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OFF-SITE MANUFACTURING AS A MEANS OF IMPROVING PRODUCTIVITY IN NEW ZEALAND CONSTRUCTION INDUSTRY: KEY BARRIERS TO ADOPTION AND IMPROVEMENT MEASURES

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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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ABSTRACT

Off-site manufacturing (OSM) of building components could be leveraged to improve the reported low productivity trend in the New Zealand (NZ) construction industry. Despite the numerous known benefits of OSM, the uptake of the technology in the industry has been discouragingly low. Previous studies offer little help in terms of prioritising identified barriers to the uptake of OSM. As a result, improvement efforts have been daunted by numerous barriers in the face of limited resources. This study aims to contribute to bridging the gap in the extant literature by identifying and prioritising the key constraints to the industry-wide uptake of prefabrication and the improvement measures. Through a nation-wide survey of consultants, contractors, employers and manufacturers, feedback was received and analysed using the multi-attribute analytical technique. Results show that the broad categories of constraints to the adoption of prefabrication in NZ are (in order of decreasing impact and relative contributions): industry and market culture (16.2%), skills and knowledge (15.5%), logistics and site operations (14.8%), cost/value/productivity (14%), supply chain and procurement (13.7%), process and programme (13.6%), and regulatory (12.2%). The subcomponents of the broad constraint categories and their relative levels of impact on the uptake of the technology were reported. In addition to addressing the key barriers identified in the study, further measures for improving the uptake of the technology in New Zealand include promotion by client through specifying OSM in the design briefs, improved education and training on the use of OSM, more marketing/ awareness campaign on the benefits of the technology and better supply chain management and transportation logistics.

To enable a methodical evaluation of the marginal value achievable by the use of a variant of OSM over and above that of the traditional stick-built system at the design and life-cycle phases of the procurement process, a decision support model was developed. The model incorporates the key performance indicators (KP1s) underlying clients' value system at the development and operational phases and compares the extent to which each variant of OSM delivers each value criterion relative to the conventional system. The sum of the marginal values at each phase of the procurement system provides the rationale basis for choosing either the OSM variant or the conventional system based on the approach that delivers the highest marginal value.

The model application to real life project was demonstrated using the modular variant of the OSM compared to the conventional stick-built system. Results of the model application at the development phase shows that the OSM was more beneficial to the client than the conventional system with an overall marginal value of 34% relative to the conventional construction approach. Individual results showed 22% improvement in the completion time for the project, 9% improvement in quality and 3% reduction in the carbon footprint at the development phase. However, the technology was found to be 2.4% more expensive than the traditional stick-built system.

Results of the model application at the operation and life-cycle phases also show that the technology achieved superior value compared to the conventional stick-built system. The overall marginal value achieved by the modular OSM application at the operation phase was 49% compared to the traditional stick-built system; this comprised 23% reduction in the running and maintenance costs, 18% reduction in the maintenance frequency of the structure and fabric, and an annual 8% reduction in the carbon footprint.

Overall, the use of modular variant of the OSM was found to deliver superior value to clients compared to the conventional system at the development, operational and life-cycle phases of the procurement process.

Keywords: Modularization, New Zealand construction industry, Off-site manufacture, Prefabrication, Productivity improvement.

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DEDICATION

I dedicate this thesis to my father, Gulzar Ahmed (Rest in Peace), who departed for the eternal world on 20th August 2010.

I wish to tell him that he will always be in my heart and I can never stop missing him.

Daddy, you are truly missed!

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Chapter 1. Introduction

1.0 Overview

This chapter presents an overview of thesis starting with the background to Off-site manufacturing (OSM), its drivers and challenges. The chapter also discusses the need for the study as part of the research problem statement, the research objectives, propositions put forward to guide the research design and data gathering, the conceptual framework of the study, scope and limitations, and the importance of the research findings. The structure of the thesis is presented at the end of chapter.

1.1. Background

The construction industry of New Zealand contributes more than 5 percent of the Gross Domestic Product (GDP) with the total capital spent in the building and construction sector averaging more than $20 billion per annum (DBH, 2008). The industry as the consumer of the services and products of allied industries also contributes significantly to the social well-being of any nation by not only employing a significant portion of the workforce but also strengthening the allied industries financially to provide and maintain employment for the teeming population. The Committee on Advancing the Competitiveness and Productivity of the U.S. Construction Industry (CACPUCI, 2009) defines construction industry productivity as “how well, how quickly, and at what cost buildings and infrastructure can be produced” (p.10). Hence it is of critical concern given its significant impact on the economy and the price to consumers of the goods and services produced by the industry.

However, the productivity of the New Zealand construction industry is very poor as evident in the Report of a taskforce commissioned by the Department of Building and Housing (DBH, 2009). The Report hints that “productivity, especially labour productivity has been disappointing and is limiting the sector’s ability to respond positively to change”. Davis (2007) submits that the productivity of the New Zealand construction sector is quite low relative to other OECD countries; the author notices a steady decline in labour productivity trend in the New Zealand construction sector from

1997 to 2008, while steady increase was reported for the economy as a whole during the same period.

In order to improve the productivity and performance in the U.S. construction industry CACPUCI (2009) has identified greater use of prefabrication, preassembly, modularization and off-site fabrication techniques and processes as one of the five interrelated sets of activities. Similarly, in EU increasing industrialised building systems with standardised modules and prefabrication are used to improve the productivity and performance in the construction industry (Gurdjian and Andonian, 2003).

The global recommendations of the use of OSM technology as productivity improvement measure are based on the various benefits associated with its use. These include shorter project duration and better quality control (Gibb, 1999); improved onsite safety, less environmental degradation and cost (Gibb, 1999; Lu, 2009; Lusby-Taylor *et al.*, 2004). Haas *et al.* (2000) also note that OSM has a tendency to address the recurring problems of the construction industry such as cost escalation, project delay and workforce issues.

However, in spite of the known benefits of the OSM, The uptake of the technology is discouragingly low in the construction industry (Gibb and Isack, 2003). Several studies have been carried out to identify the barriers which are responsible for the current low uptake of the technology within the construction industry. For instance, Chiang *et al.*(2006) and Tam *et al.* (2007) report various hindrances to the use of OSM in Hong Kong construction industry to include preference to the traditional construction methods, resistance to change, risk evasiveness and concerns for high set-up costs. Similar constraints were also found in the UK construction industry in various studies (Goodier and Gibb, 2007; Pasquire *et al.*, 2004).

Given the potential of the OSM to make a difference in the reported poor productivity and performance of the New Zealand construction industry, this study aims to contribute to the investigation of ways for improving the uptake of the technology in New Zealand. Focus is on the identification and prioritisation of the key barriers to the uptake of the technology and ways for improvement.

1.2. Statement of Research Problem

The construction industry can benefit in several ways from off-site manufacturing process (Tam *et al.*, 2007), including significant improvement in productivity and performance. The technology is therefore quite relevant to the construction industry of New Zealand given the reported steady decline in the productivity of the construction industry. Becker (2005) reports on the low application of OSM technology in New Zealand construction industry as a result of some barriers. However, the literature is replete with barriers to the uptake of OSM in the construction.

A critical gap identified in literature is the fact that the identified barriers were so overwhelming with little attempt to prioritise them according to their relative levels of influence. This would have enabled optimum disbursement of the available resources to addressing those barriers that have significant impact on the uptake of the technology. Again, there is little information on a methodical approach for a quantitative or qualitative assessment of the overall benefit of OSM compared to the traditional systems.

This study aims to contribute to filling this gap by not only identifying barriers that are relevant to the New Zealand construction industry context, but also providing a qualitative assessment of the relative levels of impact of the barriers. This way, practitioners could target the barriers that are of critical significance in line with the resource budget available. The study also aims to provide a conceptual framework for comparing value addition achievable by the OSM compared to the traditional approach.

1.3. Research Objectives

The specific objectives of the study are as follows:

1. To identify the key barriers to the uptake of the OSM in the New Zealand construction industry context;
2. To prioritise the identified barriers in terms of their relative levels of influence as constraint factors;
3. To explore effective strategies for improving industry-wide uptake of the technology;

4. To develop a decision support model for a methodical evaluation of the marginal value offered by the use of OSM relative to that of the conventional method of construction in terms of meeting the needs and preferences of clients in the procurement process.

1.4. Propositions

The following propositions provide directions to the formulation of the research strategy and the methods of data collection and analysis in order to achieve the set research objectives.

1. Consensus of opinions exists on the relative levels of impact of the broad categories of constraints to the uptake of OSM between the two major stakeholder groupings i.e. the clients and agents as the employer group, versus the contractors and the suppliers/manufacturers as the contract services group.

2. Logistics and site operation issues constitute the most significant group of factors constraining the uptake of OSM in New Zealand construction industry.

1.5. Scope and Limitations

The scope of this study was limited to the New Zealand construction industry. The study was based on the feedback collected from the stakeholders in the New Zealand construction industry; it therefore presents only the picture of construction industry in New Zealand.

Due to privacy issues related to the Privacy Act 1993, it was not possible to obtain the membership directories of the various trade and professional organisations to which the questionnaires were sent; this made it impossible to compare the proportions of the feedback received with the total number of members in each sampling frame for representation analysis.

Time constraints did not permit scouting for the sufficient data for the model application in relation to the whole building, hybrid and component/element variants of the OSM technology versus the conventional systems; therefore only the modular variant of OSM technology was compared against the conventional approach.

1.6. Importance of Research Findings

The research indentifies the key constraints to the adoption of OSM in New Zealand construction industry. It determines the relative levels of influence of the underlying constraints under each broad category of constraints.

The study also explores various measures to address the critical constraints to the uptake of OSM, in order to improve the application of OSM technology and hence leverage the numerous benefits for improving productivity in the New Zealand construction industry.

The study determines the suitability of OSM application for different types of buildings and general infrastructure projects. It further illustrates the suitability of the various building components manufactured off-site for improving the productivity of construction process.

In addition, a decision support model was developed as a methodical approach for determining the extent of improvement in value or productivity that can be achieved by the use of OSM in place of conventional construction methods.

1.7. Structure of the Thesis

The Thesis comprises six chapters. The composition of each chapter is highlighted as follows.

Chapter 1 is the introduction to the study; it highlights the background of OSM, statement of the research problem, research objectives, research propositions, scope of the study and the importance of the research findings.

Literature review carried out for this study is highlighted in Chapter 2. The chapter starts with the introduction of OSM technology and the various OSM related terms. It goes further to introduce the different types of OSM and the benefits of using OSM technology. Next sections of this chapter highlight the global trends of OSM, OSM in New Zealand construction industry and identification of barriers constraining the uptake of OSM. The chapter ends with summary of the valuable insights gained from the literature and the knowledge gaps that exist. The chapter ends with the highlight of the conceptual framework for the study.

The methodology adopted for the study is documented in Chapter 3. The chapter discusses all the key steps involved in the research including data collection, selection of sampling frames, sampling methods employed, development of data collection tool and its compliance with Massey University's Code of Ethical Conduct. The chapter further discusses the administration of the industry-wide survey, analysis and triangulation of collected data and the development of the research model.

Chapter 4 presents the analysis of the data collected during the administration of questionnaire survey in light of the research objectives. A connection of these finding is made to the relevant literature. Further to this, improvement measures are suggested to overcome the various barriers constraining the uptake of OSM in the New Zealand context.

Chapter 5 covers the testing of the research propositions and the development of the research model. Also the results of the tests carried out for the propositions, along with their conclusions are presented. The later sections present the structure, components, working and testing of the research model.

