confidence interval (CI) values of the time savings analysed from the case study.

Results in Table 6.9 and Figure 6.2 show that added benefits from prefabrication in terms of average percentage time savings analysed from the survey responses fitted within the upper and lower confidence intervals of the case study results. Hence, there is no statistical evidence for not accepting this null hypothesis for this sub-proposition. It could then be concluded that there is an additional source of evidence confirming the added benefits of prefabrication in terms of cost savings.

Table 6.9 : Comparison of time savings benefits analysed from case studies and survey feedback

Building Type	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartment
Case study analysis:					
Average Time Savings	45.39	44.95	41.47	65.22	36.82
t-value:	10.4	10.80	6.1	10.9	10.3
Maximum Value	71.25	71.79	56.65	92.36	62.41
Minimum Value	19.53	18.11	26.29	38.07	11.23
Survey Analysis:					
Average Cost Savings	42.50	46.60	45.40	46.90	44.70
Result: Survey Average Versus Case Study Interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval

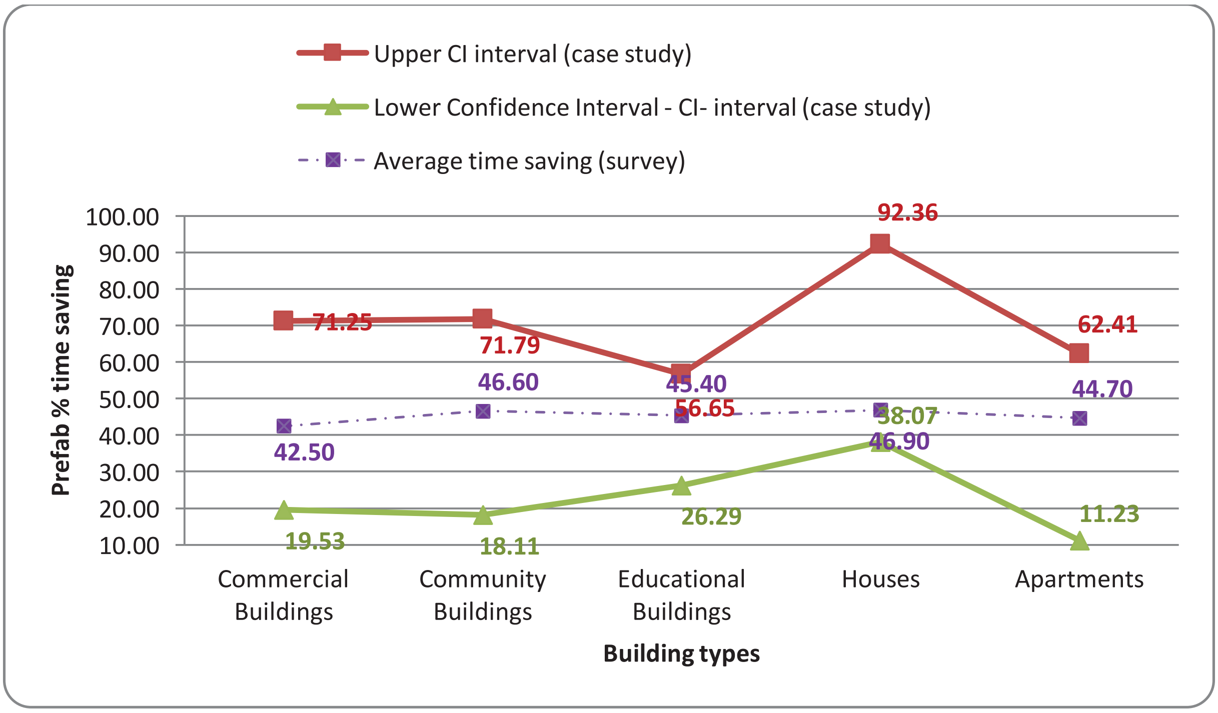

Figure 6.2 : Visual check of fit of average survey time saving benefits within the confidence intervals of case study average results

6.5.4 Sub-proposition 3.3: Productivity Improvement

The null hypothesis (Ho) for this sub-proposition assumed that the average values of the productivity improvement offered by prefabrication as analysed from the surveys would fit into their corresponding confidence interval ranges established in the case study results. The results of the analysis of the case study and survey data results in relation to this hypothesis testing are presented in Table 6.10. As shown previously, to enable better visual appreciation of the results, Figure 6.3 presents the graphical plots of the fit of the average productivity improvement analysed from the survey responses within the upper and lower confidence interval (CI) values of the corresponding values analysed from the case study.

Table 6.10: Comparison of productivity improvement benefits analysed from case studies and survey feedback

Building Type	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartment
Case study analysis:					
t-value	3.2	6.59	5.9	3.1	6.6
Maximum Value	15.32	28.33	21.09	14.80	23.23
Minimum Value	2.42	1.60	-3.02	2.20	-3.68
Survey Analysis:					
Average Productivity Improvement	7.80	8.40	8.20	8.40	8.00
Result: Survey Average Versus Case Study Interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval

The results in Table 6.10 and Figure 6.3 show that the added benefits from prefabrication in terms of average productivity improvement analysed from the survey responses fitted within the upper and lower confidence intervals of the case study results. Hence, no statistical evidence for not accepting this null hypothesis for this sub-proposition. It could then be concluded that there is an additional source of evidence confirming the added benefits of prefabrication in terms of productivity improvement across building types.

6.5.5 Conclusion on Test of Proposition 3

Table 6.11 presents the summarised results of the tests of the three subcomponents of Proposition 3. The table shows that all the criteria for accepting the null hypotheses relating to the three subcomponents of Proposition 3 were satisfied. Therefore, the overall conclusion was to accept the proposition as being true as initially formulated.

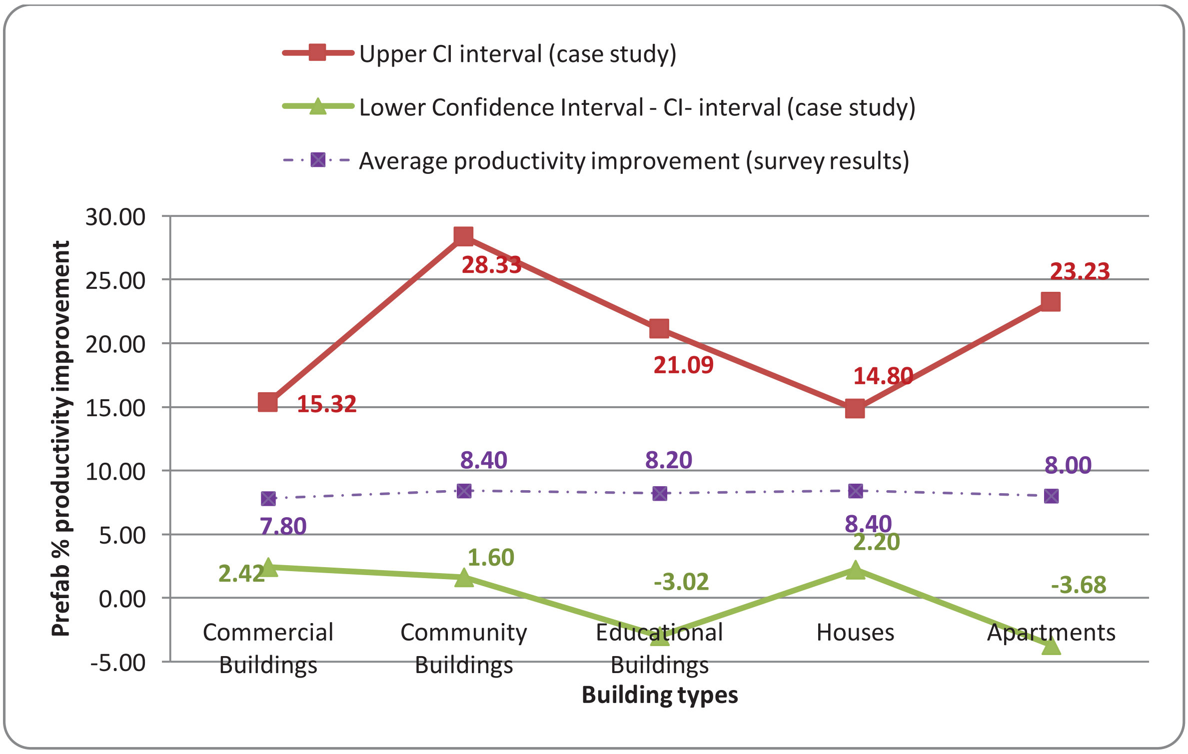

Figure 6.3 : Visual check of fit of average survey productivity improvement benefits within the confidence intervals of case study average results

Overall, the results of the Proposition 3 testing suggest that the benefits of prefabrication technology analysed from the case study building projects are not significantly different from those analysed from industry surveys in relation to cost and time savings as well as productivity improvements.

Table 6.11: Summary of tests of Proposition 3

Sr. No.	Proposition 3: Benefits of prefabrication technology analysed from case study building projects are not significantly different from those analysed from industry survey			
	Sub-Proposition:	**Acceptance Criteria**	**Observation**	**Conclusion**
1	Cost savings	$X - t^*s/\sqrt{n} \leq X_s \leq X + t^*s/\sqrt{n}$	TRUE	Accept H_0
2	Time savings	$X - t^*s/\sqrt{n} \leq X_s \leq X + t^*s/\sqrt{n}$	TRUE	Accept H_0
3	Productivity Improvement	$X - t^*s/\sqrt{n} \leq X_s \leq X + t^*s/\sqrt{n}$	TRUE	Accept H_0
		OVERALL	**TRUE**	**Accept H_0**

It could then be concluded that there is an additional source of statistical evidence confirming the added benefits of prefabrication from different perspectives. This satisfies the external validity construct requirement for the reliability and validity of the research results (Cooper and Emroy., 2009, Patton, 2003). However, the results are not inconsistent with some studies which have found that the use of the technology holds benefits for time savings and productivity improvement but not for cost savings. For instance, Goulding (2015) argued that the use of the prefabrication technology is more expensive for the capital development part of the total building life cycle costs. Since Goulding's (2015) conclusion was based on a limited sample size and did not involve rigorous statistical tests of significance his conclusion might be fraught with reliability and validity issues.

6.6 Generic Reliability and Validity Tests

In addition to the reliability and validity tests carried out under the tests of propositions in sections 6.3 to 6.5, further generic tests were carried out to satisfy the reliability and validity criteria for the research design, test instruments and overall findings of the study. These tests were discussed in section 3.12 as they apply to the study. In the following subsection the detailed test of internal consistency form of reliability involving Cronbach's Alpha is presented.

6.6.1 Test of Internal Consistency

As discussed in section 3.12, the internal consistency form of reliability uses only one test to assess consistency or homogeneity among items (Zikmund, 2012). Furthermore, IBM (2014) stated that Cronbach's Alpha is an estimate of the internal consistency associated with the scores that can be derived from a scale or composite score. IBM (2014) further noted that reliability is important because in the absence of reliability, it is impossible to associate any validity or reliability to any scale or composite score. Gliem and Gliem (2003) argued that the Cronbach's Alpha test helps to determine whether or not it is justifiable to interpret scores that have been aggregated together.

Consequently, Cronbach's Alpha was used in the data analysis to test the internal consistency of the scale (or applicable variables) for the purpose of determining the significant constructs or factors that influence the benefits prefabrication offers over and above those of the traditional building system.

The Cronbach's Alpha test was applied at two levels: at the composite or group level, and at the segregated or individual item level.

6.6.1.1 Internal Consistency at Composite Level

At the composite or group level, the Cronbach's Alpha helped to determine the overall internal consistency (or reliability) of the set of variables identified as influential factors. Foxcroft et al. (2013) advised that Cronbach's Alpha value of 0.7 is the benchmark for evaluating whether or not there was internal consistency and reliability in the scale used. Even so, there is no statistical evidence to support the use of Cronbach's Alpha value of 0.7 as a benchmark for evaluating whether or not internal consistency and reliability exist in the scale used. IBM (2014) recommends the use of the Chi Square-based f-test of significance for this purpose.

The SPSS output of the Cronbach's Alpha test of internal consistency result at the composite score level is presented in Table 6.12. The table shows an overall Cronbach's Alpha coefficient of 0.977, which is an indication of the overall internal consistency or ability of the 17 factors to reliably and consistently measure the quantitative amount of prefabrication added benefits.

Table 6.12: SPSS Reliability Statistics output for Cronbach's Alpha tests

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	No. of Items
.977	.977	17

To test the level of significance associated with the Cronbach's Alpha coefficient value of 0.977, a parallel SPSS ANOVA-based test of significance was conducted using the Chi Square f test statistic. The test involved a formulation of the following hypotheses:

Table 6.13: SPSS ANOVA table output for test of significance of Cronbach's Alpha coefficient result

		Sum of Squares	df	Mean Square	F	Level of Significance (PV)
Between Group		153.264	30	5.109		
Within Group	Between Items	159.837	16	9.990	83.285	.0002
	Residual	57.575	480	.120		
	Total	217.412	496	.438		
	Total	370.676	526	.705		

The null hypothesis assumed that the 17 items of scale for measuring the benefits of prefabrication are not measuring what they are supposed to measure. To explain it in another way, the hypothesis assumed that no significant consistency or homogeneity exists among the items that measure a particular construct – in this case, the benefits of prefabrication. Expressions of the null hypothesis (H_0) and the corresponding alternative hypothesis (HA) for the purpose of conducting statistical test of significance are provided as follows:

H0: $PV_{\text{F-test statics}} > 0.05$ Equation 6.10

HA: $PV_{\text{F-test statics}} \leq 0.05$ Equation 6.11

Where:

$PV_{\text{F-test statics}}$ = Probability value (PV) of the Chi Square f-test statistic computed from the characteristics of the dataset

0.05 = Alpha value of the test

The result of the statistical test of significance in Table 6.13 shows that the level of significance or the probability value (PV) achieved was 0.002. This is significant since it is less than 0.05 – the alpha value of the test (IBM, 2014).

On the basis of this result, it was therefore concluded that no statistical evidence exists to support the null hypothesis. The alternative hypothesis was therefore accepted which assumed that significant consistency or homogeneity exists among the 17 items or constructs that measure the benefits of prefabrication.

Table 6.14: SPSS Item-Total Statistics showing influence of underlying prefabrication benefit factors on initial Cronbach's Alpha value

Factors	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Building Type	61.97	84.966	.324	.380
Location	62.16	81.540	.612	.560
Prefabrication Type	62.32	79.426	.795	.976
Contract Type	63.48	76.925	.885	.974
Procurement Type	63.26	74.865	.927	.974
Standardisation / Customisation	62.48	78.791	.889	.975
Logistics	62.29	79.746	.765	.976
Scale/Repeatability	62.45	78.723	.885	.975
Subsoil Proportion	63.84	72.673	.899	.975
Weather Condition	63.48	77.791	.888	.975
Whole of life Quality	63.26	74.865	.927	.974
Site Conditions	63.35	75.570	.920	.974
Site Layout	63.35	73.703	.897	.974
Environmental Impact	63.06	73.596	.929	.974
Project Leadership	63.19	72.695	.949	.974
Client nature	63.39	74.378	.896	.974
Contractor's Innovation	62.58	79.518	.865	.975

6.6.1.2 Internal Consistency at Individual Item Level

At the individual item level, Cronbach's Alpha score helps to identify those variables in the dataset, which should be removed to improve the internal consistency or reliability of the overall scale measure. Foxcroft et al. (2013) advised that this screening process can be carried out by examining those variables which resulted in lower Cronbach's Alpha value than the initial score obtained for the overall measure.