Chapter 6 provides the conclusions drawn from the study and makes recommendations for future research.

Chapter 2. Literature Review

2.1. Overview

This chapter provides an insight on the various concepts of off-site manufacturing (OSM) of building components based on the review of existing literature. It discusses various OSM related topics including OSM in context, origin and current state of OSM, types of OSM, potential benefits of using OSM method of construction, comparison of OSM technology with the conventional methods of construction, challenges associated with the use of OSM and most importantly the identification of barriers which are constraining the uptake of this technology in construction industry. At the end of this chapter a summary of literature review is provided which explains the extent to which the previous studies have contributed to partial achievement of the research objectives, with emphasis on the gaps identified in the literature and how this research aimed to contribute to filling the identified gaps. The conceptual framework for the study is presented drawing on the insights gained from the literature.

2.2. Off-site Manufacturing

Off-site manufacturing (OSM) can be described as the prefabrication of the key building components or assembly of building system at off-site locations (MBI, 2010a). This approach is somewhat different from the conventional construction methods, where the bulk of the building components are manufactured on-site (Arif and Egbu, 2010; Azman *et al.*, 2010; Pan *et al.*, 2007). OSM technology offers various benefits including shorter project duration, better quality control, improved onsite safety, less environmental degradation and reduced cost which results in improved productivity of the construction process (Gibb, 1999; Lu, 2009; Lusby-Taylor *et al.*, 2004) . The technology has not only been used to manufacture houses and multi storey buildings but also has been successfully employed to many civil engineering projects (Ngowi *et al.*, 2005). However, Tam *et al.* (2007) report that the current use of OSM technology so far has been unable to give satisfactory outputs to the construction industry. This finding does not agree with 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 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 five key ways for improving efficiency and productivity of the U.S. construction industry.

Mbachu (2009) sees OSM as a forerunner to mechanization and robotisation of the construction process, which have been successfully applied in the production sector with convincing results. Many researchers believe that OSM technology is the future of construction industry (Hampson and Brandon, 2004; Tam *et al.*, 2007).

2.3. OSM and Related Terms

Several terms have been used as synonyms to off-site manufacturing in the literature, including: pre-assembly, prefabrication, off-site production (OSP), off-site construction (OSC), off-site fabrication (OSF) and industrialized buildings. Another term used for off-site manufacturing is modern methods of construction (MMC). It is however very important to know the difference between MMC and OSM. OSM is a sub-set of MMC, therefore all OSM can fall under the MMCs but all MMCs are not off-site (Chris Goodier, 2007; Lusby-Taylor *et al.*, 2004).

The key aim of the use of OSM and related terminologies is to shift a large quantum of construction activities from construction site to remote places under a factory-controlled environment in order to achieve better quality, save cost and to shorten the construction time (Gibb and Isack, 2003; MBI, 2010a; Tatum *et al.*, 1986).

2.4. Types of OSM

Gibb (1999) lists four main types of OSM which are extensively used in the construction industry: panelised system, modular/ volumetric system, component/ non-volumetric system and modular/whole building system.

2.4.1. Panelised Building System

The concept of panelised building system (PBS) is based on the construction of the structural frame by making use of various building panels being manufactured in factory-controlled conditions. The building panels and components are manufactured in factory and then transported to construction site where they are assembled together to form a structural frame on a foundation specifically designed for this type of assembly. Langdon and Everest (2004) provide two main types of panelised systems: open and closed panels. Open panels are simpler and less complex forms such as simple timber or light steel frames, while closed panels are more complex forms that are factory-finished units complete with insulation, lining, windows, doors, and services.

Being manufactured under factory-controlled conditions, this system has the ability to be adapted easily to meet the building codes and standards of different city councils. Additionally, the system provides an opportunity to the builder to reduce overhead costs through transferring the bulk of on-site activities to the factory resulting in quicker on-site completion time.

Langdon and Everest (2004) report that the main market for panelised systems (in UK) is residential construction due to numerous benefits such as speed of construction, reduced exposure of the works programme to adverse weather and flexibility in terms of layout and room size.

2.4.2. Modular/Volumetric OSM

Modular or volumetric OSM is the type of OSM, where complete unit, providing usable space are built off-site. These units only form a part of the buildings and not the complete buildings. In volumetric OSM, the produced units are almost complete to be transported and installed in their respective positions within the building; they require only a small amount of work to be completed on-site. Some examples of modular systems include pods for various functional units such as rooms, bathrooms, toilets, plant rooms, lift shafts or service risers.

Langdon and Everest (2004) observe that the modular/ volumetric systems are usually more applicable for manufacturing in highly serviced areas or making of building modules in factory conditions.

2.4.3. Non-Volumetric OSM

Non-volumetric OSM includes pre-assembly of units which do not enclose usable space. Some examples of non-volumetric units are building services ductwork, precast concrete bridge sections, structural steelwork trusses etc. These are mostly the units which are preferably built off-site.

2.4.4. Whole Buildings

Whole buildings can also be constructed in the production yard, remote from the project site. The completed building is then transported to the project site for installation. All the jobs are done off-site except for the onsite service connections and foundation. These building solutions are different from mobile homes as they are installed permanently in their designated locations. Modular buildings can be used as temporary as well as permanent facilities, while providing solutions to building requirements in remote areas where skilled labour is in shortage. Modular buildings have shown great potential for reconstruction of disaster hit areas.

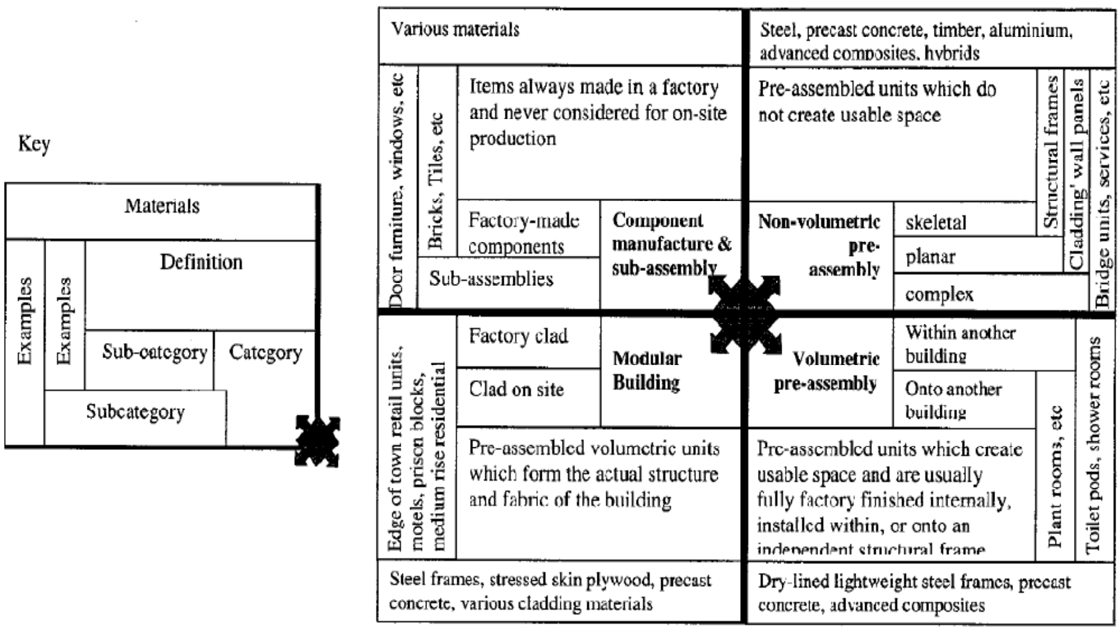

Figure 1: Types of OSM, definitions, subcategories, examples and main materials
[Source: (Gibb and Isack, 2003, p1)]

2.4.5. Hybrid systems

Hybrid systems enable the combination of the benefits of modules for highly serviced areas and the flexibility of the panelised systems for other functional areas of a building. Thus, the use of hybrid systems ensures speed of construction while maintaining sufficient flexibility required for adaptation of the design to unique site characteristics and wider on-site challenges. Langdon and Everest (2004) note that in addition to housing, the hybrid systems could equally be applied in public infrastructure projects where urgent construction is required, such as reconstruction programmes after disaster incidence.

Gibb and Isack (2003) provide a schematic illustration of the key types of OSM and the underlying components as shown in Figure 1.

2.5. Benefits of OSM

OSM is certainly not a new construction technology. The technology is globally regarded as efficient, cost effective, sustainable and of good quality. Figure 2 provides a model of the benefits accruable from the use of OSM in the construction process as adapted from the CRC (CRC, 2007b) study. Various benefits associated with off-site manufacture of building components have been well documented. Gibb (1999) provides a robust list of OSM benefits as follows:

- Allows prototype testing, which is particularly important for buildings planned in seismic zones. This enables greater predictability of project outcomes, which results in the reduction of defects and ultimately reducing the post-construction defect liability period.
- Improved supervision of materials and workmanship in factory-controlled environment enables manufacturing of good quality building components and subsequently results in good quality end product.
- Parallel activities taking place on-site and off-site reduces the overall construction completion time of the project.
- Factory manufactured components, which are ready to install on-site, shortens the duration of site activities.
- Reduces the wastage produced at construction site thereby minimising the carbon footprint of the development.

- Components are manufactured in remote areas and hence there is much less material handling on site, which results in better management of construction site.
- Can result in considerable saving of project cost.

In addition, (Jaillon and Poon, 2010) argue that OSM products are generally defect free, which is rare in case of site built projects. This is because an efficient quality control system is difficult to achieve onsite unlike factory environment.

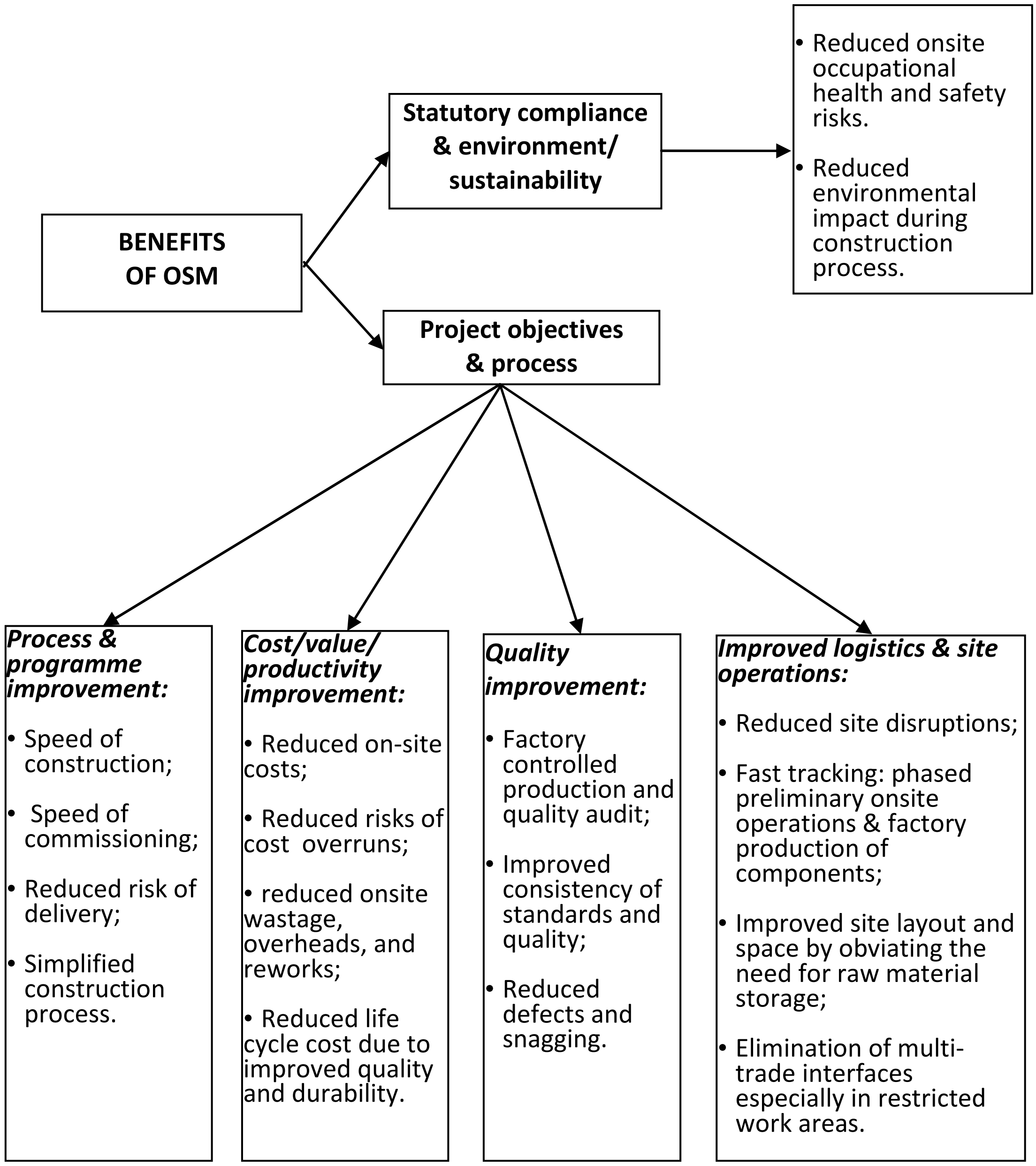

Figure 2: Benefits of OSM [Source: Adapted from CRC (2007)]

With the use of off-site manufacturing, there is a little requirement of storing material onsite, which reduces losses and misplacements (MBI, 2010a). Becker (2005) identifies the drivers of OSM in New Zealand construction industry as summarized in Figure 3.

Drivers of Off-site Production in New Zealand:

A) Speed of construction required by speculative/ volume market.

B) Cost certainty/minimizing remedial and on-site costs.

C) Quality failure of traditional on-site methods

D) Move towards weather resistant, better performing, better quality buildings

E) Review of contractual relationships following litigation.

F) Lack of on-site operative skills.

G) Focus on safety of building occupants due to structural failures.

H) Health and safety of operatives potentially easier to satisfy offsite.

I) Integrated supply chain.

J) Development of strategic partnerships may favour factory based production.

K) Failed environmental performance of on-site buildings.

L) Tradition of portable homes and relocation as opposed to demolition and re-build.

M) Historically timber based buildings.

N) Strong self build, holiday home and export markets adapted to offsite.

O) Immigration and population increasing rapid demand.

Figure 3: Driver of OSM [Source: (Becker, 2005, p23)]

Other benefits of OSM are as follows.

- Manufacturing of building components in factory controlled setup benefits the environment as less dust, noise and waste is generated during construction activities. In addition to this, OSM methods of construction consume less amount of energy (Luo, 2008).

- Off-site production of components can help overcome the problems associated with shortage of skilled labour, while meeting the market demands (MBI, 2010a; Nadim and Goulding, 2009).

- Heavy investments made by the manufacturer on setting up manufacturing units and providing required training to the workmen, provide the opportunity of stable employment (Bell, 2009).
- Off-site manufacturing is independent of weather conditions and the delays caused by the inclement weather are curtailed with the use of this approach (Bell, 2009).
- Off-site manufacturing is known to be resource-efficient and environment friendly (MBI, 2010a).

2.6. Comparison of OSM and Traditional Construction Methods

Goodier and Gibb (2007) note that the choice between the use of OSM and the traditional construction methods is usually based on development cost rather than the life cycle value of the project. However, the most appreciated advantage of using OSM over other methods of construction is its speed of construction.

OSM is more environmental friendly. Barret and Weidmann (2007) argue that when compared to traditional construction methods, OSM clearly outperforms the traditional construction approach in terms of green house gas emissions.

The MBI (2010a) Report provides the following comparison between OSM and the traditional construction methods.

- Comparatively, OSM provides potential for optimizing the use of construction material, minimizing waste and providing a high quality product to the clients.
- As the materials are kept and manufactured in factory-controlled environment, this eliminates the chances of moisture being trapped in fabric of the new construction after installation.
- As majority of components or modules are manufactured off-site, this reduces congestion on site. Similarly, the requirement of machinery and equipment is reduced on site.
- Construction workers at a site of conventionally built project are exposed to extreme weather conditions; temperature, rain and winds. Additionally there is a

potential of being injured due to falls and other site risks. Whereas, in factory conditions, a safe workplace is provided where the workers are fully equipped with the required tools and materials.

- An Australian study (CRC, 2007a) finds that modular construction schedule results in new buildings being open 30 – 50% sooner than the conventional construction schedule based on the ability to achieve simultaneous site development and building construction at the factory with the modular system.

In the UK, Wilson (2006) notes the advantages of using OSM methods of construction over the traditional methods of construction as follows:

- With the use of OSM, overall productivity of UK construction industry is increased by almost 2.5 times,
- OSM improved the productivity of the construction industry by 12 percent on- site and 2 percent off-site,
- Use of OSM resulted in reducing project delays by half that of existing traditional methods,
- Off-site manufacturing resulted in better planning and sequencing of all the construction activities, which resulted in further time saving,
- Construction materials were better organized and grouped in the factories with the use of OSM than on-site construction;
- OSM often has wide cost benefits, although some of these are difficult to evaluate besides higher initial set up cost required for establishing production facility.

A Hong Kong case study (Jailon and Poon, 2009) compared the use of OSM with traditional construction methods with the following findings.

- Use of OSM resulted in improved quality,
- OSM reduces the construction time by 20 percent compared to conventional methods of construction,

- The waste generated during the construction phase is reduced by 56 percent with the use of OSM method,
- Use of OSM presents considerable cost benefits to the developers.

In New Zealand, a number of prefab manufacturers (Degeest, 2011; StanleyGroup, 2011) claim that OSM has a number of benefits compared to the conventional method including easier to coordinate planning and programming of project, elimination of pilferage, earlier returns on investment, easier to develop in difficult and/ or remote sites, ability to work in bad weather conditions, easier to monitor quality standards, reduced material wastage, etc.

2.7. Global Trends of OSM

In the following sections trends of OSM are discussed in different countries.

2.7.1. OSM in the UK Construction Industry

National statistic (2005) highlights the trend of the UK construction industry towards the adoption of innovation including OSM. Off-site manufacturing was found to be around 2.1% of all construction or 3.6% of all new buildings (Goodier and Gibb, 2007). Taylor (2009) reports an increase of 25% market share of OSM each year in UK.

Phillipson (2003) advocates that in UK, off-site is very well taken option but still there are certain barriers which are constraining the utilization of its potential. These barriers are mostly hinged on the past experiences of OSM and particularly the negative stigma of poor quality construction with the use of OSM. Phillipson (2003) further reports that the UK housing market is most affected by the perceptions of OSM.

Pan *et al*. (2005) reports that the present application of OSM in the UK construction industry leans towards high rise residential buildings compared to the individual housing units.

Various benefits of using OSM realized by UK construction industry (Phillipson, 2003) are:

- Delivery of high quality construction products to client
- Overall enhanced productivity of the construction industry

- Improved profits for the contractors
- Environmental sustainability

"Buildoffsite" is an umbrella industry organization in UK, which is promoting the greater uptake of OSM technology in UK construction industry. Buildoffite is a coalition among the industry stakeholders – consultants, contractors, clients, developers, suppliers, manufacturers, government and researchers. This organization is very actively engaged in improving the quality and productivity of UK construction industry by the use of off-site manufacturing. The target of 'Buildoffsite' is to increase the current uptake of OSM by ten times.

2.7.2. OSM in the US Construction Industry

MBI (2010a) observe the US construction industry is facing shortage of skilled labour and declining number of new entrants is posing a challenge for the industry (Lu and Liska, 2008). Further to this, the clients want their projects to be completed on fast track basis, be cost effective and not to compromise the quality and safety compliance. Lu and Liska (2008) further identify OSM as the best way of overcoming the challenges faced by US construction industry.

In the U.S. the use of OSM is mostly for construction of industrial projects, whereas its application to commercial and infrastructure projects is less appealing (Azman *et al.*, 2010). It is believed that if used properly OSM can deliver lower cost projects, reduced project completion, better quality and efficient use of resources in the U.S. construction industry (MBI, 2010a). Widespread use of OSM, preassembly, off-site manufacturing and modularization is likely to improve the performance of U.S. construction industry (Industry, 2009).

2.7.3. OSM in the Australian Construction Industry

Blismas and Wakefield (2007) hint that, like all other developed economies, Australia has long recognised the use of off-site manufacturing and the various benefits associated with its application. But despite the known benefits of OSM the application of this technology is not widespread in Australia.

Cooperative Research Centre (CRC) which was established in 2001 to enhance construction innovation in Australia has taken a national initiative to develop an industry vision ‘Construction 2020’. The purpose of this initiative is to identify the future goals of the construction industry, investigate the constructs to achieve these goals and to explore the requirement of research. Off-site manufacture has been identified as a key vision for improving the industry during this effort (Hampson and Brandon, 2004).

The CRC (2007a) Report recognises the various benefits of using OSM in the Australian context, including: shortened construction time, simplification of construction processes, better control resulting in improved quality, cost reduction particularly when there is a shortage of resources, reduction in on-site risks, waste reduction and improved energy performance.

Blismas and Wakefield (2007) hold the view that like many other countries, Australia needs to undergo a change in its structure, as OSM requires an entirely different work approach and culture. To realise the complete advantages of OSM, a thorough understanding of the OSM principles is required. However, realizing the importance of OSM and its contribution to the efficiency of construction industry, an action plan has been developed to address the barriers to the uptake of OSM in the Australian construction industry (CRC, 2007b). Blismas *et al.* (2009) observe that fragmented nature of the industry and under supply of housing provides a potential to explore opportunities provided by OSM. Another positive indication is that in most recent years, as many as seven key projects in Australia have been implemented using OSM (CRC, 2007c).

2.7.4. OSM in the Hong Kong Construction Industry

Hong Kong is a developed city with a large number of state of the art buildings and infrastructure facilities; however, only few building projects in Hong Kong are carried out using innovative construction methods, sustainability approach and cost effectiveness (Wilson, 2006). Tam (2002) reports that the Hong Kong construction industry is labour intensive with about 300,000 construction workers. Hong Kong construction industry largely depends on the traditional construction methods which are primarily labour intensive, dangerous and polluting and hardly produce a defect-free product (Jaillon and Poon, 2008). Wilson (2006) corroborates the report that the use of off-site manufacturing is not common in Hong Kong.

Tam (2002) identifies three major barriers to the uptake OSM technology in Hong Kong:

- the monotonous patterns of modular units are totally against the town planning concept of Hong Kong,
- existing multi storey buildings in Hong Kong can lead to the problems pertaining to joints and connections, and
- the requirement of weather and water tight structures in Hong Kong climate.