Table 6.14 presents the SPSS item total statistics output showing individual items' (i.e., the underlying prefabrication benefit factors') influences on the initial Cronbach's Alpha value output (see Table 6.12).

The table shows that none of the 17 factors improved the initial Cronbach's Alpha value 0.977 when deleted in the iterated analysis.

The above results suggested that each of the 17 factors contributed in a unique way in determining the prefabrication benefits and so should be retained in the set as significantly influential factors. From the reliability and validity point of view, there is statistical evidence to suggest that the 17 factors were all measuring the same construct – i.e., the prefabrication benefits and therefore provide evidence of the internal consistency form of reliability for the scale of measurement adopted and the findings.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 Overview

This concluding chapter summarises the key findings of the research in relation to the objectives and presents the findings and implications thereof with respect to industry and practice and the key contributions to the overall knowledge. Recommendations are put forward for the benefit of clients, design consultants, contractors, prefabrication manufacturers and policy makers and regulators of the construction industry. Areas for further investigations are also recommended. In addition, the limitations of the study are highlighted in relation to the ability of the findings to be generalised beyond the scope of the research. The chapter ends by highlighting the key findings of the study to be provided to the respondents who participated in the surveys.

7.2 Findings in Relation to the Research Objectives

The primary focus of this research study has been to analyse cost savings, time- savings, and the productivity improvement achievable with the use of panelised/framed prefabrication in place of the alternative traditional building system. The following sub-sections summarise the findings as previously discussed in earlier chapters.

7.2.1 Cost Saving, Time Saving and Productivity Improvement: Case Study Results

The first objective of the study has been to quantify the benefits that panelised prefabrication technology can offer in terms of cost savings, time savings and productivity improvements, over and above the corresponding benefits achievable with the use of traditional building system. The results are discussed in the following sub-sections.

7.2.1.1 Cost Savings

In relation to cost savings, the results show that using prefabrication in place of the traditional building system resulted in an average 21 percent cost savings in the five building types investigated in the case studies. This result was not significantly different across the three major cities delineated for the study - Auckland, Christchurch and Wellington. The results further showed that of the five building types, for community building projects, maximum cost saving of 30 percent was observed. The least cost savings of 13.4 percent were observed in the isolated house types of residential building projects. And 21.5 percent, 21.3 percent and 18.6 percent cost savings was observed for educational, apartment and commercial building projects, respectively.

Overall, the findings of this study show a reasonable reduction in the project completion costs by the use of prefabrication technology in place of traditional building system. This provides the basis to acknowledge ‘cost savings’ associated with the use of prefabrication technology as a key benefit of this system.

7.2.1.2 Time Savings

In regard to time savings, the results showed that using prefabrication in place of the traditional building system resulted in an average of a 47 percent saving in completion times for the five building types investigated in the case studies. This result was also not significantly different across the three major cities delineated for the study - Auckland, Christchurch and Wellington. Comparatively, a maximum time savings of 65 percent was observed for housing projects. On the other hand, apartment buildings offered the least time savings of 37 percent. The time savings for the other building types are as follows: Commercial buildings (45 percent), community buildings (45 percent) and educational buildings (41 percent).

The findings of this study clinches ‘time saving’ as an important benefit of prefabrication technology that can stimulate the improved uptake of this technology. The fact that prefabrication takes the bulk of the construction activities from construction sites to factory-controlled environments was among the most cited reasons for the superior time saving benefits of the prefabrication system.

7.2.1.3 Productivity Improvement

The results related to productivity improvement showed that, when used in place of traditional building system, prefabrication can offer an average of 10 percent improvement in productivity in the five building types investigated in the study and across the three New Zealand cities. The highest productivity improvement value of 15 percent was observed for community building projects while the least productivity improvement of 8.5 percent was observed for housing projects. The productivity improvement values for the other projects were 9.8 percent (for apartments), 9.03 percent (for educational), and 8.9 percent (for commercial building projects).

The above productivity improvement results are very encouraging. The most frequently mentioned reasons for the superior productivity improvement benefits of prefabrication included just-in-time procurement, safer working conditions and reduced need of skilled labour (Hamilton, 2007, Winter et al., 2006).

7.2.2 Factors Influencing Prefabrication Benefits: Survey Results

The second objective of the study was to identify and prioritise the factors that can significantly influence the benefits that are achievable by the use of prefabrication technology.

Accomplishing this objective was one of the principal aims of the qualitative pilot study and quantitative industry survey. Seventeen factors were identified at the pilot study phase. Respondents’ ratings regarding the relative influences of the identified factors were analysed using SPSS factor analysis.

Results showed that all 17 factors were rated moderate to a very high influence on the 5-point Likert rating scale used. No factor was rated low or very low. Additional factors supplied by the respondents in the open-ended section of the questionnaire were found to be rewordings of the factors already included in the list. This means during the survey no new factors were suggested.

Of the 17 factors, three rated 'moderate' in influence and contract type occupied the top of this group. Seven factors were rated 'high' in terms of their influence, with environmental impact topping the list. Factors with a 'very high' influence rating comprised building type and location as the most influential of all of the 17 factors. The lowest standard deviations associated with these two factors relative to the others showed that the respondents were more consistent in their ratings than for the others. This indicated a strong consensus among the respondents concerning the high influence of these factors on the potential benefits prefabrication offers.

Building type as the most influential factor means that the amount of benefit the technology can offer could vary significantly depending on the type of building. This survey finding is consistent with the results of case studies, which showed variation in cost savings, time savings and productivity improvement across the five different building categories investigated in this research. This however is in contrast with a number of previous studies (Hamilton, 2007; Lusby et al. 2004) that reported prefabrication benefits across the board without qualifying the benefits in relation to the purpose group of the building.

Location as the second most influential factor on potential prefabrication benefits is understandable and is in agreement with the popular buzzword in the property circle that the three most important underpinnings of the attractiveness and value of a residential property value are 'location', 'location' and 'location'. In a previous study, Burgess et al. (2013) noted their expectation that the benefits of prefabrication might mainly be limited to seven main cities in New Zealand including: Auckland, Christchurch, Dunedin, Hamilton, Napier, Tauranga and Wellington. Together with the third most influential factor – logistics, location impacts heavily on the potential benefits of prefabrication technology, depending on the distance between the construction site and the prefabrication factory site, as well as the logistics and other challenges involved in transporting the prefabricated components. Factors like cost of transportation, traffic challenges and risks of delay in supply make the use of prefabrication a less preferred alternative to the traditional construction method in remote areas.

The type of prefabrication is also listed as having a very high influence on the prefabrication benefits. This is because, for instance modular prefabrication is more suitable for high-rise buildings then a residential house due to the economies of scale. Similarly, whole building prefabrication is most suitable for motels and portable buildings.

7.2.3 Reliability and Validity of Research Outcomes

The third objective of this study was to examine how the benefits analysed from case studies of completed project records compared to survey results that involved feedback from industry stakeholders.

Achieving this objective required the use of the Student t-test to examine whether or not the average values of time and cost savings and productivity improvement analysed from the survey ratings would fit into the confidence interval value ranges established for these benefits in the case study results. The results showed no significant differences between the time and cost savings and productivity improvement values analysed from the case studies and the survey feedback. There was therefore empirical evidence to support the reliability and validity of the research findings based on the external construct validity test results. It could also be concluded that the findings of the study could be generalised beyond the study scope to wider settings.

7.3 Key Contributions to Knowledge

Given the lack of quantitative evidence in relation to the benefits associated with the use of panelised prefabrication technology in New Zealand (Scofield et al., 2009b), clients and designers are reluctant to invest in the technology merely on the basis of anecdotal benefits

(Bell, 2009). To fill this knowledge gap, this study has provided statistical empirical evidence on the quantitative benefits of the technology that clients need to justify investment outlay in the adoption of the technology.

In addition, this study has contributed to the body of existing knowledge by deepening the literature related to the productivity performance of panelised prefabrication technology, for the benefit of future research in this and related subject areas.

Specifically the contributions of this research to the existing knowledge are as follows:

1. The study helps in improving the understanding of prefabrication technology and associated perceptions about the benefits achievable with the use of panelised prefabrication technology in terms of cost savings, time savings and productivity improvement.
2. The research provided information to construction industry stakeholders, i.e., clients, consultants and contractors on approximately how much money and time they can save by choosing panelised prefabrication in place of traditional building system for certain building types.
3. The research has enhanced in the understanding of the concept of project level productivity in the construction process and how the productivity performance of the construction project is computed.
4. The study serves to enrich the knowledge of construction industry practitioners especially the consultants involved in project planning and design, regarding various factors that can significantly influence the level of benefits achievable with the use of panelised prefabrication technology in place of traditional building system.
5. Overall, the methodology developed in this study could be replicated for studying related phenomena in the industry, especially in the investigation of the cost and time saving and resulting productivity improvement that can be achieved by the application of other types of prefabrication across building types and locations.

7.4 Benefits of the Research Findings to Key Industry Stakeholders

The following are some of the key benefits of the research findings to the clients, design consultants, contractors, prefabrication suppliers and policy makers and regulators in the construction industry with respect to panelised prefabrication technology use/applications for optimal outcomes.

7.4.1 Benefits and Recommendations to Clients

The study has provided evidence-based quantitative benefits related to the use of panelised prefabrication technology in place of the traditional building system. The lack of information on prefabrication technology has caused clients to view the anecdotal evidence presented in the literature with suspicion. Based on the research findings, clients have statistical evidence of the cost savings, time savings and overall productivity improvement they could achieve in their projects by choosing panelised prefabrication in place of the traditional building system.

It is expected that this will ensure greater uptake of the technology and hence improved productivity performance of the construction industry overall. Findings in relation to building types suited for optimal outcome could guide clients to maximise returns on investment by targeting those building types that have highest values of cost and time savings, especially community buildings (for highest cost savings and productivity improvement), and isolated houses (for highest time savings).

7.4.2 Benefits to Designers

Design consultants are often consulted to provide professional advice to clients about which type of building technology to use for the implementation of a particular building project (Yau, 2006). Lack of empirical evidence on the superior benefits of prefabrication over the traditional building system may have encouraged the designers to stick to the traditional building system (Bell, 2009, Scofield et al., 2009b). The findings of this study will guide design consultants to provide reliable advice in this regard. Perhaps, this could see increased panelised prefabrication-based design solutions and specifications and less of the traditional building system which have been known to be fraught with several faults and inefficiencies (Gibb and Isack, 2003).

7.4.3 Benefits to Contractors

Completing projects on time, within budget and to quality targets is the key project goal of contractors. Delay in completion time incurs a financial liability and could result in the contractor being 'black-listed' from a client's future job plan. Prefabrication technology enables a contractor to achieve the three key project objectives more cost-effectively than could be achieved utilising the traditional building system. The findings of this study could guide the contractor to effectively deploy the panelised/framed prefabrication method in ways that can optimise the contractor's profit in a job, especially in relation to design-and-build procurements where the contractor is in full control of the decisions and choice of design and construction process.

7.4.4 Benefits to Prefabrication Suppliers

Prefabrication manufacturers and suppliers are at the forefront of the marketing and publicity strategies required to improve the uptake of prefabrication technology in the industry. In terms of the lack of evidence-based benefits of prefabrication, it is limiting the size of their businesses. The research findings offer the necessary empirical evidence of the quantifiable benefits of the technology, and hence will assist prefabrication suppliers to market their products with confidence.

7.4.5 Benefits to Policy Makers and Regulators

Policy and regulatory frameworks affect all facets of the construction industry. Policy makers and regulators within the New Zealand construction industry, such as, the Councils, lack empirical evidence regarding the benefits of prefabrication to formulate policies and initiatives that could drive the uptake of the technology within the public sector, as well as enable sustainable prefabrication operations in the private sector. The findings of this study provide the empirical evidence needed for the formulation of enabling policies and regulations around the design, specifications, construction, inspections and certification of prefabrication works.

7.5 Limitations and Recommendations for Future Research

The following comprise the key limitations of this study and recommendations put forward to remedy them in future research:

1. Scope of investigations: The case study projects were limited to five building types: Commercial, community, educational, apartments and houses. The rationale for the choice of these projects was on the basis that they were the most frequently procured buildings in New Zealand (Statistics, 2014). However, there are 10 building types as discussed in section 3.9.2 of Chapter 3. While it is expected that the findings of this study would cover the issues relating to the subject matter, further investigations are required for other building types including: industrial, healthcare, recreational, agricultural and hospitality buildings to gain a more holistic perspective on the issues.

2. Scope of coverage: 151 projects were investigated in the case studies. Although this number may be good for a qualitative study, it may not suffice to represent the majority of building projects in New Zealand.

3. Other prefabrication types: As discussed in section 2.3.2 of Chapter 2, there are five types of prefabrication. These include: componentized, panelised/framed, modular, hybrid and whole building types (Bell and Southcombe, 2012). This study focused on the most popular type of prefabrication used in New Zealand – the panelised/framed (Page and Norman, 2014). The results of the principal component analysis carried out in this research showed that prefabrication type could influence the prefabrication benefits, even though not to the extent of influence credited to building type and location. Moreover, to gain a holistic perspective on the true benefits of prefabrication, further research should focus on investigating the

benefits achievable by the use of other prefabrication types. The methodology developed in this study presents a framework for such investigation.

4. The study focused on the productivity improvement and the cost saving and time saving associated with the use of prefabrication. Other benefits of prefabrication include improved quality, reduced wastage and environmental sustainability (Bell, 2009), and improved onsite safety (Gibb, 1999). This study could not extend to assessing these other benefits because of the lack of available records. Further research is required to explore the qualitative and quantitative benefits of prefabrication related to these other aspects.

5. With respect to the absence of sufficient private sector clients' input, no formal organization exists for private sector construction clients in New Zealand. The Construction Clients Group (CCG) comprises a wide array of industry stakeholders and a few private sector clients. Since clients make the initial decisions about the preferred design, construction method and material specifications, further research should be targeted to canvass their input on the subject since this will help to gain deeper understanding about clients' preferences in relation to prefabrication matters.

6. The proportion of the value of prefabrication components compared to the overall value of a project could have some influence on the observed prefabrication benefits. This aspect was not covered in the investigations carried out in this study due to lack of records. Further investigations are recommended to explore the impact of the ratio of prefabrication in comparison to the overall project cost and the effect it has on the observed benefits.

7.6 Summary of Key Research Findings

Key findings in relation to the research objectives are summarised in the following section. These will be provided to the study participants in order to honour the promise of making this information available as an incentive for their time and valuable contributions to the research.

7.6.1 Findings in Relation to the First Objective

The first objective of the study was to identify the benefits that panelised prefabrication technology is able to offer in terms of cost savings, time savings and productivity improvements, over and above the corresponding benefits achievable from the use of the traditional building system. Results in relation to cost savings showed that using prefabrication in place of the traditional building system resulted in an average of 21 percent cost savings for five building types investigated across the three major cities delineated for the study, namely, Auckland, Christchurch and Wellington. Similarly results showed an average of a 47 percent savings in project completion times in relation to the case study buildings investigated. Further results related to productivity improvement showed that, when used in place of the traditional building system, prefabrication is able to offer an average of a 10 percent improvement in project productivity.