In Hong Kong, one big concern is the landfill areas used for disposal of solid waste. Hong Kong is a densely populated city covered with high rise buildings. Jaillon *et al.* (2009) report that in 2005 construction industry produced 21.5 million tonnes of waste. In Hong Kong waste is disposed off in landfills, which are getting filled up at a shocking speed. The amount of construction and demolition waste is particularly very high. It is estimated that more than 25 percent of the solid waste disposed off in these landfill areas comes from the construction industry (RSE, 2009). Use of OSM methods of construction can cut down the waste generated during the construction activities. Application of OSM with due consideration to design-for-deconstruction can provide a solution to this prevailing problem. In addition to this Wilson (2006) argue that the use of OSM improves the safety level of dangerous construction sites by enabling a clean and tidy environment.

Jaillon and Poon (2008) conducted some case studies in Hong Kong and provided evidence of success including an average reduction of construction waste by 65 percent, reduction of on-site labour requirements by 16 percent, saving in construction time by 15 percent and 63 percent reduction in accident rates. It is believed that widespread adoption of OSM in Hong Kong can greatly benefit the industry as well as the economy.

2.8. OSM in the New Zealand Construction Industry

New Zealand is a new country with a small open economy which operates on free market principles. Construction industry of New Zealand is regarded as an inefficient industry with considerable lack of productivity (Scofield *et al.*, 2009a). Historically New Zealand construction industry has used on-site timber construction. Despite the fact that OSM is not very well taken up in the New Zealand construction industry, the technology is not a new concept to New Zealanders. New Zealand has a long history of using OSM for housing, starting from importation of panelised housing kits from UK and US in early 1800 (Scofield *et al.*, 2009b). However, Scofield *et al.* (2009a) explain that the construction industry finds it easier to use traditional design and construction approach to meet the market demands while achieving compliance of the Building Act. This is because the industry is reluctant to take the risk of trying innovative methods of construction and therefore prefers following the tried and tested traditional methods which appear less risky. Becker (2005) report that though the use of OSM is low in New Zealand construction industry, the industry is ready to adopt innovative construction methods. He further adds that the New Zealand building regulations are based on performance and they allow alternatives to achieve performance; this brightens the prospects for improved adoption of OSM in the future.

Bell (2009) argues that the use of OSM can provide a good opportunity for the New Zealand construction industry to develop an environmental friendly and sustainable culture.

2.9. Barriers Constraining the uptake of OSM

In order to promote the application of OSM technology in the construction industry, there is the need to identify the barriers constraining its uptake. Several studies have been carried out to identify the barriers to the uptake of OSM technology in the construction industry. For instance, Chiang *et al.*(2006) and Tam *et al.* (2007) report on various hindrances to the use of OSM in the Hong Kong construction industry. Constraints relevant to the UK industry were reported by Goodier and Gibb (2007) and Pasquire *et al.* (2004). Constraints to the application of prefabrication in the U.S. construction industry were identified by MBI (2010a) report. Similarly, CRC (2007b) Report identifies the barriers to the uptake of prefabricated construction in the Australian context. It is believed that in spite of the many barriers to the uptake of OSM technology, the construction industry has a potential to benefit from off-site manufacturing (Tam *et al.*, 2007).

The barriers to the uptake of OSM technology as identified by the Australian study (CRC, 2007b) were taken as the starting point for this study (Figure 4). The feedback received from the industry members during the pilot interviews revealed that these constraints are pertinent to the New Zealand context with minor adjustments. The nine broad constraint groups identified in the Australian study were reduced to seven in the New Zealand context:

1. Process and programme;
2. Cost, value and productivity;
3. Regulations;
4. Industry and market culture;
5. Supply chain and procurement;
6. Skills and knowledge;
7. Logistics and site operations.

The broad constraint groups are discussed in following subsections.

2.9.1. Barriers Pertaining to Process and Programme

The use of OSM technology is a process which requires integration of planning, design, manufacturing, supply and installation. Various barriers relating to the process and programme of the OSM technology have been identified in previous studies.

OSM projects adopt an entirely different approach as design needs to be finalized at very early stage so that manufacturing of components can commence earlier and components are ready as soon as construction activities begin on site. OSM design takes longer than usual due to proper management of interfaces during design. Kelly (2009) advocates that OSM projects usually take longer time due to the precise design information which is required prior to the beginning of the project. This requires extensive coordination of clients, architects, management consultants and contractors. All these activities increase the lead period of project. Longer lead time is seen as a major barrier to the adoption of OSM technology (CRC, 2007b). Goodier and Gibb (2007) also indentifies longer lead time as key constraint to the uptake of OSM; this is particularly of critical concern to the contractors as they are interested in early commencement of the project.

Murray *et al.* (2003) reports that the construction industry has realized the need for improving the current practises and it has identified use of information technology and off-site manufacturing as potential ways of improving the quality and efficiency issues. Rivard (2000) suggests the need for computer-integrated design and construction. However, limited use of information technology, especially among the small and medium sized construction firms is a key concern (Love and Irani, 2004). This low integration of information technology has also been pointed out as a barrier to the widespread use of OSM technology (CRC, 2007b).

The CRC (2007b) Report stresses that the overall advantage of using OSM technology is only possible if the project is designed as an OSM project at the onset. This is mainly due to the fact that manufacturing of components starts much earlier than the start of construction activities (Jaillon and Poon, 2010).

One of the requirements of using OSM method of construction is to freeze the project design at an early stage. The inability to freeze the project design at an early stage is seen as a barrier to the uptake of OSM technology (CRC, 2007b; Jaillon and Poon, 2010).

The OSM components which are manufactured in factories or yards are designed in such a way to match the interfaces during the installation on construction site. Haas and Fagerlund (2002) highlights the need for engineering care in the interface management. Mismatch of interfaces can cause large scale problems owing to the inflexible nature of factory built components as they cannot be modified on the spot. This inflexibility constrains the application of OSM (CRC, 2007b; Scofield *et al.*, 2009a).

2.9.2. Barriers Pertaining to Cost, Value and Productivity

One of the widely reported barriers under the broad category of cost, value and productivity is the perception of the construction industry that OSM projects are more expensive than the traditional site-built projects (Blismas and Wakefield, 2007; CRC, 2007b; Phillipson, 2003). Gibb and Isack (2003) confirm that the use of OSM method of construction is more costly than the conventional site-built methods. This higher cost of using OSM method of construction can be associated to the steel moulds used for off-site fabrication being more expensive than the traditional timber formworks used on site (Jaillon and Poon, 2010). Similarly, the CRC (2007b) Report observes that design fees are much higher with the use of OSM. However, Haas *et al.* (2000) believe that under certain conditions, use of OSM technology can save cost compared to conventionally built projects. Taking into consideration the life cycle value of the project and adopting measures like standardization of components and their repetitive use can enhance the cost benefits of using OSM (Haas *et al.*, 2000; Jaillon and Poon, 2010).

OSM requires the establishment of factory units or production yards for carrying out manufacturing process; the cost associated with the establishment of such a setup is very high. This high initial setup cost is found to be responsible for holding back the widespread application of OSM technology (Blismas and Wakefield, 2007; CRC, 2007b; Pan *et al.*, 2005).

The factory built components require more use of cranes to lift and install the components in their positions on construction site; this sometimes calls for the need of specialized cranes due to site constraints, heavy component weight and unusual dimensions of the components or modules. The widespread use of cranes while carrying out an OSM project is cost extensive and likely to constrain the use of OSM.

Another barrier identified under this broad category of constraints is the cost involved in the transportation of large sized OSM components from factory to the construction site (CRC, 2007b; Pasquire *et al.*, 2004). This cost is dependent on the distance between the factory location and the construction site; long distances are likely to be more expensive, thereby increasing the overall cost of the project.

2.9.3. Barriers Pertaining to Regulations

One of the main issues with the regulatory frameworks is that they are not structured to facilitate the use of OSM. The lack of knowledge about OSM in policies and code of practice for construction industry makes it a difficult choice for designers to consider. MBI (2010a) Report hint that building codes are among the key constraints which discourage the use of OSM technology.

CRC (2007b) Report also document that there are very few OSM codes and standards available. Overall, these regulations are restrictive, onerous and costly. Similarly, the use of cranes to handle heavy prefabricated components has safety compliance issues which are not only expensive to meet, but also time-consuming and discouraging to contractors.

2.9.4. Barriers Pertaining to Industry and Market Culture

Industry and market culture plays a significant role to encourage or discourage innovation. The New Zealand construction industry is generally not very innovative and the industry and market culture is responsible for holding back the application of OSM (Scofield *et al.*, 2009a). Risk associated with innovation is one important reason that holds back the industry to try something new.

Ideally, the construction industry is a labour intensive sector and labour has its own stakes against the new and emerging technologies. Resistance of labour market to accept OSM technology is likely to hinder its uptake (CRC, 2007b). Similarly, clients have their own stakes based on their perceptions. It is assumed that the preferences of the client are the most important considerations, while making decision on the method of construction to adopt (Gibb and Isack, 2003). Becker (2005) believes that the New Zealand clients prefer the tried and tested traditional designs; they are not usually in support of new and innovative ideas such as the OSM. This restricts the application of OSM technology.

Conservative approach of the industry towards adoption of OSM is pointed out as a constraint to its uptake (CRC, 2007b). Designers tend to continue using the traditional design methods based on a set of specifications. They are reluctant to try new design approaches. Likewise, contractors appear reluctant to adopt a different supply chain procedure.

Another factor is the pessimism which surrounds the quality of building materials and poor craftsmanship associated with the previous use of OSM (POST, 2003). Pan *et al.* (2005) reports that there are significant concerns about the application of OSM technology among the clients who feel that OSM needs to be tested to make sure it offers better quality outputs compared to conventional construction methods. The poor quality impression of OSM technology dates back to the post World War period, when enormous housing demand during the re-construction phase was handled with prefabricated buildings. These building were of poor quality and the industry outputs were less than what was expected.

Lusby-Taylor *et al.* (2004) hint that clients do not want houses which are made using OSM techniques. This is made worse by the fact that it is sometimes difficult to obtain finances and insurance for OSM projects, as financial service providers including insurers and credit lenders require sufficient guarantees commensurate with the perceived financial risk associated with the projects based on OSM (Barker, 2003). This situation can be a barrier for the developers to adopt OSM.

2.9.5. Barriers Pertaining to Supply Chain and Procurement

Supply chain and procurement is of fundamental importance for any civil engineering projects; it is even more critical for OSM projects. The CRC (2007b) Report identifies the limited capacity of suppliers as a supply chain barrier to the uptake of OSM. The Report further hints that market control by traditional suppliers and loss of project control during on-site activities also construct the adoption of OSM.

OSM cash flows are different from routine cash flows of the construction projects. In a traditionally built project, payments to the suppliers are made on the delivery of the product; this is contrary to the OSM method of construction where the suppliers have to wait until the final installation of product during on-site interface compliance issues. Wilson (2006) highlights that the gap between the procurement of raw materials and final payment can be frustrating for the suppliers.

Another supply chain issue is that importation of the OSM products is prone to logistic and building code compliance issues (CRC, 2007b).

2.9.6. Barriers Pertaining to Skill and Knowledge

Use of OSM requires OSM specific skills; the level of these skills will determine the likelihood of its demand and application.

When compared to the traditional construction methods, the skills required to design and maintain OSM projects are significantly lacking. Scofield *et al.* (2009a) report shortage of skills as a barrier to application of OSM. CRC (2007b) also identifies a general lack of skills required to handle OSM projects; this includes design and manufacturing skills. OSM requires high degree of precision during planning and design phase or proper interfacing of various components (Yau, 2006). The low tolerance of OSM interfaces and inflexibility to resolve the problems arising during the construction phase also pose a barrier to the uptake of OSM (Becker, 2005; CRC, 2007b; Scofield *et al.*, 2009a).

Another barrier identified pertaining to this broad category is that work force lacks the required skills specially the qualification of manufacturers and contractors is inadequate; this hinders the use of OSM method of construction (CRC, 2007b; Gibb and Isack, 2003).

CRC (2007b) further observe that skill and training at all levels is still focusing on the traditional methods of construction and considerable attention has not been paid to the need for improving skills and providing training on innovative methods of construction. Additionally, there is a lack of guidance on the use of OSM and there is not much awareness of OSM products, practices and success stories.

Increased research and development process is needed for continuous improvement and troubleshooting of the emerging problems associated with OSM. Lack of research and development in the area of OSM has also been identified as a barrier to its uptake (Bell, 2009; CRC, 2007b).

2.9.7. Barriers Pertaining to Logistics and Site Operations

OSM method of construction involves transportation of large sized components from factory to the site; these components can be as large as complete modules to be installed in the structure as well as complete and ready-to-install buildings. The size factor sometimes makes the transportations very complicated. With large sized components, the site operation also becomes difficult. Haas *et al.* (2000) report that while using OSM, transportation logistics plays a vital role as it has many limitations including size and weight of components, route selection and the need for resources to lift heavy components.

Site restrictions like access to the site, limited site movement due to the layout or available space and storage of prefabricated components on the site could also constrain the application of OSM (CRC, 2007b; Pasquire *et al.*, 2004; Scofield *et al.*, 2009a).

The low tolerant nature of OSM components, especially in relation to on-site interfaces, and the availability of skilled labour to handle these components also constitute barriers to the uptake of the technology (CRC, 2007b; Pasquire *et al.*, 2004).

2.9.8. Further Challenges Facing OSM

As OSM is comparatively a new and emerging technology, there are few challenges associated with its use. These challenges need to be addressed to overcome the barriers constraining the uptake of OSM and to improve the wider uptake of the technology in the construction industry. Overcoming the OSM challenges will lead to the utilization of all the potential benefits the technology has to offer. These challenges as discussed below include planning, design, transportation and logistics, and perceptions:

Project Planning Challenges

The implementation of OSM in the construction works requires a substantial engineering effort upfront. The main disadvantage of using OSM is the longer lead time which is mainly due to the additional requirement of full understanding of the needs of the construction works. Erection and installation works also require a close coordination for successful implementation of OSM project. The planning and design is then precisely conducted to incorporate the construction work needs. This is a challenge that needs to be addressed to overcome the reluctance of the industry to implement OSM. Standardization of components and their repetitive use can be a potential solution to this problem. Also improved IT integration of construction processes is likely to overcome this challenge.

Design Challenges

Inflexible nature of OSM components to make any design modifications at a later stage is an important challenge of using OSM. Off-site construction work is normally conducted with structural or non-structural elements that are built in places other than construction site. This reduces the possibility of making any changes during on-site erection process, resulting in reluctance among the industry to apply the construction technique. If OSM provides flexibility to make changes during critical phases of the construction process, the usage of this technique can be increased.

It is generally perceived that using OSM always means repeating the use of similar components and having similar structures all the time. This however is no longer an issue as computer-aided design and high tech digital manufacturing machines have enabled OSM construction methods to deliver buildings with variable designs (Yau, 2006).

Transportation and Logistic Challenges

The feasibility of using OSM methods of construction largely depends on transportation and logistics of large sized components and modules. Sometimes dynamic impacts during the transportation require special care to be undertaken during design and construction.

Transportation and logistics is critical due to the weight limits and dimensions of roads, bridges and tunnels etc. Considerable care needs to be taken during loading and offloading the components and special lifting machinery is required for this purpose. Similarly installation of modules requires specialised cranes and qualified crane operators to handle and place the heavy components.

Misperception Challenges

Despite the various known benefits of OSM, this technology is facing challenges of negative perceptions associated with its use. These perceptions are mainly based on the housing supplies built after the World War I and World War II. During these periods housing demand was enormous and it was met with the use of prefabricated houses. Unfortunately these were not good quality houses and ever since then this poor quality became a stigma on OSM. The negative perceptions associated with the use of OSM also come from the fact that people sometimes confuse mobile homes or holiday homes with prefabricated homes.

2.10. Conceptual Framework of the Study

Figure 4 presents the OSM constraints which form the starting point of the current research investigations.

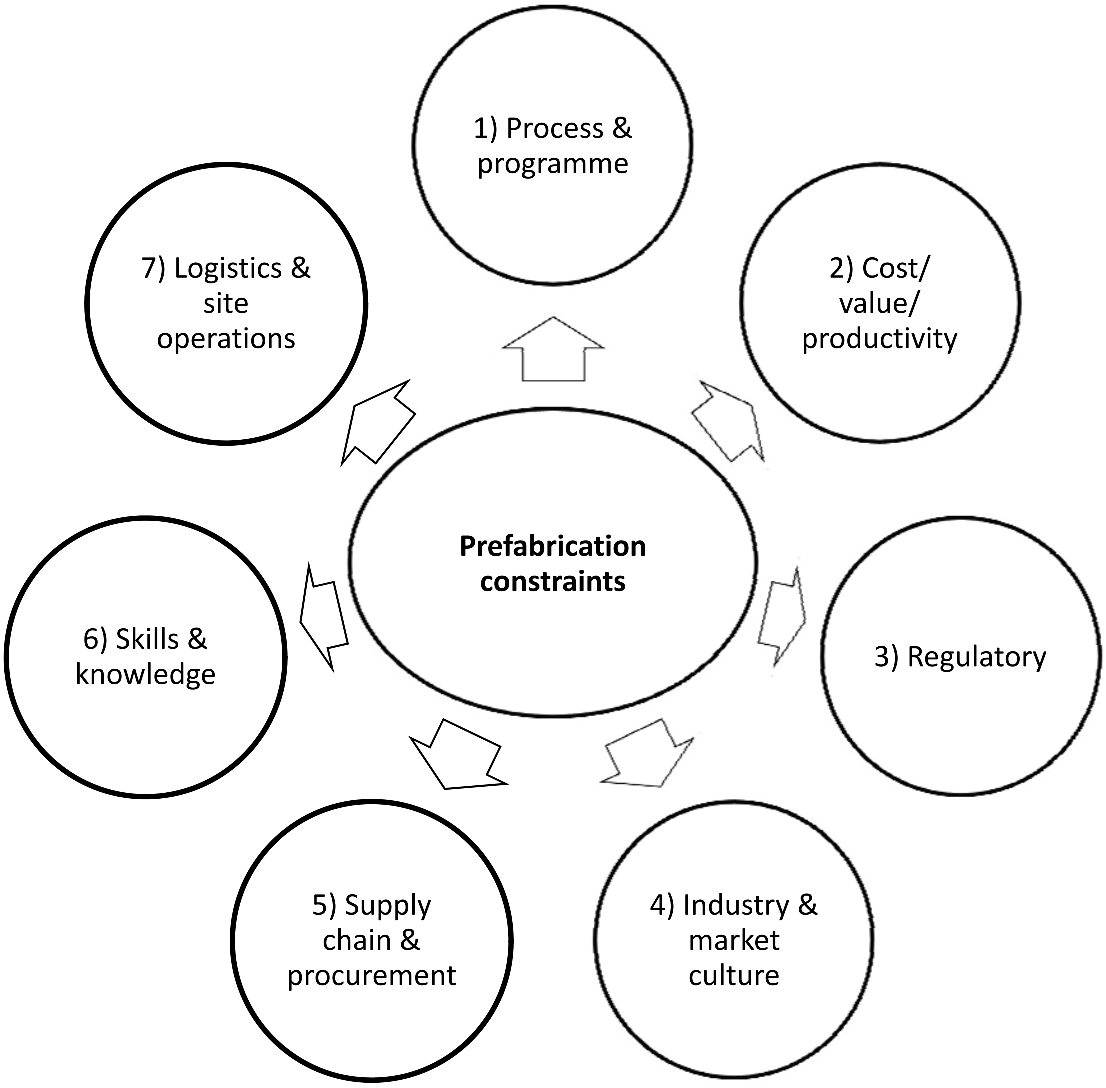

Figure 4: Broad categories of constraints to the uptake of OSM in the New Zealand construction industry. [Source: Adapted from CRC (2007, p.19)]

2.11. Summary

Comprehensive literature review carried out for this study largely served for the identification of the gaps in existing literature. The reviews have shown that various attempts have been made to identify the barriers to the uptake of OSM in different parts of the world. A critical knowledge gap in the literature is that the identification of the barriers to the uptake of OSM has been carried out without an attempt to prioritize the identified barriers in line with their relative levels of impacts. This can be discouraging to practitioners given the limited resources available to addressing myriads of constraints. This study aims to contribute to filling this gap by not only identifying barriers that are relevant to the New Zealand construction industry context, but also providing a qualitative assessment of the relative levels of impact of the barriers. This way, practitioners could target the barriers that are of critical significance in line with the resource budget available.

Mainly the findings of Australian study (CRC, 2007b) formed the basis of the investigations carried out in this study.

Chapter 3. Research Methodology

This chapter provides an overview of the methodology adopted in this research. Discussions centre on the research method and the research strategy used in the design, planning and implementation of the data gathering, data analysis and result interpretation. The chapter also highlights the ethical approval process followed in the research process, later stage confirmatory/ triangulation surveys and the research model.

3.1. Research Method

For the purpose of this study, data was gathered by using the descriptive survey method. Use of the descriptive survey method is the most appropriate approach when the primary data is obtained through feedback from interviews or surveys (Zikmund, 1997). The qualitative data for the study was obtained from an extensive review of extant literature. The constructs obtained from the literature were used to design a self-administrated survey questionnaire. The questionnaire was left open-ended in order to capture further constructs from the respondents.

3.2. Research Strategy

The research strategy employed for this study included a comprehensive literature review, data collection, data analysis and development of a decision support model. Figure 5 presents the flow chart of the research activities from conception to completion.

3.2.1. Secondary Data Sources

A comprehensive literature review was carried out to gain insights into previous works related to the topic, including the background of OSM, benefits of OSM, productivity trend of New Zealand construction sector, acceptance of OSM, barriers to the uptake of OSM, optimization of OSM application and global trends of the technology. The most robust work in the area found from the literature review was that of the Australian study

CRC (2007b); this therefore formed the basis of the investigations carried out in the study.

3.2.2. Primary Data Collection

The primary data for this study was collected by carrying out stake holders' consultation throughout the New Zealand construction industry during two stages: the questionnaire pre-test stage and of the nation-wide survey stage. The relevance of the constructs generated in the Australian study to the New Zealand construction industry context was tested during the questionnaire pre-test conducted with a convenience sample of 12 industry members; these were drawn from the target population of key industry stakeholders comprising consultants, manufacturers, suppliers, contractors, and clients in the New Zealand construction industry. The feedback obtained during the pre-test surveys facilitated the re-design of the survey questionnaire. This was then used to collect data for quantitative analysis during the industry wide survey. The essence of the latter survey was to test the reliability of the constructs underlying the questionnaire design by subjecting them to importance/ relevance ratings by a wider audience.