7.6.2 Findings in Relation to the Second Objective

The second objective of the study was to identify and prioritise the factors that can significantly influence the benefits that are achievable by the use of prefabrication technology. While the results show that 'building type' and 'location' are the most significant factors that influence the benefits that are achievable by the use of prefabrication, 'sub-soil proportion' is the least influential factor. Other factors that influence the benefits of prefabrication include: logistics, type of prefabrication, scale/repeatability, standardisation, contractor's level of innovation, environmental impact, project leadership, type of procurement, whole of life quality, site conditions, site layout and client's nature.

7.6.3 Findings in Relation to the Third Objective

The third objective of this study was to examine how the benefits analysed from the case studies of the completed project records compared to those from the industry stakeholders' feedback. The results showed that there is no significant difference between the time and cost savings and productivity improvement values as analysed from the case studies of the building projects and the survey feedback.

Table 7.1: Summary of Prefabrication benefits

Building Type	Cost Savings		Time Savings		Productivity Improvement	
	Obtained from Case Studies	Obtained from Survey	Obtained from Case Studies	Obtained from Survey	Obtained from Case Studies	Obtained from Survey
Commercial	18.36%	21.80%	45.39%	42.50%	8.87%	7.8%
Community	30.32%	23.20%	44.95%	46.60%	14.97%	8.4%
Educational	21.55%	22.90%	41.47%	45.40%	9.03%	8.2%
Houses	13.40%	21.40%	65.22%	46.90%	8.5%	8.4%
Apartments	21.25%	21.80%	37.82%	44.70%	9.77%	8%

The results obtained from the case studies and the industry survey related to cost saving, time saving and productivity improvement achievable with the use of prefabrication technology are summarised in table 7.1.

7.7 Framework for Practical Application of Findings in the Industry

A framework for practical application of the findings of this study is presented in Figure 7.1.

The figure shows that three key decisions are needed to be made which require evidence-based inputs provided by the study findings: Decisions on the key quantitative project objectives – cost, time and productivity targets; decision on the building type, and decision on the location for the project. Information on the added value to the design solutions which could be achieved by using prefabrication in place of traditional building system (TBS) is provided by navigating through the decision tree following the pathways presented by the options under each of the three key decision criteria – key project targets, building type and location – and reading the associated empirical finding off the Results row.

To illustrate the application of the above decision-tree model, assuming a client is interested in knowing the quantitative added value she could achieve in relation to time targets by using prefab in place of the traditional building system; if her building type is Commercial and the location is Auckland, the green pathway points to 37% time saving which could be read off the Results row. Using this approach the cost savings and productivity improvement for this type of building in Auckland could also be read off as 23% and 9%, respectively. This way, the client can decide whether or not the quantitative added benefit is sufficient to justify making a decision on the use of prefab in place of the traditional building system.

It should be noted that the framework covers decisions relating to five building types and three locations. The five building types were chosen due to their popularity and their representative nature among various building types. Also the three locations were chosen for the same reason. For other building types, it is suggested that the decision maker should use the information for one of the five building types that closely resemble the other building type in question. For instance, information about the health care project could be based on the data for education building project which is the closest match (Nadim and Goulding, 2009). The same goes for other location. For instance, information about projects located in Hamilton could be based on the Auckland data; the decision-maker may apply a subjective factor that could take care of the expected variations between Auckland and Hamilton conditions.

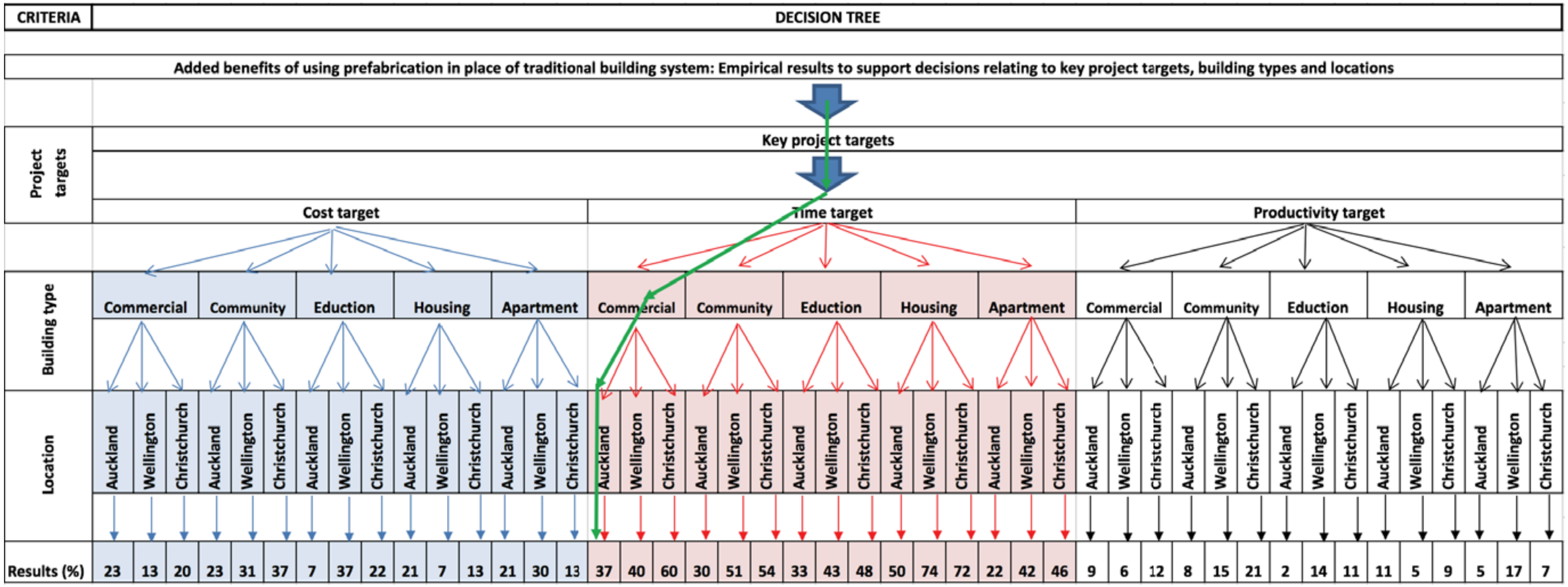

Figure 7.1: Decision tree framework for practical application of findings in support of decisions relating to key project targets, building types and locations

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APPENDICES

Appendix A: Low Risk Notification

MASSEY UNIVERSITY
ALBANY

6 March 2013

Wajiha Shahzad
1-43 Woodward Rd
Mt Albert
AUCKLAND 1025

Dear **Wajiha**

Re: Comparative analysis of the productivity levels achieved through the use of prefab systems with those of traditional construction methods

Thank you for your Low Risk Notification which was received on 11 January 2013.

Your project has been recorded on the Low Risk Database which is reported in the Annual Report of the Massey University Human Ethics Committees.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis that it is safe to proceed without approval by one of the University's Human Ethics Committees.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

A reminder to include the following statement on all public documents:

> *"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.*
>
> *If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director (Research Ethics), telephone 06 350 5249, e-mail humanethics@massey.ac.nz".*

Please note that if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to provide a full application to one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

J. O'Neill

John G O'Neill (Professor)
Chair, Human Ethics Chairs' Committee and
Director (Research Ethics)

Te Kunenga ki Pūrehuroa
Research Ethics Office
Private Bag 102 904, Auckland, 0745, New Zealand Telephone +64 9 414 0800 ex 9539 humanethicsnorth@massey.ac.nz

cc Dr Jasper Mbachu
School of Engineering & Advanced Technology
Albany

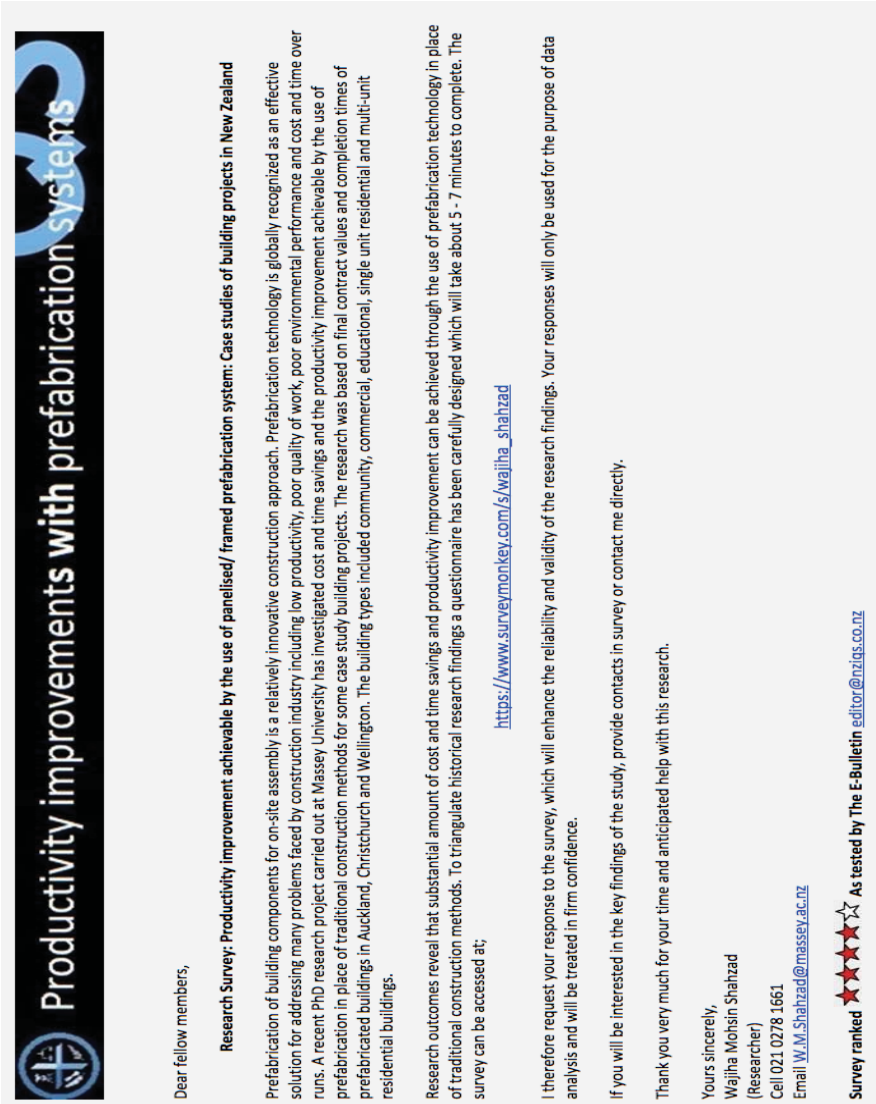
Prof D Cleland, HoS
Manawatu campus

Te Kunenga
ki Pūrehuroa

Research Ethics Office
Private Bag 102 904, Auckland, 0745, New Zealand Telephone +64 9 414 0800 ex 9539 humanethicsnorth@massey.ac.nz

Appendix B: Newsletters

Appendix B1 (NZIQS Newsletter)


Productivity improvements with prefabrication systems

Dear fellow members,

Research Survey: Productivity improvement achievable by the use of panelised/ framed prefabrication system: Case studies of building projects in New Zealand

Prefabrication of building components for on-site assembly is a relatively innovative construction approach. Prefabrication technology is globally recognized as an effective solution for addressing many problems faced by construction industry including low productivity, poor quality of work, poor environmental performance and cost and time over runs. A recent PhD research project carried out at Massey University has investigated cost and time savings and the productivity improvement achievable by the use of prefabrication in place of traditional construction methods for some case study building projects. The research was based on final contract values and completion times of prefabricated buildings in Auckland, Christchurch and Wellington. The building types included community, commercial, educational, single unit residential and multi-unit residential buildings.

Research outcomes reveal that substantial amount of cost and time savings and productivity improvement can be achieved through the use of prefabrication technology in place of traditional construction methods. To triangulate historical research findings a questionnaire has been carefully designed which will take about 5 - 7 minutes to complete. The survey can be accessed at;

https://www.surveymonkey.com/s/wajiha_shahzad

I therefore request your response to the survey, which will enhance the reliability and validity of the research findings. Your responses will only be used for the purpose of data analysis and will be treated in firm confidence.

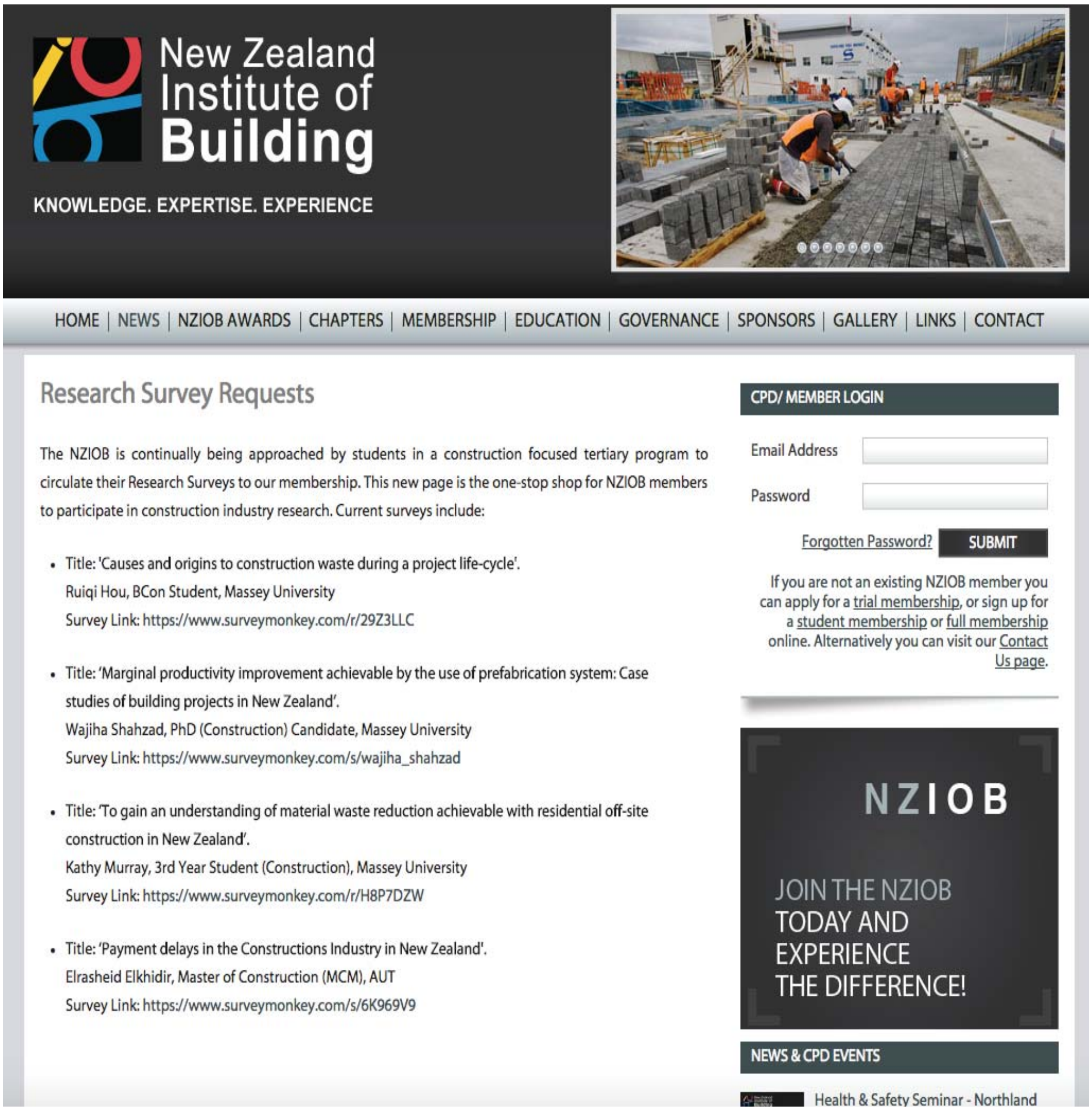
If you will be interested in the key findings of the study, provide contacts in survey or contact me directly.