3.2.3. Sampling Frames

In order to capture representative views of the major stakeholders in the New Zealand construction industry, the sampling frames selected for this study comprised members of the key trade and professional associations representing clients, contractors, management consultants, designers, suppliers and manufacturers. .

The participating trade and professional associations included:

1. Architectural Design New Zealand (ADNZ),
2. Institute of Professional Engineers New Zealand (IPENZ),
3. New Zealand Institute of Architects (NZIA),
4. New Zealand Institute of Building (NZIOB),
5. New Zealand Institute of Quantity Surveyors (NZIQS),
6. Prefab New Zealand (PrefabNZ) (an umbrella organization for off-site manufacturers),

7. Property Council of New Zealand,

8. Registered Master Builders Federation (RMBF),

9. Building Industry Federation and off-site manufacturers.

3.2.4. Sampling Method

Initially it was planned to use the random stratified sampling method for the study, which would have ensured that feedback was obtained from, and representative of, the major stakeholder groupings. However, due to privacy issues related to the Privacy Act 1993, it was not possible to obtain the membership directories of the various trade and professional associations to which survey questionnaires were sent; this situation made it impossible to compare the proportions of the feedback received with the total number of members in each sampling frame for representative analysis.

3.2.5. Survey Questionnaire

The questionnaire used to generate empirical data for the study comprised three sections: the introduction, the main questions and the demographic sections. A brief introduction prefaced the main question section stating the purpose of the study, and instructions on how to answer the questions. The constraints to the uptake of OSM technology were broadly classified in seven broad categories as confirmed in the pre-test surveys. The subcomponents of barriers under each broad category were transformed into structured questions with fixed responses based on 5-point Likert rating scale.

As the research was based on qualitative assessment of expert opinions, the research instrument was designed as a structured but open-ended questionnaire with multiple-choice answers. The multi-choice answers comprised ratings from 5 to 1 on the level of impact of a given barrier to the uptake of OSM as follows:

a. Strongly Agree (SA) = 5 (translates to a very high impact);

b. Agree (A) = 4 (translates to a high impact);

c. Somewhat Agree (SwA) = 3 (translates to a moderate impact);

d. Disagree (D) = 2 (translates to low impact);

e. Strongly Disagree (SD) =1 (translates to a very low impact).

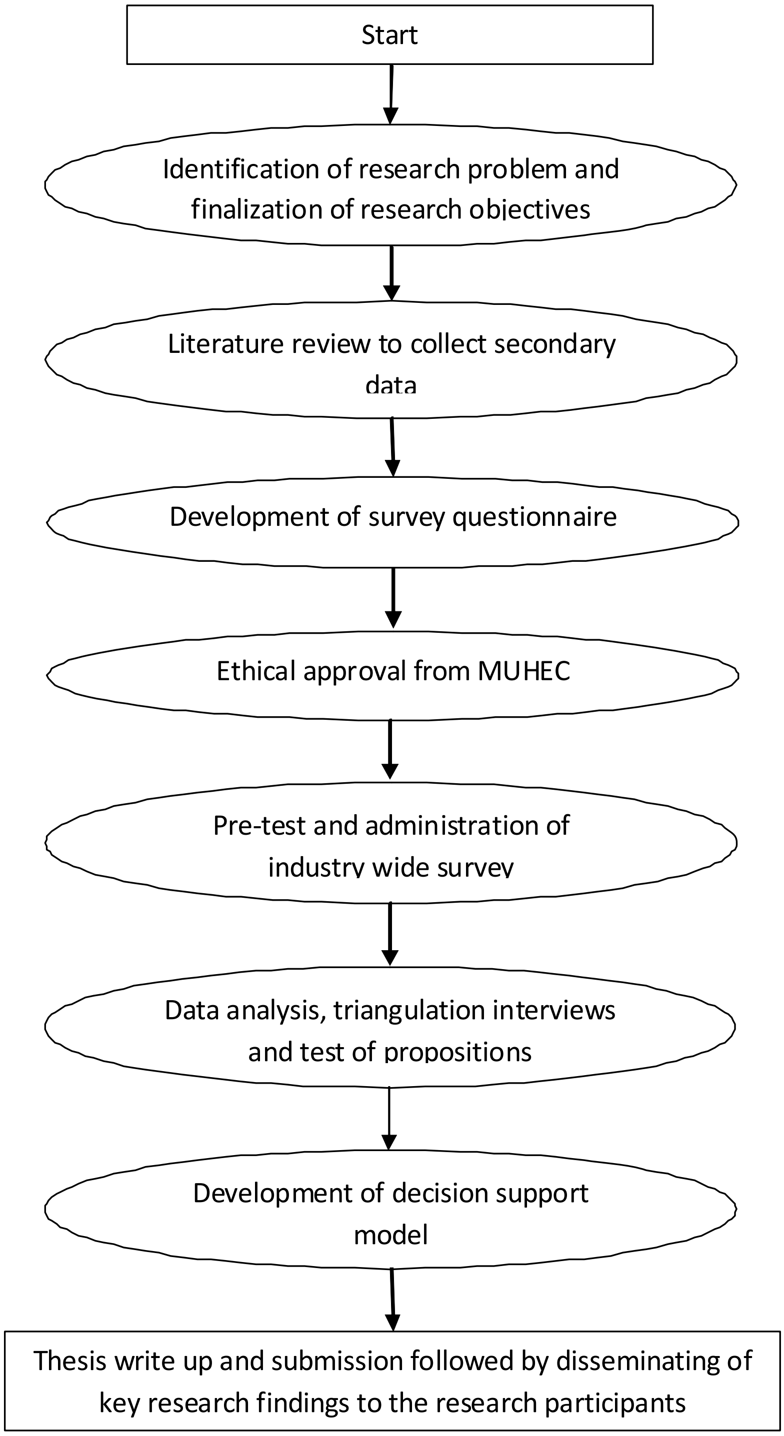

Figure 5: Flow chart of the research activities from conception to completion.

A ‘No idea’ choice was provided for respondents who might not have knowledge of the question asked or the variable being rated. This was to minimise bias and improve the reliable of the responses.

At the end of each broad category, an open ended section was provided for respondents to add further constraints not included in the subset.

The demographic section of the questionnaire was strategically positioned as the last part. The information sought in the demographic section helped to capture the level of experience of the respondents, their official designations in their respective organisations, and the trade/ professional affiliations. 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 give reliable feedback on the issues - experienced professionals at important positions in their respective organizations.

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

3.2.6. Ethical Approval

In order to fulfil the ethical requirements set by the Massey University (MUHEC, 2010), ethical approval was sought for this study. The survey questionnaire developed to collect data and other supporting documents were submitted to the Massey University Human Ethics Committee (MUHEC). The committee adjudged the study as a 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 at the end section of the survey questionnaire.

3.2.7. Pre-testing of Survey Questionnaire

Prior to carrying out industry-wide survey, a pre-test of the survey questionnaire was conducted to obtain feedback from the industry stakeholders. The pre-test served largely to: 1) test the relevance of the constructs in the New Zealand construction industry context; 2) identify further constructs not captured from the secondary sources; 3) test the clarity and relevance of the questions; 4) modify the look and feel of the questionnaire; and 5) explore ways of improving the questionnaire's appeal and response rate.

The questionnaire was pre-tested by eight industry stakeholders drawn from the target population of the study. Responses revealed a need to improve the clarity of a few questions. Part of the feedback received from the pre-test was the need to add "Don't Know" or "No idea" to the five point rating system. This was to avoid any guesses from the participants who might not be clear about the question or might not have the background knowledge of some particular constraints.

Based on the recommendations at the pre-test stage, slight modifications were made to the sampling frame of the study. Architectural Design New Zealand (ADNZ) and Institute of Professional Engineers New Zealand (IPENZ) were added to the initial sampling frames with a view to have wider industry perspectives about the barriers to the adoption of OSM technology.

3.2.8. Industry Survey

Following successful completion of the pre-test of the questionnaire and its subsequent modification for improved appeal and response rate, the next step was to conduct an industry wide survey. Keeping in view the preferences of participants, the survey questionnaire was made available in two formats;

1. Paper based questionnaire: four page questionnaire to be completed and returned either by post or by fax (see **Appendix B**).
2. Online format: online version of the survey was hosted on the Survey Monkey website; this is a portal for research-based surveys. The website provides the statistics of responses and response rates of the survey.

A covering letter (**Appendix C**) accompanied the questionnaire; it provided information about the researcher, purpose/objective of the study, importance of findings, why the participants should participate, approximate time of filling the survey, how to return the completed survey and a note of appreciation for participation

As discussed earlier, privacy issues related to the Privacy Act 1993, made it impossible to obtain the membership directories of the various trade and professional organisations.

The questionnaire was therefore circulated among the trade and professional associations included in the sampling frames through their respective secretariats.

During the questionnaire administration, a note was provided advising those who participated at the pilot interviews and pre-tests to ignore the industry-wide questionnaire, should they receive it through the secretariat of their organizations.

3.2.9. Data Analysis

The data collected was analyzed using the multi-attribute technique. The technique involves analysing the ratings of the respondents to establish the mean rating (MR) for each attribute in a set which should be a representative of the various rating points assigned by the respondents. The ranking of the attributes in the set was based on the MR values. Mbachu (2008) provides the expression for the computation of the MR value (see Equation 1).

$$MRj = \sum_{k=1}^{5}(R_{pjki} \times \%R_{jk}) \qquad (1)$$

Where:

MRj = Mean Rating for attribute j;

Rpjk = Rating point k (ranging from 1 – 5);

Rjk% = Percentage response to rating point k, for attribute j.

The most significant constraint factor in a subset was one with the highest MR value. The constraint factor having an average or higher level of impact on the uptake of the technology is considered significant as shown in Equation 2, while the insignificant factors are identified using Equation 3.

Significant constraint factor: $MR > 2.5$ (2)

Non-significant constraint factor: $MR < 2.5$ (3)

Where:

$1 < MR < 5$ on 5-point Likert rating scale.

Based on the mean rating (MR) values of the constraints in a given set, the relative contribution index (RCI) was computed to provide indication of the relative level of contribution of each constraint factor in constraining the uptake of prefabrication in the industry. Mbachu and Nkado's (2007) framework for doing this was adapted as shown in Equation 4.

$$\%RCIi = \frac{MRi \times 100}{\sum_{i=1}^{n} MRi} \qquad (4)$$

Where:

- %RCIi = Percentage relative contribution index for the i^{th} constraint in a subset;
- MRi = Mean rating for the i^{th} constraint in a given subset as computed in Equation 1;
- ∑MRi = Summation of the MRi for all the *n* constraints in a given subset.

3.2.10. Rank Correlation Analyses

In order to enhance the reliability of the research outcomes and to carry out the testing of the research propositions a comparison was carried out between the sets of opinions of two major stakeholder groupings involved in the study. The opinions of the employer group which comprise clients and their agents were compared to the opinions of the service provider group which comprises contractors, suppliers and manufacturers. This analysis involved comparing the rankings given to the each broad category of constraints by the two stakeholder groups.