Thank you very much for your time and anticipated help with this research.

Yours sincerely,
Wajiha Mohsin Shahzad
(Researcher)
Cell 021 0278 1661
Email W.M.Shahzad@massey.ac.nz

Survey ranked ★★★★☆ As tested by The E-Bulletin editor@nziqs.co.nz

Appendix B2 (NZIOB Newsletter)



New Zealand Institute of Building

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Research Survey Requests

The NZIOB is continually being approached by students in a construction focused tertiary program to circulate their Research Surveys to our membership. This new page is the one-stop shop for NZIOB members to participate in construction industry research. Current surveys include:

- Title: 'Causes and origins to construction waste during a project life-cycle'.
  Ruiqi Hou, BCon Student, Massey University
  Survey Link: https://www.surveymonkey.com/r/29Z3LLC
- Title: 'Marginal productivity improvement achievable by the use of prefabrication system: Case studies of building projects in New Zealand'.
  Wajiha Shahzad, PhD (Construction) Candidate, Massey University
  Survey Link: https://www.surveymonkey.com/s/wajiha_shahzad
- Title: 'To gain an understanding of material waste reduction achievable with residential off-site construction in New Zealand'.
  Kathy Murray, 3rd Year Student (Construction), Massey University
  Survey Link: https://www.surveymonkey.com/r/H8P7DZW
- Title: 'Payment delays in the Constructions Industry in New Zealand'.
  Elrasheid Elkhidir, Master of Construction (MCM), AUT
  Survey Link: https://www.surveymonkey.com/s/6K969V9

CPD/ MEMBER LOGIN

Email Address

Password

Forgotten Password? SUBMIT

If you are not an existing NZIOB member you can apply for a trial membership, or sign up for a student membership or full membership online. Alternatively you can visit our Contact Us page.

NZIOB

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NEWS & CPD EVENTS

Health & Safety Seminar - Northland

Appendix B3 (NZIA Newsletter)

New Zealand
Institute of Architects
Incorporated

NZIA Bulletin

29 May 2015

From the President

Some of you will know my antipathy to acronyms but I now find myself deeply immersed in them. I am uncertain whether my inability to remember what they stand for is due to increasing decrepitude or just resentment at the lazy mindtext way of communicating that they represent. Some though have been around for so long they have a mnemonic quality that transcends the literal interpretation of the words for which they do service. And so it was that on the beginning of day two of the recent Australian Institute of Architects conference I found myself on stage [*right*] signing an MoU between the NZIA and the AIA - I am sure you will be able to decode.

The signing was the culmination of conversations that the two Institutes had had for the last few months, the decision to sign reached at a meeting involving CEOs David Parken and Teena Hale-Pennington, Australian President David Karotkin and me at our own February conference. The agreement is an affirmation of the closeness of the relationship between the two organisations, a relationship that we both seek to build on and which will facilitate the sharing of each country's Institute resources such as policy strategies and papers.

ICOMOS in Auckland - call for papers
The International Council on Monuments and Sites (ICOMOS) New Zealand advises that its 2015 conference, which coincides with ICOMOS International's 50th anniversary, will be held in Auckland on 17-18 October 2015. ICOMOS members and non-members are invited to present papers or share thoughts more informally on topics relating to past, present or future heritage practice in New Zealand and the Pacific. For details about topics and the format for abstracts go here.

Athfield in Eastbourne - open day

759 Marine Drive - a.k.a the Windy Point tower house or Logan House - is a landmark property in Eastbourne, Wellington. The 1970s house [*right*] is one of Sir Ian Athfield's earliest works and features many of his signature flourishes: towers; curved walls; slit windows; and a wonderful hobbit hole or step-in library. This Queen's Birthday Monday there's a rare opportunity to check it out - the owners have volunteered to open their home to raise money for a local boy who is wheelchair-bound due to the effects of cerebral palsy. Funds raised will go towards providing him with a walking aid.

Monday 1 June; entry via gold coin donation. More information here or contact Sinead Diederich on 021 0258 1960.

Prefab survey
Wajiha Shahzad, PhD candidate at School of Engineering and Advanced Technology (SEAT), Massey University, seeks professional feedback on his research topic: "Marginal productivity improvement achievable by the use of prefabrication system: Case studies of building projects in New Zealand". Wajiha is trying to determine the cost and time savings, and the resulting productivity improvement, that can be achieved through the use of prefabrication in place of traditional construction methods. He says the first phase of his research has produced encouraging results; to "triangulate" his findings, he has prepared a survey questionnaire which can be accessed - and quickly answered - here.

Come into the Parlour
Architecture editor, writer, critic and researcher Justine Clarke will be next speaker in this year's City Talks series, presented by the Wellington Branch and City Gallery Wellington.

Appendix B4 (ACENZ Newsletter)

Improving productivity with panelised/ framed prefabrication systems: Case studies of building projects in New Zealand, *by Wajiha Shahzad*

Wajiha Shahzad is completing her PhD (Construction) from School of Engineering and Advanced Technology (SEAT) at Massey University. Her research requires liaison with some of the major construction industry stakeholders including members of ACENZ. His research topic is, ***"Productivity improvement achievable by the use of panelised/ framed prefabrication system: Case studies of building projects in New Zealand"***. The objective is to determine cost and time savings, and resulting productivity improvement that can be achieved with the use of prefabrication in place of traditional construction methods.

The **first phase** of research outcomes reveal substantial cost & time savings and productivity improvements when using prefabrication technology in place of traditional construction methods. To triangulate these research findings a questionnaire which takes 5 - 7 minutes, has been carefully designed. The survey can be accessed at **https://www.surveymonkey.com/s/wajiha_shahzad**

ACENZ is happy to support this research, as the more responses can be gathered, the more robust and valid the research findings.

Participation in the survey will be voluntary and all the responses will only be used for the purpose of data analysis and will be treated in firm confidence.

Please consider circulating this questionnaire to your staff. Send any questions to: Wajiha Mohsin Shahzad, PhD Researcher, SEAT at Massey. e: W.M.Shahzad@massey.ac.nz, c:+64 21 0278 1661.

What is the key objective of this study?

The key objective of this study is to determine the cost and time savings, and the resulting productivity improvement that can be achieved with the use of prefabrication in place of traditional construction methods.

What research method is adopted for the study?

The study adopts archival/ historical research method. Case studies of various types of building projects are being investigated in Auckland, Christchurch and Wellington to determine the amount of savings achievable in the costs and durations of some prefabricated building projects.

What is prefabrication?

In the context of this study, 'prefabrication' is defined as the process of manufacturing and assembling major building components at remote offsite locations for their subsequent onsite installation (MBI, 2010). By focusing more on offsite construction, it differs from the traditional stick-built system popularly adopted in the industry, and which focuses more on onsite construction of the building components.

What is productivity?

Productivity is a measure of how well resources are leveraged to achieve set objectives (Durdyev and Mbachu, 2011). There are various perspectives on the concept and types of 'productivity', the most popular being labour and multi-factor productivity (APC, 2008). For this study, productivity is defined as the product of cost and time savings in a project. This strategic perspective resonates well with the goal-oriented focus in the construction industry. It draws upon industry's view that productivity performance depends largely on the cost and schedule performance on a project; i.e. savings in construction cost and time translate to productivity improvement in the project delivery.

What are the key benefits of this study?

It is widely believed that prefabrication system holds brighter prospects for being able to be leveraged to improve the reported low productivity of New Zealand construction industry, compared to traditional construction methods (DBH, 2009). However, industry-wide uptake of the technology is low due largely to lack of empirically determined and quantifiable evidence of these benefits. Clients and designers are reluctant to act on anecdotal evidence. This study aims to contribute to bridging existing information gap by seeking to provide evidence-based quantifiable benefits which clients and other stakeholders can rely on to commit to improved investment in the technology, and hence improve its uptake in the industry.

Appendix C: Survey Package

Appendix C1 (Cover Letter)

MASSEY UNIVERSITY

School of Engineering & Advanced Technology
Private Bag 102 904 North Shore 0745, Auckland, New Zealand;
Tel: 021 0278 1661; Fax: 09 443 9774; W.M.Shahzad@massey.ac.nz

Dr Wayne Sharman   Date: __ May 2015
Strategic Business Development & Contract Manager
Building Research Association of New Zealand
Wellington.

Dear Dr Sharman

Research Survey: Productivity improvement achievable by the use of prefabrication system: Case studies of building projects in New Zealand

Prefabrication of building components for on-site assembly is a relatively innovative construction approach. Prefabrication technology is globally recognized as an effective solution to address many problems faced by construction industry including low productivity, poor quality of work, poor environmental performance and cost and time over runs. A recent PhD research project carried out at Massey University has investigated cost and time savings and the productivity improvement achievable by the use of prefabrication in place of traditional construction methods for some case study building projects. The research was based on final contract values and completion time of prefabricated buildings in Auckland, Christchurch and Wellington. The building types included community, commercial, educational, single unit residential and multi unit residential buildings.

Research outcomes reveal that substantial amount and time savings and productivity improvement can be achieved through the use of prefabrication in place of traditional construction methods. To triangulate research findings a questionnaire has been carefully designed that will take 5 – 7 minutes to complete. The survey can be accessed here www.surveymonkey.com/s/wajiha_shahzad. I therefore request your response to the survey, which will enhance the reliability and validity of the research findings. Your participation in this self-administered survey is voluntary. Your responses will only be used for the purpose of data analysis and will be treated in firm confidence.

If you will be interested in the key findings of the study, please fill the attached Summary Request Form; the form could be faxed / email separately should you desire anonymity.

Thank you very much for your time and anticipated help in making this survey possible.

Yours sincerely,

____

Wajiha Mohsin Shahzad
(Researcher)

Appendix C2 (Participant Information Sheet)

MASSEY UNIVERSITY

School of Engineering & Advanced Technology
Private Bag 102 904 North Shore 0745, Auckland, New Zealand;
Tel: 021 0278 1661; Fax: 09 443 9774; W.M.Shahzad@massey.ac.nz

INFORMATION SHEET

Productivity improvement achievable by the use of prefabrication system: Case studies of building projects in New Zealand

Prefabrication is defined as the process of manufacturing and assembling major building components at remote offsite locations for their subsequent onsite installation (MBI, 2010). Benefits of prefabrication technology are globally recognised by various industry organizations. It is believed that prefabrication system holds brighter prospects for being leveraged to improve the reported low productivity of New Zealand construction industry compared to traditional construction methods (DBH, 2009).

Productivity is a measure of how well resources are leveraged to achieve the set objectives (Durdyev and Mbachu, 2011). There are various means of defining productivity, most popular being the labour productivity and multi factor productivity (APC, 2008). For this study, productivity however is defined from the perspective of construction industry. In construction industry context, productivity performance depends largely on the cost and schedule performance. i.e. saving in construction cost and time translates into productivity improvement of construction process.

The objective of this study was to determine the cost and time savings and resulting productivity improvement that can be achieved with the use of prefabrication in place of traditional construction methods. For this purpose, case studies of various types of building projects were investigated in Auckland, Christchurch and Wellington to determine the amount of savings achievable in project cost and duration of prefabricated buildings. Research outcomes reveal that substantial amount and time savings and productivity improvement can be achieved through the use of prefabrication in place of traditional construction methods. A questionnaire survey has been planned to triangulate research findings.

You are requested to voluntarily participate in this research survey, your participation will be treated in complete anonymity and findings of this study will only be used for academic purpose.

Appendix C3 (Questionnaire)

MASSEY UNIVERSITY

School of Engineering & Advanced Technology

Private Bag 102 904 North Shore 0745, Auckland, New Zealand; Tel: 021 0278 1661; Fax: 09 443 9774; W.M.Shahzad@massey.ac.nz

Research Survey

Productivity improvement achieveable by the use of prefabrication system: Case studies of building projects in New Zealand

By:

Wajiha Mohsin Shahzad

BENEFITS ACHIEVEABLE BY THE USE OF PREFABRICATION SYSTEM

1 Prior research has shown that the use of prefab (mostly framed/ panelised system) in place of traditional building system offers a number of benefits, including cost and time savings, and productivity improvement.The savings and improvement vary according to building types. For each of the listed building types, please rate the range of % options you believe is the most appropriate in relation to cost and time savings and productivity improvement as shown below. Where you believe the most appropriate % savings or improvement is not indicated, please specify what you

A ***COST SAVINGS ACHIEVABLE FOR VARIOUS BUILDING TYPES***

****Range of % savings: 10 - 15%; 16 - 20%; 21 -25%; 26 - 30%; Other % (if not included in the***

	Building type	***Range of savings**					**No Idea**
		10-15%	**16-20%**	**21-25%**	**26-30%**	**Other ?**	
i	Commercial Buildings						
ii	Educational Buildings						
iii	Community Buildings						
iv	Multi Unit Residential Buildings						
v	Single Unit Residential Buildings						

B ***TIME SAVINGS ACHIEVEABLE FOR VARIOUS BUILDING TYPES***

****Range of % savings: 35 - 40%; 41 - 45%; 46 -50%; 51 - 55%; Other % (if not included in the***

	Building type	***Range of savings**					**No Idea**
		35-40%	**41-45%**	**46-50%**	**51-55%**	**Other ?**	
i	Commercial Buildings						
ii	Educational Buildings						
iii	Community Buildings						
iv	Multi Unit Residential Buildings						
v	Single Unit Residential Buildings						

C ***PRODUCTIVITY IMPROVEMENT ACHIEVEABLE FOR VARIOUS BUILDING TYPES***

****Range of % savings: 4 - 6%; 6.1 - 8%; 8.1 -10%; 10.1 - 12%; Other % (if not included in the***

	Building type	***Range of savings**					**No Idea**
		4-6%	**6.1-8%**	**8.1-10%**	**10.1-12%**	**Other ?**	
i	Commercial Buildings						
ii	Educational Buildings						
iii	Community Buildings						
iv	Multi Unit Residential Buildings						
v	Single Unit Residential Buildings						

2 The following have been identified as potential factors that could influence the level of marginal benefits derivable from prefab compared to the traditional building system. Please rate the relative levels of influence of the identified factors on the prefab marginal benefits using the rating scale provided. It will be appreciated if you could add additional factors in the textbox area.