For the purpose of comparing the significance in the differences of the pair wise rank correlation between the two sets of ranked data, the Spearman rank order correlation technique was used. This approach was advocated as the most suitable technique for statistical analysis of the level of correlation between two related samples of ranked data (Cooper and Ermory, 1995; Zikmund, 1997). Naoum (2007) also reports that the correlation test is an appropriate methodical approach for determining the significance of correlation between the rankings based on the opinions of people. Equation 5 provides the expression for the Spearman rank-order correlation coefficient rho (ρ).

$$\rho = 1 - \frac{6\sum_{i=1}^{n} di^2}{n^3 - n} \qquad (5)$$

Where:

- di = Difference between ranks given to the *ith* attribute in each set;
- n = Number of objects being ranked.

T-Score Test

Zikmund (1997) hints that the Spearman rank-order correlation coefficient ρ as expressed in Equation 5 gives a reliable result only where the number of objects being ranked are thirty or more, suggesting that while dealing with less than thirty objects to be ranked, transformation of the Spearman rank-order correlation coefficient ρ to the Student-T test should be carried out to obtain more reliable correlation. The expression for Student-T score test is shown in Equation 6.

$$t = \rho\sqrt{\frac{n-2}{1-\rho^2}} \qquad (6)$$

Where:

- ρ = Spearman rank-order correlation;
- n = Number of objects being ranked;
- t = Student t test value obtained by transforming Spearman rank correlation coefficient.

Test of significance

Kamarazaly (2007) suggests reformulation of proposition as a hypothesis to allow statistical test of significance. Zikmund (1997) also hints that to provide a certain level of confidence to research outcomes propositions need to be transformed into hypothesis so that they can be tested for statistical significance.

The test of significance assumes a null hypothesis (H_0) which indicates that no significant correlation exists between rankings by the two groups involved in the rating or ranking process. An alternating hypothesis (H_1) is formulated to the null hypothesis. Both hypotheses are expressed by Equation 7 and 8, respectively.

H_0: $t \leq t_c$ (7)

(I.e. no significant correlation exists between the rankings by the two groups; if so, H_0 is accepted)

H_1: $t > t_c$ (8)

(I.e. significant correlation exists between two groups; if so, H_0 is rejected and H_1 is accepted).

Where:

- t = Student t test value obtained by transforming Spearman rank correlation coefficient.
- tc = Critical value of Student t test, computed for a defined degree of freedom.

3.2.11. Triangulation of the Survey Results

Seven confirmatory interviews were carried out, with some construction industry members. These confirmatory interviews largely served to: 1) validate the feedback received at the census surveys; and 2) ensure that significant number of additional barriers was not left out in the study.

Depending on location and availability of interview participants, some of these interviews were conducted face-to-face, while some other interviews were conducted by telephone. A sample interview has been attached (see **Appendix G**).

3.2.12. Research Model

It is difficult to make a choice between OSM technology of construction and the conventional method of construction, in the absence of a decision making tool. Due to a lack of the decision support model in the existing literature, such decisions were mostly made by considering the project costs rather than giving consideration to the life cycle value of the project. Also such one-factor decision excludes other equally important variables such as quality and environmental impact. There is therefore the need for a tool for use as a methodical approach to evaluate the potential benefits accruable from the use of OSM relative to those from the conventionally constructed buildings. Pasquire *et al*. (2002) also recommend research into such a tool. As a part of this research aim a decision support model was targeted to be developed to evaluate suitable areas of application and the ways by which it can contribute to enhance the productivity of New Zealand construction industry. The model is discussed in detail in Chapter 5.

Chapter 4. Data Presentation, Analysis and Discussion of Results

This chapter presents the data collected during the questionnaire survey and their analysis. Results were discussed in relation to the research objectives. Subsections of this chapter comprise the survey responses, key constraints to the uptake of OSM technology, relative levels of impact of the identified constraints to the uptake of OSM in New Zealand construction industry, areas of OSM application and measures to improve the current low uptake of OSM. Demographic profiles of the research participants were analysed for contextual interpretation of the analysed data.

4.1. Survey Responses

Sixty eight usable responses were received by the cut-off date set for the study. As earlier indicated, the inability to access the membership directories of the target populations delineated for the study on the grounds of privacy concerns made it impossible to compute the percentage response rates from each of the sampling frames. The sixty eight responses were from manufacturers and suppliers (29%), engineering consultants (21%), contractors (18%), project management consultants/client representatives (18%), architects (10%) and building inspectors (4%). The inputs coming from diverse stakeholder groupings in the industry added to the balanced viewpoints. However, the majority of the respondents being manufacturers and suppliers meant that the findings were influenced more by the greater inputs from this group than the others.

4.2. Demographic Profile of Survey Participants

Professional affiliations of the survey participants to the various trades and professional organizations included in the sampling frames of this research are shown in Figure 6.

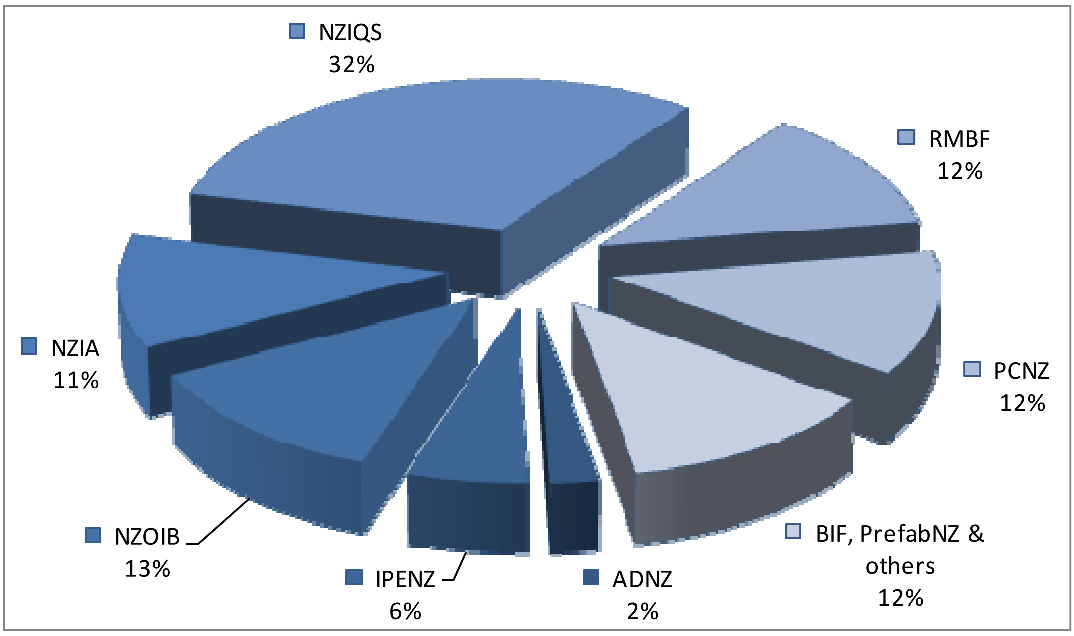

Figure 6: Professional affiliation of survey participants

The Figure shows that 32% of the survey participants were members of the New Zealand Institute of Quantity Surveyors (NZIQS); 13% were registered project managers who were members of the New Zealand Institute of Building (NZIOB). The responses from the members of Registered Master Builders Federation (RMBF) and Property Council of New Zealand were 12% each; consulting engineers comprised 24% of the total responses. Participation of Building Industry Federation (BIF) members and other manufacturers including PrefabNZ members provided 12% of the total responses. The participation of New Zealand Institute of Architects (NZIA) and Architectural Design New Zealand (ADNZ) members were 11% and 2% of the total responses, respectively. The little input by the architects is a concern given their role as key influencers of the choice and specification of materials and construction method at the early stage. The findings of the study were influenced largely by the quantity surveyors due to their greatest proportion (i.e. 32%) of the responses; this is not too bad given that they are the construction economists and so are worthy of authoritative and relevant feedback on the subject matter.

The role of the survey participants in their respective organizations is depicted in Figure 7. The 68 survey responses comprised feedback from 12 contractors (18 %), 12 project management consultants or client representatives (18 %), 14 engineering consultants

(21 %), 7 architects (10 %), and 3 building officials (4 %). The remaining 20 responses (29 %) were from manufacturers and suppliers of OSM components. The feedback received was therefore mainly from the manufacturers and the suppliers of OSM components 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 major responses of the OSM manufacturers and suppliers to their own credit. The findings and conclusions could be interpreted in this context.

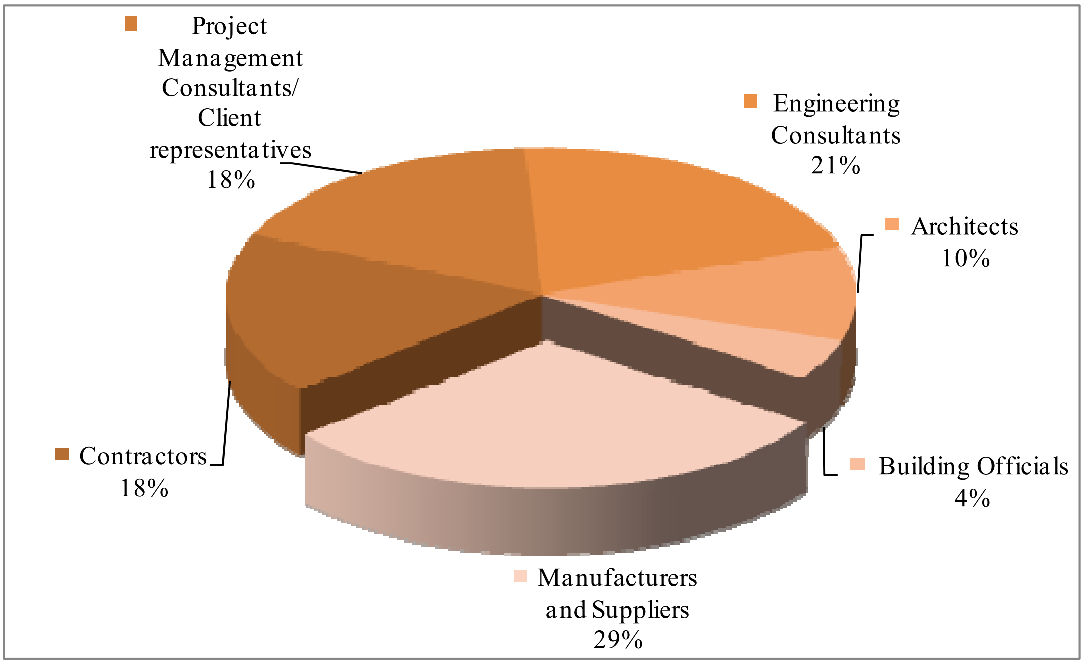

Figure 7: Participants demographic information

The length of experience of the survey participants in their respective areas of expertise is summarized in Figure 8.

It is apparent from Figure 8 that the majority of the survey participants (56 %) had professional work experience in the construction industry for more than 16 years. This Figure added to the reliability of the feedback and the ensuing findings, as the bulk of the responses came from highly experienced industry operators who, on account of their rich experience, knew much about the problems of the industry and therefore could provide authoritative feedback on the subject matter.

The feedback received from the questionnaire pre-test/ interviews revealed that the broad categories of constraints established for Australian context were relevant to the

New Zealand context with slight modifications, which included a reduction of the nine broad constraint categories to seven Figure 4.