Relative levels of influence: 5 = Very high; 4 = High; 3 = Average; 2 = Low; 1 = Very low

	Factors influencing prefab marginal benefits	**Levels of restraint to OSM**					**No Idea**
		5	**4**	**3**	**2**	**1**	
		Very high	High	Average	Low	Very low	
a	Building type (e.g. commercial, residential)						
b	Location (e.g. city)						
c	Prefab type (e.g. modular, panelised, whole building)						
d	Type of building contract						
e	Level of design standardisation/ customisation						
f	Logistics & supply conditions (e.g. transportation, distance to site)						
g	Scale and repeatability of prefab components						
h	Proportion of subsoil or site specific component costs to the overall project value						
i	Weather conditions (e.g. harsh versus fair weather for site operations)						
j	Level of whole-of-life quality expectation for the project						
k	Site working conditions (e.g. health & safety consideration)						
l	Site layout conditions (e.g. congested versus open site)						
m	Environmental impact performance for the project (e.g. need to minimise waste)						
n	Quality of project leadership/project management attitude						
o	Nature of client and client project management attitude						
p	Contractor's level of innovation experience						
Other? Please specify:							
q							
r							

3	DEMOGRAPHIC BACKGROUND		
1	Please indicate your professional affiliation.		
☐	IPENZ	NZIA	☐
☐	NZIOB	NZIQS	☐
☐	Other (please specify):____________________	PrefabNZ	☐
2	Please indicate your position in your organization.		
☐	Managing Director	Supervisor	☐
☐	Manager	Trainee	☐
☐	Other (please specify):____________________		
3	Please indicate your professional role.		
☐	Architect	Building Official	☐
☐	Contractor	Engineer	☐
☐	Project Manager	Quantity Surveyor	☐
☐	Other (please specify): ____________________		
4	Please indicate your length of experience.		
☐	< 5 yrs	5 - 10 yrs	☐
☐	11 - 15 yrs	16 - 20 yrs	☐
☐	21 - 25 yrs	> 25 yrs	☐

APPRECIATION

Thank you for your time. Please return the completed questionnaire as an email attachment to W.M.Shahzad@massey.ac.nz; alternatively you may wish to fax it to: 09 443 9774 ; Attention: Wajiha Mohsin Shahzad.

If you have any comments in relation to the contents or you may wish to contact the researcher by phone 021 0278 1661 (cell) or email; else, please state your overall comments below, if any:

DISCLAIMER

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the Massey University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research. If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director (Research Ethics), telephone 06 350 5249, email: humanethics@massey.ac.nz.

Appendix C4 (Request for Research Findings)

Form for requesting summary of the key research findings

ATTENTION: Wajiha Mohsin Shahzad

FAX: +64 9 443 9774

REASEARCH ON
Productivity improvement achievable by the use of framed/panelized prefabrication system: Case studies of building projects in New Zealand

I would like to receive a summary of the key findings of the research. My contact details are as follows.

Name and address of company (optional): ____________________
____
____
____

Fax:

Attention:

E-mail:

Appendix C5 (Online Survey)

MASSEY UNIVERSITY

Productivity Improvement Achievable by the use of Framed/ Panelised Prefabrication System: Case Studies of Building Projects in New Zealand

INTRODUCTION

My name is Wajiha Shahzad. I am doing PhD (Construction) from School of Engineering and Advanced Technology (SEAT) at Massey University. This survey is a part of my PhD research entitled "**Productivity improvement achievable by the use of framed/ panelised prefabrication system: Case studies of building projects in New Zealand**". First phase of this research has investigated cost and time savings and the productivity improvement achievable by the use of prefabrication technology in place of traditional construction methods for some case study building projects. The research was based on final contract values and completion time of prefabricated buildings in Auckland, Christchurch and Wellington. The building types included community, commercial, educational, single-unit residential and multi-unit residential buildings. Further details are provided in the Fact Sheet below.

First phase research findings reveal that substantial amount of cost and time savings and productivity improvement can be achieved through the use of prefabrication technology in place of traditional construction methods.

This survey is aimed at triangulating the research findings. The survey will take 5 – 7 minutes to complete. Your participation in this survey is voluntary. Your responses will only be used for the purpose of data analysis and will be treated in firm confidence.

If you are interested in the key findings of the study, please fill in the attached Summary Request Form.

Should you have any questions please email or phone me using the contact details below.

Thank you very much for your time and anticipated help in making this survey possible.

Yours sincerely,

Wajiha Shahzad
Email: W.M.Shahzad@massey.ac.nz
Mobile: 021 0278 1661

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Disclaimer

"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research. If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director (Research Ethics), telephone 06 350 5249, email: humanethics@massey.ac.nz".

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MASSEY UNIVERSITY

Productivity Improvement Achievable by the use of Framed/ Panelised Prefabrication System: Case Studies of Building Projects in New Zealand

FACT SHEET

The key objective of this study is to determine the cost and time savings, and the resulting productivity improvement that can be achieved with the use of prefabrication in place of traditional construction methods.

In the context of this study, 'prefabrication' is defined as the process of manufacturing and assembling major building components at remote offsite locations for their subsequent onsite installation (MBI, 2010). By focusing more on offsite construction, it differs from the traditional stick-built system popularly adopted in the industry, and which focuses more on onsite construction of the building components.

Productivity is a measure of how well resources are leveraged to achieve set objectives (Durdyev and Mbachu, 2011). There are various perspectives on the concept and types of 'productivity', the most popular being labour and multi-factor productivity (APC, 2008). For this study, productivity is defined as the product of cost and time savings in a project. This strategic perspective resonates well with the goal-oriented focus in the construction industry. It draws upon industry's view that productivity performance depends largely on the cost and schedule performance on a project; i.e. savings in construction cost and time translate to productivity improvement in the project delivery.

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MASSEY UNIVERSITY

Productivity Improvement Achievable by the use of Framed/ Panelised Prefabrication System: Case Studies of Building Projects in New Zealand

BENEFITS ACHIEVABLE BY THE USE OF PREFABRICATION

Framed/ panelised prefabrication system is increasingly being used in the building industry. Prior research has shown that the use of prefabrication (mostly framed/ panelised system) in place of traditional building system offers a number of benefits, including cost and time savings, and productivity improvement.The savings and improvement vary according to building types. For each of the listed building types, please rate the range of % options you believe is the most appropriate in relation to cost and time savings and productivity improvement as shown below. Where you believe the most appropriate % savings or improvement is not indicated, please specify what you have in mind in the 'Other' column.

4

1. COST SAVINGS ACHIEVABLE FOR VARIOUS BUILDING TYPES

Range of % savings: 10 - 15%; 16 - 20%; 21 -25%; 26 - 30%; Other % (if not included in the ranges)

	10 - 15%	16 - 20%	21 - 25%	26 - 30%	Others?	No Idea
a. Commercial Buildings	○	○	○	○	○	○
b. Educational Buildings	○	○	○	○	○	○
c. Community Buildings	○	○	○	○	○	○
d. Multi Unit Residential Buildings	○	○	○	○	○	○
e. Single Unit Residential Buildings	○	○	○	○	○	○

(After each building type:) If you ticked the 'Other' column, please write down the value you have in mind here for the building type:

5

2. TIME SAVINGS ACHIEVABLE FOR VARIOUS BUILDING TYPES

Range of % savings: 35 - 40%; 41 - 45%; 46 -50%; 51 - 55%; Other % (if not included in the ranges)

	35 - 40%	41 - 45%	46 - 50%	51 - 55%	Other?	No Idea
a. Commercial Buildings	○	○	○	○	○	○
b. Educational Buildings	○	○	○	○	○	○
c. Community Buildings	○	○	○	○	○	○
d. Multi Unit Residential Buildings	○	○	○	○	○	○
e. Single Unit Residential Buildings	○	○	○	○	○	○

Under each building type (a–e): If you ticked the 'Other' column, please write down the value you have in mind here for the building type:

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3. PRODUCTIVITY IMPROVEMENT ACHIEVABLE FOR VARIOUS BUILDING TYPES

Range of % savings: 4 - 6%; 6.1 - 8%; 8.1 -10%; 10.1 - 12%; Other % (if not included in the ranges)

	4 - 6%	6.1 - 8%	8.1 - 10%	10.1 - 12%	Other?	No idea
a. Commercial Buildings	◯	◯	◯	◯	◯	◯
b. Educational Buildings	◯	◯	◯	◯	◯	◯
c. Community Buildings	◯	◯	◯	◯	◯	◯
d. Multi Unit Residential Buildings	◯	◯	◯	◯	◯	◯
e. Single Unit Residential Buildings	◯	◯	◯	◯	◯	◯

a. Commercial Buildings — If you ticked the 'Other' column, please write down the value you have in mind here for the building type:

b. Educational Buildings — If you ticked the 'Other' column, please write down the value you have in mind here for the building type:

c. Community Buildings — If you ticked the 'Other' column, please write down the value you have in mind here for the building type:

d. Multi Unit Residential Buildings — If you ticked the 'Other' column, please write down the value you have in mind here for the building type:

e. Single Unit Residential Buildings — If you ticked the 'Other' column, please write down the value you have in mind here for the building type:

7

MASSEY UNIVERSITY

Productivity Improvement Achievable by the use of Framed/ Panelised Prefabrication System: Case Studies of Building Projects in New Zealand

FACTORS INFLUENCING PREFABRICATION BENEFITS

The following have been identified as potential factors that could influence the level of benefits derivable from prefabrication compared to the traditional building system. Please rate the relative levels of influence of the identified factors on the prefabrication benefits using the rating scale provided. It will be appreciated if you could add additional factors in the text box area.

4. FACTORS INFLUENCING PREFABRICATION BENEFITS

Levels of influence on potential prefabrication benefits
Relative levels of influence: 5 = Very high; 4 = High; 3 = Average; 2 = Low; 1 = Very low

	5	4	3	2	1	No idea
a. Building type (e.g. commercial, residential)						
b. Location/city						
c. Prefab type (e.g. framed, panelised, modular, whole building)						
d. Type of building contract (e.g. lumpsum fixed price, cost reimbursement)						

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	5	4	3	2	1	No Idea
e. Type of procurement system (e.g. traditional, design & build, project mgt)	○	○	○	○	○	○
f. Level of design standardisation/ customisation	○	○	○	○	○	○
g. Logistics & supply conditions (e.g. transportation, distance to site)	○	○	○	○	○	○
h. Scale and repeatability of prefab components	○	○	○	○	○	○
i. Proportion of subsoil or site specific component costs to the overall project value	○	○	○	○	○	○
j. Weather conditions (e.g. harsh versus fair weather for site operations)	○	○	○	○	○	○
k. Level of whole-of-life quality expectation for the project	○	○	○	○	○	○
l. Site working conditions (e.g. health & safety consideration)	○	○	○	○	○	○
m. Site layout conditions (e.g. congested versus open site)	○	○	○	○	○	○
n. Environmental impact performance for the project (e.g. need to minimise waste)	○	○	○	○	○	○

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	5	4	3	2	1	No Idea
o. Quality of project leadership/project management attitude of project team	○	○	○	○	○	○
p. Nature of client and client project management capabilities	○	○	○	○	○	○
q. Contractor's level of innovation experiance	○	○	○	○	○	○

Other (please specify)

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Productivity Improvement Achievable by the use of Framed/ Panelised Prefabrication System: Case Studies of Building Projects in New Zealand

DEMOGRAPHIC BACKGROUND

5. Please indicate your professional affiliation

- ☐ ACENZ / IPENZ
- ☐ NZIA
- ☐ NZIOB
- ☐ NZIQS
- ☐ PrefabNZ

Other (please specify)

____

6. Please indicate your position in your organization

- ◯ Managing Director
- ◯ Manager
- ◯ Supervisor
- ◯ Trainee

Other (please specify)

____

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7. Please indicate your professional role

- Architect
- Building Official
- Contractor
- Engineer
- Project Manager
- Quantity Surveyor

Other (please specify)

8. Please indicate your length of experience

- < 5 years
- 5 - 10 years
- 11 - 15 years
- 16 - 20 years
- 21 - 25 years
- > 25 years

9. Summary of Research Findings *(If you are interested to know about key findings, please provide your email address or fax number)*

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Appendix D: Cost Saving Analysis

Appendix D1 (Cost Saving Analysis: Commercial Buildings)

Appendix D1.1

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Auckland commercial building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	5,900	6	2005	Basic	6,000,000	14,553,000	58.77
2	1,290	2	2008	Basic	1,500,000	3,160,500	52.54
3	2,850	2	2008	Basic	5,500,000	6,982,500	21.23
4	5,400	2	2013	Basic	7,000,000	10,665,000	34.36
5	4,082	1	2013	Basic	7,000,000	8,061,950	13.17
6	1,001	1	2012	Medium	2,000,000	3,461,000	42.21
7	9,000	1	2011	Basic	8,000,000	14,085,000	43.20
8	150	2	2009	Basic	160,000	189,000	15.34
9	100	1	2013	Basic	220,000	243,000	9.47
10	10,000	8	2012	Medium	30,000,000	35,400,000	15.25
11	2,100	3	2012	Basic	3,200,000	3,831,100	16.47
12	10,000	4	2008	Basic	19,000,000	20,488,000	7.26
13	23,000	6	2013	High	105,000,000	112,125,000	6.35
14	5,240	4	2008	Basic	9,600,000	12,602,200	23.82
15	2,100	1	2012	Medium	6,500,000	6,615,000	1.74
16	1,547	5	2013	High	7,800,000	7,967,050	2.10
						Average	**22.71**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.10, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D1.2

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Christchurch commercial building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	7,940	1	2013	Basic	5,000,000	6,828,400	26.78
2	2,340	1	2008	Basic	2,000,000	3,042,000	34.25
3	5,460	13	2008	High	22,000,000	22,713,600	3.14
4	33	1	2014	Medium	70,840	78,705	9.99
5	8,000	1	2012	Basic	7,500,000	10,200,000	26.47
6	34,100	1	2005	Basic	13,000,000	22,165,000	41.35
7	1,300	2	2013	Medium	2,750,000	3,165,500	13.13
8	3,900	1	2013	Basic	4,700,000	5,070,000	7.30
						Average	**20.30**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.10, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D1.3

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Wellington commercial building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	10,500	1	2011	Basic	13,200,000	15,750,000	16.19
2	48,000	15	2010	High	120,000,000	150,240,000	20.13
3	4,000	1	2013	High	10,000,000	11,980,000	16.53
4	5,000	2	2011	Basic	6,000,000	6,250,000	4.00
5	8,000	1	2011	Basic	8,000,000	9,800,000	18.37
6	800	2	2011	High	2,000,000	2,600,000	23.08
7	14,500	10	2010	High	55,000,000	56,000,000	1.79
8	30,000	12	2011	High	100,000,000	103,200,000	3.10
						Average	**12.90**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.10, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D2 (Cost Saving Analysis: Community Buildings)

Appendix D2.1

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Auckland community building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	2,000	2	2011	Medium	6,000,000	6,900,000	13.04
2	20,000	7	2012	Basic	12,000,000	13,800,000	13.04
3	2,500	1	2013	High	7,000,000	16,625,000	57.89
4	650	2	2012	Medium	2,250,000	2,950,000	23.73
5	3,415	3	2009	Medium	7,400,000	9,732,750	23.97
6	365	1	2011	Basic	900,000	967,250	6.95
7	8,000	5	2006	Basic	16,000,000	20,000,000	20.00
						Average	**22.66**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D2.2

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Christchurch community building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	1,600	2	2009	Basic	7,000,000	8,800,000	20.45
2	7,600	1	2012	Basic	22,000,000	22,420,000	1.87
3	2,300	1	2012	Basic	3,500,000	4,600,000	23.91
4	2,300	2	2012	Basic	6,300,000	8,280,000	23.91
5	500	1	2011	Basic	171,350	587,500	70.83
6	2,100	3	2014	High	13,000,000	41,475,000	68.66
7	304	1	2013	Basic	563,706	1,140,000	50.55
						Average	**37.17**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D2.3

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Wellington community building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	3,200	1	2008	Basic	14,000,000	20,640,000	32.17
2	2,200	2	2011	Basic	6,500,000	6,930,000	6.20
3	1,800	1	2014	Basic	9,800,000	10,000,000	2.00
4	850	1	2003	Basic	2,060,000	5,060,000	59.29
5	194	1	2014	Basic	625,000	572,300	-9.21
6	500	1	2009	High	5,500,000	8,250,000	33.33
7	3,748	1	2008	Basic	1,400,000	24,174,600	94.21
						Average	**31.14**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D3 (Cost Saving Analysis: Educational Buildings)

Appendix D3.1

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Auckland educational building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	3,896	3	2008	Basic	5,300,000	5,905,500	10.25
2	1,210	2	2013	Basic	2,000,000	2,195,152	8.89
3	1,050	2	2013	Basic	1,600,000	1,732,510	7.65
4	12,000	3	2009	Basic	25,700,000	27,240,000	5.65
5	7,100	2	2012	Basic	12,500,000	13,150,050	4.94
6	1,824	1	2009	Basic	10,000,000	11,050,250	9.50
7	8,300	7	2004	Basic	16,500,000	17,430,000	5.34
8	3,320	2	2010	Basic	6,000,000	6,723,000	10.75
9	20,000	12	2013	Basic	74,000,000	77,000,000	3.90
10	3,000	2	2011	Basic	9,200,000	9,750,000	5.64
11	19,500	12	2012	High	750,000,000	785,000,000	4.46
12	10,600	10	2005	Basic	28,000,000	29,680,000	5.66
						Average	**6.89**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D3.2

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Christchurch educational building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	2,400	2	2005	Medium	10,000,000	9,800,000	-2.04
2	14,976	1	2011	Basic	26,500,000	39,686,400	33.23
3	7,000	2	2014	High	35,000,000	36,700,000	4.63
4	700	1	2014	High	3,300,000	3,646,000	9.49
5	850	2	2011	Basic	1,340,000	1,636,250	18.11
6	800	1	2010	Basic	1,000,000	1,500,000	33.33
7	2,655	1	2014	Medium	3,400,000	8,230,500	58.69
						Average	**22.21**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D3.3

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Wellington educational building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	3,600	5	2012	High	16,200,000	20,000,000	19
2	13,500	11	2009	Medium	40,000,000	43,200,000	7.41
3	600	1	2009	Basic	1,400,000	1,590,000	11.95
4	5,000	4	2012	Basic	6,200,000	9,625,000	35.58
5	1,811	2	2012	Basic	2,400,000	3,486,175	31.16
6	11,040	1	2009	Basic	1,900,000	22,632,000	91.60
7	5,950	2	2010	Basic	5,400,000	11,305,000	52.23
						Average	**35.56**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D4 (Cost Saving Analysis: Houses)

Appendix D4.1

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Auckland houses case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	70	1	2014	High	141,000	141,750	0.53
2	100	1	2014	High	166,800	199,100	16.22
3	100	1	2014	High	158,750	199,100	20.27
4	115	1	2014	High	252,000	229,562	-9.77
5	140	1	2014	High	280,900	267,540	-4.99
6	60	1	2014	High	112,000	114,660	2.32
7	90	1	2014	High	168,000	171,990	2.32
8	114	1	2013	Basic	119,000	167,580	28.99
9	98	1	2013	Basic	196,000	144,060	-36.05
10	45	1	2014	High	74,150	85,995	13.77
11	59	1	2014	High	89,930	112,749	20.24
12	60	1	2014	High	87,840	114,660	23.39
13	68	1	2014	High	93,920	129,948	27.72
14	69	1	2014	High	94,830	131,859	28.08
15	70	1	2014	High	94,200	133,770	29.58
16	86	1	2014	High	107,900	164,346	34.35
17	93	1	2014	High	128,220	177,723	27.85
18	97	1	2014	High	129,350	185,367	30.22
19	102	1	2014	High	144,790	194,922	25.72
20	105	1	2014	High	153,000	200,655	23.75
21	109	1	2014	High	166,040	208,299	20.29
22	111	1	2014	High	146,570	212,121	30.90
23	113	1	2014	High	149,200	215,943	30.91
24	114	1	2014	High	155,950	217,854	28.42
25	116	1	2014	High	162,860	221,676	26.53
26	120	1	2014	High	183,480	229,320	19.99
27	121	1	2014	High	166,790	231,231	27.87
28	125	1	2014	High	179,850	238,875	24.71
29	135	1	2014	High	179,050	257,985	30.60
30	122	1	2014	High	171,200	233,142	26.57
31	147	1	2014	High	191,690	280,917	31.76
32	118	1	2014	High	156,780	225,498	30.47
33	153	1	2014	High	196,980	292,383	32.63
						Average	**20.19**

**Prefabrication cost, **Equivalent traditional building system cost. Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9.*

Appendix D4.2

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Christchurch houses case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	105	1	2013	Basic	192,158	193,000	0.44
2	228	2	2013	Basic	421,800	444,600	5.13
3	232	1	2013	Basic	426,280	436,000	2.23
4	248	2	2013	Basic	462,520	477,400	3.12
5	170	1	2013	Basic	311,460	314,500	0.97
6	160	1	2013	Basic	284,160	296,000	4.00
7	304	1	2013	High	563,706	1,140,000	50.55
8	156	1	2014	Basic	248,421	265,200	6.33
9	66	1	2014	Medium	143,346	157,580	9.03
10	215	1	2013	High	534,000	806,250	33.77
11	208	1	2010	Basic	250,000	353,600	29.30
						Average	**13.17**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D4.3

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Wellington houses case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	147	1	2013	Basic	276,358	284,600	2.90
2	158	1	2013	Basic	283,954	284,400	0.16
3	225	1	2013	Basic	392,175	405,000	3.17
4	228	2	2013	Basic	416,432	430,400	3.25
5	278	1	2013	High	509,608	681,100	25.18
6	105	1	2013	High	227,184	252,000	9.85
7	199	1	2013	Basic	346,182	358,200	3.36
						Average	**6.84**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D5 (Cost Saving Analysis: Apartment Buildings)

Appendix D5.1

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Auckland apartment building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	3,887	3	2011	Basic	6,300,000	10,417,160	39.52
2	3,218	2	2003	Basic	7,200,000	8,045,000	10.50
3	25,000	4	2005	Basic	40,000,000	50,625,000	20.99
4	6,700	18	2010	High	25,000,000	29,495,000	15.24
5	2,500	14	2011	High	8,900,000	11,995,000	25.80
6	2,700	2	2010	High	10,000,000	10,800,000	7.41
7	2,266	3	2007	Basic	4,100,000	5,438,400	24.61
						Average	**20.58**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D5.2

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Christchurch apartment building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	2,317	2	2014	Medium	6,700,000	7,066,850	5.19
2	4,770	3	2008	High	15,000,000	16,122,600	6.96
3	1,872	2	2014	High	5,100,000	6,336,560	19.51
4	3,076	3	2010	Basic	5,900,000	6,520,500	9.52
5	840	2	2010	High	2,880,000	3,007,200	4.23
6	1,984	2	2013	Basic	3,580,000	4,067,200	11.98
7	2,280	2	2014	Basic	3,200,000	4,674,000	31.54
						Average	**12.70**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix D5.3

Analysis of cost savings achieved by using prefabrication technology in place of traditional building system: Wellington apartment building case studies

Project	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Cost ($)	**Equiv TBS Cost ($)	Percent Cost Savings
1	7,000	11	2014	High	50,000,000	52,500,000	4.76
2	8,000	16	2014	Basic	42,000,000	45,500,000	7.69
3	4,561	11	2011	High	12,500,000	15,644,230	20.10
4	27,000	12	2009	Basic	180,000,000	202,500,000	11.11
5	991	2	2014	Basic	300,900	3,171,200	90.51
6	4,656	4	2012	Basic	4,000,000	8,380,800	52.27
7	1,243	4	2000	Basic	2,000,000	2,734,600	26.86
						Average	**30.47**

**Prefabrication cost, **Equivalent traditional building system cost.*
Note: Percentage cost saving is calculated using equation 3.8, Average percentage cost saving is calculated using equation 3.9, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix E: Time Saving Analysis

Appendix E1 (Time Saving Analysis: Commercial Buildings)

Appendix E1.1

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Auckland commercial building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	6,000,000	5,900	6	2005	Basic	72	84	14.29
2	1,500,000	1,290	2	2008	Basic	24	52	53.85
3	5,500,000	2,850	2	2008	Basic	32	64	50.00
4	7,000,000	5,400	2	2013	Basic	48	72	33.33
5	7,000,000	4,082	1	2013	Basic	32	66	51.52
6	2,000,000	1,001	1	2012	Medium	36	50	28.00
7	8,000,000	9,000	1	2011	Basic	32	84	61.90
8	160,000	150	2	2009	Basic	4	10	60.00
9	220,000	100	1	2013	Basic	16	18	11.11
10	30,000,000	10,000	8	2012	Medium	80	100	20.00
11	3,200,000	2,100	3	2012	Basic	30	52	42.31
12	19,000,000	10,000	4	2008	Basic	60	90	33.33
13	105,000,000	23,000	6	2013	High	112	130	13.85
14	9,600,000	5,240	4	2008	Basic	40	76	47.37
15	6,500,000	2,100	1	2012	Medium	40	60	33.33
16	7,800,000	1,547	5	2013	High	44	64	31.25
							Average	**36.59**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories.

Appendix E1.2

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Christchurch commercial building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	5,000,000	7,940	1	2013	Basic	32	74	56.76
2	2,000,000	2,340	1	2008	Basic	24	60	60.00
3	22,000,000	5,460	13	2008	High	64	126	49.21
4	70,840	33	1	2014	Medium	8	36	77.78
5	7,500,000	8,000	1	2012	Basic	36	90	60.00
6	13,000,000	34,100	1	2005	Basic	50	120	58.33
7	2,750,000	1,300	2	2013	Medium	28	60	53.33
8	4,700,000	3,900	1	2013	Basic	24	68	64.71
							Average	**60.01**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories.

Appendix E1.3

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Wellington commercial building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	13,200,000	10,500	1	2011	Basic	40	104	61.54
2	120,000,000	48,000	15	2010	High	156	192	18.75
3	10,000,000	4,000	1	2013	High	40	92	56.52
4	6,000,000	5,000	2	2011	Basic	52	74	29.73
5	8,000,000	8,000	1	2011	Basic	48	84	42.86
6	2,000,000	800	2	2011	High	24	52	53.85
7	55,000,000	14,500	10	2010	High	96	120	20.00
8	100,000,000	30,000	12	2011	High	96	144	33.33
							Average	**39.57**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories.

Appendix E2 (Time Saving Analysis: Community Buildings)

Appendix E2.1

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Auckland community building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	6,000,000	2,000	2	2011	Medium	56	72	22.22
2	12,000,000	20,000	7	2012	Basic	48	76	36.84
3	7,000,000	2,500	1	2013	High	44	86	48.84
4	2,250,000	650	2	2012	Medium	36	56	35.71
5	7,400,000	3,415	3	2009	Medium	48	72	33.33
6	900,000	365	1	2011	Basic	32	36	11.11
7	16,000,000	8,000	5	2006	Basic	72	90	20.00
							Average	**29.72**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories.

Appendix E2.2

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Christchurch community building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	7,000,000	1,600	2	2009	Basic	56	88	36.36
2	22,000,000	7,600	1	2012	Basic	44	72	38.89
3	3,500,000	2,300	1	2012	Basic	20	66	69.70
4	6,300,000	2,300	2	2012	Basic	20	40	50.00
5	171,350	500	1	2011	Basic	8	36	77.78
6	13,000,000	2,100	3	2014	High	48	68	29.41
7	563,706	304	1	2013	Basic	10	38	73.68
							Average	**53.69**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories.

Appendix E2.3

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Wellington community building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	14,000,000	3,200	1	2008	Basic	68	120	43.33
2	6,500,000	2,200	2	2011	Basic	48	76	36.84
3	9,800,000	1,800	1	2014	Basic	56	90	37.78
4	2,060,000	850	1	2003	Basic	26	64	59.38
5	625,000	194	1	2014	Basic	12	66	81.82
6	5,500,000	500	1	2009	High	40	84	52.38
7	1,400,000	3,748	1	2008	Basic	68	132	48.48
							Average	**51.43**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories.

Appendix E3 (Time Saving Analysis: Educational Buildings)

Appendix E3.1

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Auckland educational building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	5,300,000	3,896	3	2008	Basic	16	60	73.33
2	2,000,000	1,210	2	2013	Basic	26	46	43.48
3	1,600,000	1,050	2	2013	Basic	26	42	38.10
4	25,700,000	12,000	3	2009	Basic	48	96	50
5	12,500,000	7,100	2	2012	Basic	44	68	35.29
6	10,000,000	1,824	1	2009	Basic	36	52	30.77
7	16,500,000	8,300	7	2004	Basic	60	88	31.82
8	6,000,000	3,320	2	2010	Basic	48	62	22.58
9	74,000,000	20,000	12	2013	Basic	112	144	22.22
10	9,200,000	3,000	2	2011	Basic	72	74	2.70
11	750,000,000	19,500	12	2012	High	96	120	20.00
12	28,000,000	10,600	10	2005	Basic	68	96	29.17
							Average	**33.29**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories.

Appendix E3.2

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Christchurch educational building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	10,000,000	2,400	2	2005	Medium	72	96	25.00
2	26,500,000	14,976	1	2011	Basic	24	72	66.67
3	35,000,000	7,000	2	2014	High	56	120	53.33
4	3,300,000	700	1	2014	High	12	56	78.57
5	1,340,000	850	2	2011	Basic	32	50	36.00
6	1,000,000	800	1	2010	Basic	32	48	33.33
7	3,400,000	2,655	1	2014	Medium	48	84	42.86
							Average	**47.97**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix E3.3

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Wellington educational building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	16,200,000	3,600	5	2012	High	32	72	55.56
2	40,000,000	13,500	11	2009	Medium	80	144	44.44
3	1,400,000	600	1	2009	Basic	24	44	45.45
4	6,200,000	5,000	4	2012	Basic	48	72	33.33
5	2,400,000	1,811	2	2012	Basic	24	48	50.00
6	1,900,000	11,040	1	2009	Basic	48	72	33.33
7	5,400,000	5,950	2	2010	Basic	24	40	40.00
							Average	**43.16**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix E4 (Time Saving Analysis: Houses)

Appendix E4.1

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Auckland houses case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	141,000	70	1	2014	High	12	16	25.00
2	166,800	100	1	2014	High	16	20	20.00
3	158,750	100	1	2014	High	16	20	20.00
4	252,000	115	1	2014	High	12	22	45.45
5	280,900	140	1	2014	High	12	24	50.00
6	112,000	60	1	2014	High	8	16	50.00
7	168,000	90	1	2014	High	8	18	55.56
8	119,000	114	1	2013	Basic	12	16	25.00
9	196,000	98	1	2013	Basic	16	20	20.00
10	74,150	45	1	2014	High	6	10	40.00
11	89,930	59	1	2014	High	6	12	50.00
12	87,840	60	1	2014	High	6	12	50.00
13	93,920	68	1	2014	High	7	12	41.67
14	94,830	69	1	2014	High	7	12	41.67
15	94,200	70	1	2014	High	7	14	50.00
16	107,900	86	1	2014	High	8	18	55.56
17	128,220	93	1	2014	High	8	18	55.56
18	129,350	97	1	2014	High	8	20	60.00
19	144,790	102	1	2014	High	9	20	55.00
20	153,000	105	1	2014	High	9	22	59.09
21	166,040	109	1	2014	High	9	22	59.09
22	146,570	111	1	2014	High	9	20	55.00
23	149,200	113	1	2014	High	10	22	54.55
24	155,950	114	1	2014	High	10	20	50.00
25	162,860	116	1	2014	High	10	20	50.00
26	183,480	120	1	2014	High	10	22	54.55
27	166,790	121	1	2014	High	8	24	66.67
28	179,850	125	1	2014	High	9	24	62.50
29	179,050	135	1	2014	High	9	26	65.38

30	171,200	122	1	2014	High	8	24	66.67
31	191,690	147	1	2014	High	9	28	67.86
32	156,780	118	1	2014	High	7	20	65.00
33	196,980	153	1	2014	High	12	28	57.14
							Average	**49.82**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11.

Appendix E4.2

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Christchurch houses case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	192,158	105	1	2013	Basic	6	16	62.50
2	421,800	228	2	2013	Basic	8	32	75.00
3	426,280	232	1	2013	Basic	8	30	73.33
4	462,520	248	2	2013	Basic	8	32	75.00
5	311,460	170	1	2013	Basic	7	28	75.00
6	284,160	160	1	2013	Basic	7	28	75.00
7	563,706	304	1	2013	High	10	38	73.68
8	248,421	156	1	2014	Basic	8	30	73.33
9	143,346	66	1	2014	Medium	6	20	70.00
10	534,000	215	1	2013	High	11	40	72.50
11	250,000	208	1	2010	Basic	10	28	64.29
							Average	**71.79**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix E4.3

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Wellington houses case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	276,358	147	1	2013	Basic	6	24	75
2	283,954	158	1	2013	Basic	6	24	75
3	392,175	225	1	2013	Basic	8	32	75
4	416,432	228	2	2013	Basic	8	32	75
5	509,608	278	1	2013	High	9	36	75
6	227,184	105	1	2013	High	6	20	70
7	346,182	199	1	2013	Basic	8	30	73.33
							Average	**74.05**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix E5 (Time Saving Analysis: Apartment Buildings)

Appendix E5.1

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Auckland apartment building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	6,300,000	3,887	3	2011	Basic	44	74	40.54
2	7,200,000	3,218	2	2003	Basic	48	64	25.00
3	40,000,000	25,000	4	2005	Basic	84	104	19.23
4	25,000,000	6,700	18	2010	High	68	80	15.00
5	8,900,000	2,500	14	2011	High	48	68	29.41
6	10,000,000	2,700	2	2010	High	64	74	13.51
7	4,100,000	2,266	3	2007	Basic	48	56	14.29
							Average	**22.43**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix E5.2

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Christchurch apartment building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	6,700,000	2,317	2	2014	Medium	40	76	47.37
2	15,000,000	4,770	3	2008	High	76	108	29.63
3	5,100,000	1,872	2	2014	High	44	74	40.54
4	5,900,000	3,076	3	2010	Basic	60	76	21.05
5	2,880,000	840	2	2010	High	36	62	41.94
6	3,580,000	1,984	2	2013	Basic	20	76	73.68
7	3,200,000	2,280	2	2014	Basic	22	68	67.65
							Average	**45.98**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix E5.3

Analysis of time savings achieved by using prefabrication technology in place of traditional building system: Wellington apartment buildings case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Level of Complexity	*Prefab Duration (Weeks)	**Equiv TBS Duration (Weeks)	Percent Time Saving
1	50,000,000	7,000	11	2014	High	96	144	33.33
2	42,000,000	8,000	16	2014	Basic	68	96	29.17
3	12,500,000	4,561	11	2011	High	48	72	33.33
4	180,000,000	27,000	12	2009	Basic	96	144	33.33
5	300,900	991	2	2014	Basic	12	64	81.25
6	4,000,000	4,656	4	2012	Basic	44	80	45.00
7	2,000,000	1,243	4	2000	Basic	44	72	38.89
							Average	**42.04**

**Prefabrication duration, **Equivalent traditional building system time.*
Note: Percentage time saving is calculated using equation 3.10, Average percentage time saving is calculated using equation 3.11, Level of complexity is assigned by the contractors based on managerial, technical and operational challenges presented such as type and complexity of crainage required, nature of the site (e.g. whether sloping or level or requiring to be de-watered), number of stories

Appendix F: Productivity Improvement Analysis

Appendix F1 (Productivity Improvement Analysis: Commercial Buildings)

Appendix F1.1

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Auckland commercial building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	6,000,000	5,900	6	2005	58.77	14.29	8.40
2	1,500,000	1,290	2	2008	52.54	53.85	28.29
3	5,500,000	2,850	2	2008	21.23	50.00	10.62
4	7,000,000	5,400	2	2013	34.36	33.33	11.45
5	7,000,000	4,082	1	2013	13.17	51.52	6.79
6	2,000,000	1,001	1	2012	42.21	28.00	11.82
7	8,000,000	9,000	1	2011	43.20	61.90	26.74
8	160,000	150	2	2009	15.34	60.00	9.21
9	220,000	100	1	2013	9.47	11.11	1.05
10	30,000,000	10,000	8	2012	15.25	20.00	3.05
11	3,200,000	2,100	3	2012	16.47	42.31	6.97
12	19,000,000	10,000	4	2008	7.26	33.33	2.42
13	105,000,000	23,000	6	2013	6.35	13.85	0.88
14	9,600,000	5,240	4	2008	23.82	47.37	11.28
15	6,500,000	2,100	1	2012	1.74	33.33	0.58
16	7,800,000	1,547	5	2013	2.10	31.25	0.66
						Average	**8.76**

Appendix F1.2

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Christchurch commercial building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	5,000,000	7,940	1	2013	26.78	56.76	15.20
2	2,000,000	2,340	1	2008	34.25	60.00	20.55
3	22,000,000	5,460	13	2008	3.14	49.21	1.55
4	70,840	33	1	2014	9.99	77.78	7.77
5	7,500,000	8,000	1	2012	26.47	60.00	15.88
6	13,000,000	34,100	1	2005	41.35	58.33	24.12
7	2,750,000	1,300	2	2013	13.13	53.33	7.00
8	4,700,000	3,900	1	2013	7.30	64.71	4.72
						Average	**12.10**

Appendix F1.3

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Wellington commercial building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	13,200,000	10,500	1	2011	16.19	61.54	9.96
2	120,000,000	48,000	15	2010	20.13	18.75	3.77
3	10,000,000	4,000	1	2013	16.53	56.52	9.34
4	6,000,000	5,000	2	2011	4.00	29.73	1.19
5	8,000,000	8,000	1	2011	18.37	42.86	7.87
6	2,000,000	800	2	2011	23.08	53.85	12.43
7	55,000,000	14,500	10	2010	1.79	20.00	0.36
8	100,000,000	30,000	12	2011	3.10	33.33	1.03
						Average	**5.74**

Appendix F2 (Productivity Improvement Analysis: Community Buildings)

Appendix F2.1

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Auckland community building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	6,000,000	2,000	2	2011	13.04	22.22	2.90
2	12,000,000	20,000	7	2012	13.04	36.84	4.81
3	7,000,000	2,500	1	2013	57.89	48.84	28.27
4	2,250,000	650	2	2012	23.73	35.71	8.47
5	7,400,000	3,415	3	2009	23.97	33.33	7.99
6	900,000	365	1	2011	6.95	11.11	0.77
7	16,000,000	8,000	5	2006	20.00	20.00	4.00
						Average	**8.17**

Appendix F2.2

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Christchurch community building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	7,000,000	1,600	2	2009	20.45	36.36	7.44
2	22,000,000	7,600	1	2012	1.87	38.89	0.73
3	3,500,000	2,300	1	2012	23.91	69.70	16.67
4	6,300,000	2,300	2	2012	23.91	50.00	11.96
5	171,350	500	1	2011	70.83	77.78	55.09
6	13,000,000	2,100	3	2014	68.66	29.41	20.19
7	563,706	304	1	2013	50.55	73.68	37.25
						Average	**21.33**

Appendix F2.3

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Wellington community building case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	14,000,000	3,200	1	2008	32.17	43.33	13.94
2	6,500,000	2,200	2	2011	6.20	36.84	2.29
3	9,800,000	1,800	1	2014	2.00	37.78	0.76
4	2,060,000	850	1	2003	59.29	59.38	35.20
5	625,000	194	1	2014	-9.21	81.82	-7.53
6	5,500,000	500	1	2009	33.33	52.38	17.46
7	1,400,000	3,748	1	2008	94.21	48.48	45.68
						Average	**15.40**

Appendix F3 (Productivity Improvement Analysis: Educational Buildings)

Appendix F3.1

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Auckland educational buildings case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	5,300,000	3,896	3	2008	10.25	73.33	7.52
2	2,000,000	1,210	2	2013	8.89	43.48	3.87
3	1,600,000	1,050	2	2013	7.65	38.10	2.91
4	25,700,000	12,000	3	2009	5.65	50	2.83
5	12,500,000	7,100	2	2012	4.94	35.29	1.74
6	10,000,000	1,824	1	2009	9.50	30.77	2.92
7	16,500,000	8,300	7	2004	5.34	31.82	1.70
8	6,000,000	3,320	2	2010	10.75	22.58	2.43
9	74,000,000	20,000	12	2013	3.90	22.22	0.87
10	9,200,000	3,000	2	2011	5.64	2.70	0.15
11	750,000,000	19,500	12	2012	4.46	20.00	0.89
12	28,000,000	10,600	10	2005	5.66	29.17	1.65
						Average	**2.46**

Appendix F3.2

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Christchurch educational buildings case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	10,000,000	2,400	2	2005	-2.04	25.00	-0.51
2	26,500,000	14,976	1	2011	33.23	66.67	22.15
3	35,000,000	7,000	2	2014	4.63	53.33	2.47
4	3,300,000	700	1	2014	9.49	78.57	7.46
5	1,340,000	850	2	2011	18.11	36.00	6.52
6	1,000,000	800	1	2010	33.33	33.33	11.11
7	3,400,000	2,655	1	2014	58.69	42.86	25.15
						Average	**10.62**

Appendix F3.3

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Wellington educational buildings case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	16,200,000	3,600	5	2012	19	55.56	10.56
2	40,000,000	13,500	11	2009	7.41	44.44	3.29
3	1,400,000	600	1	2009	11.95	45.45	5.43
4	6,200,000	5,000	4	2012	35.58	33.33	11.86
5	2,400,000	1,811	2	2012	31.16	50.00	15.58
6	1,900,000	11,040	1	2009	91.60	33.33	30.53
7	5,400,000	5,950	2	2010	52.23	40.00	20.89
						Average	**14.02**

Appendix F4 (Productivity Improvement Analysis: House)

Appendix F4.1

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Auckland houses case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	141,000	70	1	2014	0.53	25.00	0.13
2	166,800	100	1	2014	16.22	20.00	3.24
3	158,750	100	1	2014	20.27	20.00	4.05
4	252,000	115	1	2014	-9.77	45.45	-4.44
5	280,900	140	1	2014	-4.99	50.00	-2.50
6	112,000	60	1	2014	2.32	50.00	1.16
7	168,000	90	1	2014	2.32	55.56	1.29
8	119,000	114	1	2013	28.99	25.00	7.25
9	196,000	98	1	2013	-36.05	20.00	-7.21
10	74,150	45	1	2014	13.77	40.00	5.51
11	89,930	59	1	2014	20.24	50.00	10.12
12	87,840	60	1	2014	23.39	50.00	11.70
13	93,920	68	1	2014	27.72	41.67	11.55
14	94,830	69	1	2014	28.08	41.67	11.70
15	94,200	70	1	2014	29.58	50.00	14.79
16	107,900	86	1	2014	34.35	55.56	19.08
17	128,220	93	1	2014	27.85	55.56	15.47
18	129,350	97	1	2014	30.22	60.00	18.13
19	144,790	102	1	2014	25.72	55.00	14.15
20	153,000	105	1	2014	23.75	59.09	14.03
21	166,040	109	1	2014	20.29	59.09	11.99
22	146,570	111	1	2014	30.90	55.00	17.00
23	149,200	113	1	2014	30.91	54.55	16.86
24	155,950	114	1	2014	28.42	50.00	14.21
25	162,860	116	1	2014	26.53	50.00	13.27
26	183,480	120	1	2014	19.99	54.55	10.90
27	166,790	121	1	2014	27.87	66.67	18.58
28	179,850	125	1	2014	24.71	62.50	15.44
29	179,050	135	1	2014	30.60	65.38	20.01
30	171,200	122	1	2014	26.57	66.67	17.71
31	191,690	147	1	2014	31.76	67.86	21.55
32	156,780	118	1	2014	30.47	65.00	19.81
33	196,980	153	1	2014	32.63	57.14	18.65
						Average	**11.07**

Appendix F4.2

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Christchurch houses case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	192,158	105	1	2013	0.44	62.50	0.27
2	421,800	228	2	2013	5.13	75.00	3.85
3	426,280	232	1	2013	2.23	73.33	1.63
4	462,520	248	2	2013	3.12	75.00	2.34
5	311,460	170	1	2013	0.97	75.00	0.72
6	284,160	160	1	2013	4.00	75.00	3.00
7	563,706	304	1	2013	50.55	73.68	37.25
8	248,421	156	1	2014	6.33	73.33	4.64
9	143,346	66	1	2014	9.03	70.00	6.32
10	534,000	215	1	2013	33.77	72.50	24.48
11	250,000	208	1	2010	29.30	64.29	18.83
						Average	**9.39**

Appendix F4.3

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Wellington houses case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	276,358	147	1	2013	2.90	75	2.17
2	283,954	158	1	2013	0.16	75	0.12
3	392,175	225	1	2013	3.17	75	2.38
4	416,432	228	2	2013	3.25	75	2.43
5	509,608	278	1	2013	25.18	75	18.88
6	227,184	105	1	2013	9.85	70	6.89
7	346,182	199	1	2013	3.36	73.33	2.46
						Average	**5.05**

Appendix F5 (Productivity Improvement Analysis: Apartment Buildings)

Appendix F5.1

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Auckland apartment buildings case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	6,300,000	3,887	3	2011	39.52	40.54	16.02
2	7,200,000	3,218	2	2003	10.50	25.00	2.63
3	40,000,000	25,000	4	2005	20.99	19.23	4.04
4	25,000,000	6,700	18	2010	15.24	15.00	2.29
5	8,900,000	2,500	14	2011	25.80	29.41	7.59
6	10,000,000	2,700	2	2010	7.41	13.51	1.00
7	4,100,000	2,266	3	2007	24.61	14.29	3.52
						Average	**5.30**

Appendix F5.2

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Christchurch apartment buildings case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvement
1	6,700,000	2,317	2	2014	5.19	47.37	2.46
2	15,000,000	4,770	3	2008	6.96	29.63	2.06
3	5,100,000	1,872	2	2014	19.51	40.54	7.91
4	5,900,000	3,076	3	2010	9.52	21.05	2.00
5	2,880,000	840	2	2010	4.23	41.94	1.77
6	3,580,000	1,984	2	2013	11.98	73.68	8.83
7	3,200,000	2,280	2	2014	31.54	67.65	21.33
						Average	**6.62**

Appendix F5.3

Analysis of productivity improvement achieved by using prefabrication technology in place of traditional building system: Wellington apartment buildings case studies

Project	Project Cost ($)	Gross Floor Area (m2)	Storey	Year Completed	Percentage Cost Savings	Percentage Time Saving	Percentage Productivity Improvemen t
1	50,000,000	7000	11	2014	4.76	33.33	1.59
2	42,000,000	8000	16	2014	7.69	29.17	2.24
3	12,500,000	4561	11	2011	20.10	33.33	6.70
4	180,000,000	27000	12	2009	11.11	33.33	3.70
5	300,900	990.66	2	2014	90.51	81.25	73.54
6	4,000,000	4656	4	2012	52.27	45.00	23.52
7	2,000,000	1243	4	2000	26.86	38.89	10.45
						Average	**17.39**

Appendix G: Analysis of Survey Responses

Appendix G1 (Cost Saving Analysis of Survey Responses)

Analysis of prefabrication cost savings for commercial buildings

Rating interval	0.26 - 0.30	0.21 - 0.25	0.16 - 0.20	0. 10 - 0.15	Other (open-ended)	
Average cost saving	0.28	0.23	0.18	0.125	0.08	0.05
No. of responses	24	26	33	3	1	1
					Total participants	88
					Average	0.217
					Standard deviation	0.0411
					Mode	0.18

Analysis of prefabrication cost savings for educational buildings

Rating interval	0.26 - 0.30	0.21 - 0.25	0.16 - 0.20	0. 10 - 0.15	Other (open-ended)	
Average cost saving	0.28	0.23	0.18	0.125	0.08	
No. of responses	32	35	16	7	1	
					Total participants	91
					Average	0.23
					Standard deviation	0.002
					Mode	0.23

Analysis of prefabrication cost savings for community buildings

Rating interval	0.26 - 0.30	0.21 - 0.25	0.16 - 0.20	0. 10 - 0.15	Other (open-ended)	
Average cost saving	0.28	0.23	0.18	0.125	0.03	
No. of responses	44	19	16	10	1	
					Total participants	90
					Average	0.23
					Standard deviation	0.003
					Mode	0.28

Analysis of prefabrication cost savings for apartment buildings

Rating interval	0.26 - 0.30	0.21 - 0.25	0.16 - 0.20	0. 10 - 0.15	Other (open-ended)	
Average cost saving	0.28	0.23	0.18	0.125	0.05	
No. of responses	22	35	26	7	1	
					Total participants	91
					Average	0.22
					Standard deviation	0.043
					Mode	0.23

Analysis of prefabrication cost savings for house buildings

Rating interval	0.26 - 0.30	0.21 - 0.25	0.16 - 0.20	0. 10 - 0.15	Other (open-ended)	
Average cost saving	0.28	0.23	0.18	0.125	0.04	0.05
No. of responses	30	22	24	13	1	1
					Total participants	91
					Average	0.21
					Standard deviation	0.043
					Mode	0.28

Appendix G2 (Time Saving Analysis of Survey Reponses)

Analysis of prefabrication time savings for commercial buildings

Rating interval	0.51-0.55	0.46-0.50	0.41-0.45	0.35-0.40	Other (open-ended)	
Average time saving	0.53	0.48	0.43	0.375	0.02	0.025
No. of responses	8	25	38	15	1	1
					Total participants	90
					Average	0.43
					Standard deviation	0.167
					Mode	0.43

Analysis of prefabrication time savings for education buildings

Rating interval	0.51-0.55	0.46-0.50	0.41-0.45	0.35-0.40	Other (open-ended)	
Average time saving	0.53	0.48	0.43	0.375	0.02	
No. of responses	24	28	19	16	1	
					Total participants	89
					Average	0.45
					Standard deviation	0.185
					Mode	0.48

Analysis of prefabrication time savings for community buildings

Rating interval	0.51-0.55	0.46-0.50	0.41-0.45	0.35-0.40	Other (open-ended)	
Average time saving	0.53	0.48	0.43	0.375	0.02	0.015
No. of responses	33	25	19	9	1	1
					Total participants	88
					Average	0.47
					Standard deviation	0.193
					Mode	0.53

Analysis of prefabrication time savings for apartment buildings

Rating interval	0.51-0.55	0.46-0.50	0.41-0.45	0.35-0.40	Other (open-ended)	
Average time saving	0.53	0.48	0.43	0.375	0.02	0.015
No. of responses	11	42	18	16	1	1
					Total participants	89
					Average	0.45
					Standard deviation	0.178
					Mode	0.48

Analysis of prefabrication time savings for house buildings

Rating interval	0.51-0.55	0.46-0.50	0.41-0.45	0.35-0.40	Other (open-ended)		
Average time saving	0.53	0.48	0.43	0.375	0.02	0.015	0.062
No. of responses	40	15	19	5	1	1	1
					Total participants	82	
					Average	0.47	
					Standard deviation	0.184	
					Mode	0.53	

Appendix G3 (Productivity Improvement Analysis of Survey Reponses)

Analysis of prefabrication productivity improvement for commercial buildings

Rating interval	0.101-0.12	0.081-0.1	0.061-0.08	0.04-0.06
Average productivity improvement	0.11	0.09	0.07	0.05
No. of responses	3	46	30	11
		Total participants		91
		Average		0.078
		Standard deviation		0.005
		Mode		0.09

Analysis of prefabrication productivity improvement for educational buildings

Rating interval	0.101-0.12	0.081-0.1	0.061-0.08	0.04-0.06
Average productivity improvement	0.11	0.09	0.07	0.05
No. of responses	14	39	29	8
		Total participants		91
		Average		0.082
		Standard deviation		0.005
		Mode		0.09

Analysis of prefabrication productivity improvement for community buildings

Rating interval	0.101-0.12	0.081-0.1	0.061-0.08	0.04-0.06
Average productivity improvement	0.11	0.09	0.07	0.05
No. of responses	25	27	26	11
		Total participants		90
		Average		0.084
		Standard deviation		0.005
		Mode		0.09

Analysis of prefabrication productivity improvement for apartment buildings

Rating interval	0.101-0.12	0.081-0.1	0.061-0.08	0.04-0.06
Average productivity improvement	0.11	0.09	0.07	0.05
No. of responses	6	46	28	9
		Total participants		90
		Average		0.08
		Standard deviation		0.0052
		Mode		0.09

Analysis of prefabrication productivity improvement for apartment buildings

Rating interval	0.101-0.12	0.081-0.1	0.061-0.08	0.04-0.06
Average productivity improvement	0.11	0.09	0.07	0.05
No. of responses	24	31	24	11
		Total participants		91
		Average		0.084
		Standard deviation		0.006
		Mode		0.09

Appendix G4 (Factors Influencing Prefabrication Benefits: Survey Reponses)

Factors influencing prefabrication added benefits

Factors	Mean Rating	Std. Deviation	*Remark
1) Building Type	4.9	0.301	Very high
2) Location	4.71	0.461	Very high
3) Logistics	4.58	0.502	Very high
4) Prefabrication Type	4.55	0.506	Very high
5) Scale/Repeatability	4.42	0.502	Very high
6) Standardisation/Customisation	4.39	0.495	Very high
7) Contractor's Innovation	4.29	0.461	Very high
8) Environmental Impact	3.81	0.792	High
9) Project Leadership	3.68	0.832	High
10) Procurement Type	3.61	0.715	High
11) Whole of life Quality	3.61	0.715	High
12) Site Conditions	3.52	0.677	High
13) Site Layout	3.52	0.811	High
14) Client nature	3.48	0.769	High
15) Contract Type	3.39	0.615	Moderate
16) Weather Condition	3.39	0.558	Moderate
17) Subsoil Proportion	3.03	0.875	Moderate

**Remark: "Very high" = 4.201 $\leq$ Mean $\leq$ 5; "High" = 3.401 $\leq$ mean $\leq$ 4.2; "Moderate" = 2.601 $\leq$ mean $\leq$ 3.4; "Low" = 1.801 $\leq$ mean $\leq$ 2.6; "Very low" = 1.00 $\leq$ mean $\leq$ 1.8*

Appendix G5 (Percentage Cost Savings: Survey Reponses)

Percentage Cost Savings

Cost savings achievable using prefabrication over traditional building systems across building types using t-test

	Percentage cost savings for building categories				
	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartments
Average Cost Savings	18.63	30.32	21.55	13.40	21.25
Standard Deviation	4.2	5.95	11.7	5.5	7.3
Degree of Freedom n-1	2.0	2.0	2.0	2.0	2.0
t-value	4.3	4.3	4.3	4.3	4.3
t*s/sqr(n)	10.37	14.78	29.10	13.55	18.06
μ - t*s/sqr(n)	8.27	15.54	-7.55	-0.15	3.19
Range of cost savings at 95% confidence					
Max value	29.00	45.11	50.66	26.94	39.31
Min value	8.27	15.54	-7.55	-0.15	3.19

Cost savings achievable using prefabrication over traditional building systems across locations using t-test

	Percentage cost savings achieved across locations		
	Auckland	Christchurch	Wellington
Average Cost Saving	34.37	55.89	50.05
Standard Deviation	9.04	10.43	14.13
Degree of Freedom n-1	4.00	4.00	4.00
t-value:	2.78	2.78	2.78
t*s/sqr(n)	12.55	14.49	19.62
μ - t*s/sqr(n)	21.81	41.40	30.43
Range of cost at 95% confidence			
Max Value	46.92	70.37	69.67
Min Value	21.81	41.40	30.43

Appendix G6 (Percentage Time Savings: Survey Reponses)

Percentage Time Savings

Time savings achievable using prefabrication over traditional building systems across building types using t-test

	Percentage time savings achieved for building categories				
	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartments
Average Time Saving	45.39	44.95	41.47	65.22	36.82
Standard Deviation	10.4	10.80	6.1	10.9	10.3
Degree of Freedom n-1	2.0	2.0	2.0	2.0	2.0
t-value:	4.3	4.3	4.3	4.3	4.3
t*s/sqr(n)	25.86	26.84	15.18	27.15	25.59
μ - t*s/sqr(n)	19.53	18.11	26.29	38.07	11.23
Range of time savings at 95% confidence					
Max value	71.25	71.79	56.65	92.36	62.41
Min value	19.53	18.11	26.29	38.07	11.23

Time savings achievable using prefabrication over traditional building systems across locations using t-test

	Percentage time savings across locations		
	Auckland	Christchurch	Wellington
Average Time Saving	34.37	12.01	11.52
Standard Deviation	9.04	5.58	5.72
Degree of Freedom n-1	4.00	4.00	4.00
t-value:	2.78	2.78	2.78
t*s/sqr(n)	12.55	7.75	7.95
μ - t*s/sqr(n)	21.81	4.26	3.58
Range of time saving at 95% confidence			
Max Value	46.92	19.76	19.47
Min Value	21.81	4.26	3.58

Appendix G7 (Percentage Productivity Improvement: Survey Reponses)

Percentage Productivity Improvement

Productivity improvement achievable using prefabrication over traditional building systems across building types using t-test

	Percentage productivity improvement for building categories				
	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartments
Average Productivity Improvement	8.87	14.97	9.03	8.50	9.77
Standard Deviation	2.6	5.38	4.9	2.5	5.4
Degree of Freedom n-1	2.0	2.0	2.0	2.0	2.0
t-value:	4.3	4.3	4.3	4.3	4.3
t*s/sqr(n)	6.45	13.37	12.06	6.30	13.45
μ - t*s/sqr(n)	2.42	1.60	-3.02	2.20	-3.68
Range of productivity improvement at 95% confidence					
Max value	15.32	28.33	21.09	14.80	23.23
Min value	2.42	1.60	-3.02	2.20	-3.68

Productivity improvement achievable using prefabrication over traditional building systems across locations using t-test

	Percentage productivity improvement achieved across locations		
	Auckland	Christchurch	Wellington
Average Productivity Improvement	7.15	12.01	11.52
Standard Deviation	2.98	5.58	5.72
Degree of Freedom n-1	4.00	4.00	4.00
t-value:	2.78	2.78	2.78
t*s/sqr(n)	4.14	7.75	7.95
μ - t*s/sqr(n)	3.01	4.26	3.58
Range of productivity improvement at 95% confidence			
Max Value	11.29	19.76	19.47
Min Value	3.01	4.26	3.58

Appendix H: Comparison of Case Studies and Survey Responses

Appendix H1 (Cost Saving Analysis)

<u>Comparison of Cost Saving Analysis</u>

Comparison of cost savings benefits analysed from case studies and survey feedback

Building type:	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartmen ts
Case study analysis:					
Average Cost Savings	18.63	30.32	21.55	13.40	21.25
t-value:	4.2	5.95	11.7	5.5	7.3
Max cost saving value	29.00	45.11	50.66	26.94	39.31
Min cost saving value	8.27	15.54	-7.55	-0.15	3.19
Survey analysis:					
Average Cost Savings	21.80	23.20	22.90	21.40	21.80
Result: Survey average vs case study interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval

Appendix H2 (Time Saving Analysis)

Comparison of Time Saving Analysis

Comparison of time savings benefits analysed from case studies and survey feedback

Building Type	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartments
Case study analysis:					
Average Time Savings	45.39	44.95	41.47	65.22	36.82
t-value:	10.4	10.80	6.1	10.9	10.3
Max value	71.25	71.79	56.65	92.36	62.41
Min value	19.53	18.11	26.29	38.07	11.23
Survey analysis:					
Average Cost Savings	42.50	46.60	45.40	46.90	44.70
Result: Survey average vs case study interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval

Appendix H3 (Productivity Improvement Analysis)

Comparison of Productivity Improvement Analysis

Comparison of productivity improvement benefits analysed from case studies and survey feedback

Building Type	Commercial Buildings	Community Buildings	Educational Buildings	Houses	Apartments
Case study analysis:					
t-value	3.2	6.59	5.9	3.1	6.6
Max value	15.32	28.33	21.09	14.80	23.23
Min value	2.42	1.60	-3.02	2.20	-3.68
Survey analysis:					
Average Productivity Improvement	7.80	8.40	8.20	8.40	8.00
Result: Survey average vs case study interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval	Fits within interval