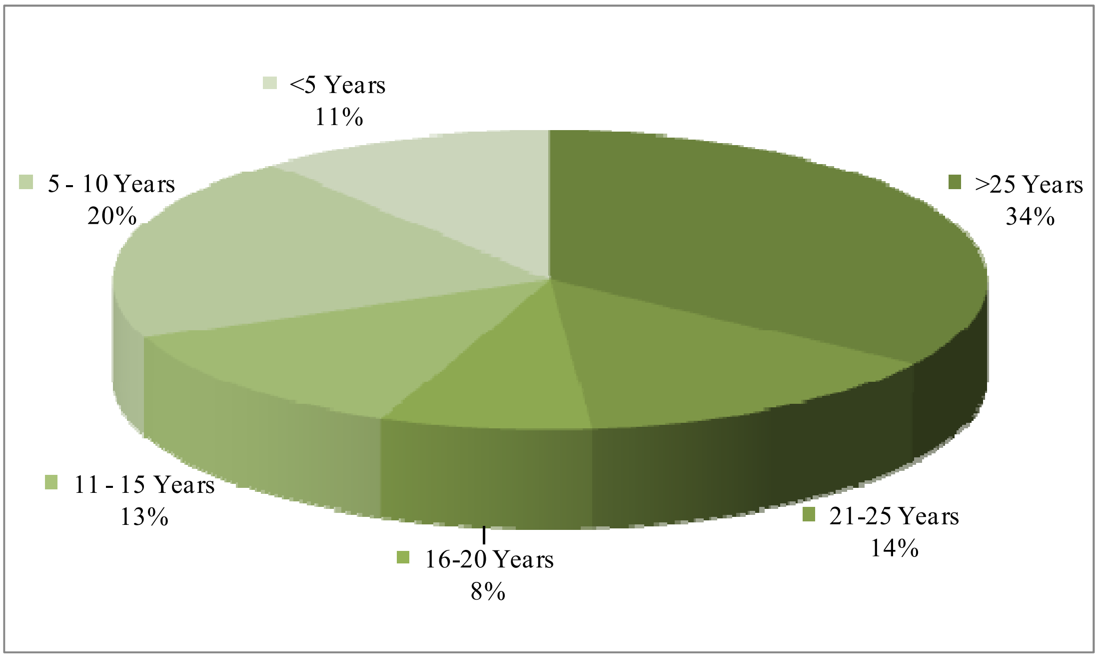

Figure 8: Experience of survey participants

Incidentally, the seven broad categories and their underlying constraints addressed the key constraints identified in the literature (Becker, 2005; Bell, 2009; Haas *et al.*, 2000; Scofield *et al.*, 2009b; Tam *et al.*, 2007). The model of Figure 4 therefore represents a more structured and robust approach to classifying the broad categories of constraints to the uptake of OSM in the construction industry.

The underlying subcomponents under each broad constraint category and their relative levels of impact were the subject of the empirical investigations that were carried out in this study; the findings are discussed in the following sub-sections.

4.3. Relative Levels of Impact of the Constraints to the OSM Uptake

The first objective of this study was to identify the key constraints to the uptake of OSM technology in the New Zealand construction industry; the second objective was to prioritise the identified barriers in order of their relative levels of impact.

Based on the outcomes of the questionnaire pre-test interviews, the constraints to the uptake of OSM underlying each broad category were identified. Relative levels of impact of the underlying constraints were rated by respondents in the industry-wide surveys. The following subsections provide the results of the analysis for each of the seven broad categories of constraint factors.

4.3.1. Constraints Related to Construction and Design Process and Programme

As the name implies, constraints under this broad category relate to the barriers to the uptake of OSM as a result of the process followed in the design and construction stages of the project implementation as well as the inhibitions from the way the activity sequencing is planned and implemented. The relative levels of impact of the identified key constraints to the uptake of OSM under this broad category were analysed in Table 1. Results show that out of the six significant subcomponents, design-related issues feature as the most influential set of constraints. The key issue here is that the choice of OSM components in the downstream construction phase can only be possible if the facility is designed and specified to be built using OSM approach at the outset. This result buttresses Tam *et al.*'s (2007) argument that the decisions made at the design stage dictate the downstream construction processes and choices.

Table 1: Constraints to uptake of OSM related to construction and design process and programme

	[a]Level of Agreement						
	SA	A	SwA	D	SD		
	5	4	3	2	1		
Constraints related to construction and design process and programme	%	%	%	%	%	[b]MR	
1) Choice of OSM components during construction is limited by design and specifications which usually favour conventional systems.	19.12	41.18	26.47	5.88	0.00	3.51	Significant (MR ≥ 2.5)
2) OSM is not suited to the frequent design changes and variation orders which are the norm in the industry	13.24	36.76	30.88	13.24	0.00	3.32	
3) Knock-on effects of problems in the manufacture process can be significant and could cascade into wider problems downstream e.g. onsite connectivity.	13.24	33.82	27.94	17.65	0.00	3.21	
4) Using OSM requires high use of IT in construction industry.	14.71	27.94	20.59	30.88	0.00	3.09	
5) Traditional design in New Zealand is not suited to OSM.	11.76	22.06	35.29	26.47	0.00	3.06	
6) OSM requires longer planning and lead times which could affect any time saving advantage.	7.35	13.24	20.59	52.94	0.00	2.57	

[a] Level of agreement of constraint statement: SA (Strongly agree) =5; A (Agree)= 4; SwA (Somewhat agree) = 3; D (Disagree) = 2; SD (Strongly disagree) =1. [b] MR = Mean rating.

Another design related barrier here is the limited freedom available under the OSM approach to make design changes after the commencement of the project. This is because any fundamental change in the design of OSM components is very expensive and almost impossible to achieve. This fact is supported by Jaillon and Poon (2010) who argue that design changes at any later stage are not possible with the use of OSM to meet the market requirement.

The third barrier relates to onsite connectivity problems owing to possible mismatch between design and the manufacturing process. With the application of factory built components/modules, extensive care is required during the manufacturing process as any mismatch in design of these components can result in a widespread problem during the installation process.

The fourth barrier hinges on the application of OSM technology requiring more use of IT integration compared to the conventional construction methods to manage the interfaces and to facilitate the coordination of project stakeholders. Wider use of OSM technology will require high level use of Information Technology within the construction industry. Scofield *et al*. (2009a) also note the requirement of high level IT application as a constraint to the uptake of OSM technology.

The fifth barrier relates to OSM not being normally adopted because by default, the design and specifications in the construction industry usually show preference to the conventional construction approach (Scofield *et al.*, 2009a) due to the familiarity with the traditional stick-built system.

Surprisingly, the concern for longer lead times is rated least among the significant constraints under this cluster. This is a departure from Stevens (1992) observation that the prefab manufacturer’s lead time and production rate could be a critical issue to be carefully taken into account in any building programme utilising OSM. Similarly, a study conducted in UK (Goodier and Gibb, 2007) report that longer lead time is seen as a major disadvantage by the contractors as it delays the start of project.

4.3.2. Constraints Related to Cost, Value and Productivity

Table 2 presents the analysis of the relative levels of impact of the key subcomponents under the broad category of cost, value and productivity as constraints to the uptake of OSM technology in the New Zealand construction industry. Results show that the factor having the most profound impact to the uptake of the technology under this broad category is the concern about the transportation costs which were perceived to be much higher than in the conventional approach, especially where long distance hauls are required. This agrees with the findings of a similar study in Hong Kong (Jaillon and Poon, 2009), where participants in a survey opined that transportation of prefabricated components is a key factor limiting their use in the industry. However, this problem relates more to the modular and whole building prefab solutions, and to a little extent, the panelised system. It may not be a problem for the component-based approach where the transportation costs for both prefab and conventional systems are almost equal (Jaillon and Poon, 2009).

Another issue raised here is increase in project cost due to specialized crane usage to handle factory built components both at the manufacturing yards and at the construction sites. UK practitioners also regard such kind of additional cost associated with the use of OSM as the major barrier to its application (Goodier and Gibb, 2007).

Table 2: Constraints to uptake of OSM related to cost/value/productivity

Constraints related to cost/value/productivity	[a]Level of Agreement					[b]MR	
	SA 5 %	A 4 %	SwA 3 %	D 2 %	SD 1 %		
1) Transportation costs are much higher especially where long distance hauls are required.	20.59	36.76	30.88	7.35	0.00	3.57	Significant (MR>2.5)
2) Cranage costs can be very high due to handling of larger sized components.	10.29	30.88	36.76	14.71	0.00	3.15	
3) Requires high internal set-up cost for factory production.	13.24	26.47	32.35	20.59	0.00	3.10	
4) OSM is often perceived to be more expensive than the conventional methods.	4.41	20.59	23.53	42.65	0.00	2.60	

[a] Level of agreement of constraint statement: SA (Strongly agree) =5; A (Agree)= 4; SwA (Somewhat agree) = 3; D (Disagree) = 2; SD (Strongly disagree) =1. [b] MR = Mean rating.

Application of OSM requires establishment of factory setup or manufacturing yards where off-site manufacturing of building components can take place in factory controlled environment. This requires high initial setup cost which is a dominant barrier to the wider adoption of OSM technology. This finding corroborates earlier study in Hong Kong (Chiang *et al.*, 2006) which noted that requirement of huge capital to launch production facilities hinders the application of OSM. OSM is therefore often perceived (though incorrectly) as an expensive construction approach compared to the conventional construction methods. This misconception about the technology also plays a vital role in constraining its industry-wide uptake.

4.3.3. Regulatory Constraints

Relative levels of influence of the regulatory constraints to the current low uptake of OSM in the industry were analysed in Table 3. Results show that the most influential factor under this set is the shortage of qualified crane operators due to the long period required for their training and certification under the H&SE Act 1992. Perhaps, this problem may relate to the recent adoption of the Code of Practice for crane operations by the Department of Labour (DoL, 2009). The Code requires employers to be responsible for ensuring that crane operators have adequate training to operate a crane safely or risk being liable for any accident that may occur as result of lack of training. The Code provides that crane operators should have the unit standards relevant for the crane type they operate, and preferably hold a National Certificate in Crane Operation. This makes it compulsory for employers to only hire crane operators with a formal qualification – the National Certificate in Crane Operation (NCCO). Perhaps, in addition to the offshore job prospects for crane operators especially in the Australia's booming mining industry, the acute shortage of qualified crane operators can be accepted as truly a key barrier to the uptake of OSM in the industry, given the crane operators huge involvement in the associated handling of the large sized components.

Other subcomponents of the regulatory constraints were perceived to be of insignificant influences to the uptake of OSM in the New Zealand construction industry. Though not rated as being significant, the issues relating to building regulations in New Zealand as possible barriers to OSM were noted by Becker (2005) who opined that regulations in New Zealand construction industry do not promote innovative construction methods; they are mainly focused on the safety of residents and building users rather than emphasizing on the methods adopted for construction.

4.3.4. Constraints Related to Industry and Market Culture

Feedback on the relative influences of the barriers related to the industry and market culture were examined in Table 4. The conservative approach often adopted by the key stakeholders in the industry was perceived as being the most significant factor inhibiting the use of OSM method of construction under this set. This corroborates the observations of Pasquire *et al*. (2002) who equally noted that the construction industry is reluctant to try innovative construction techniques and the mind set of clients in particular is responsible for low uptake of the OSM approach.

Table 3: Regulatory constraints to the uptake of OSM

	[a]Level of Agreement						
	SA	A	SwA	D	SD		
	5	4	3	2	1		
Regulatory constraints	%	%	%	%	%	[b]MR	
1) Shortage of qualified crane operators due to the long time required for training and certification under the H&SE Act 1992.	29.41	41.18	8.82	2.94	0.00	3.44	Significant (MR≥2.5)
2) Handling and cranage of large sized components involve tedious safety compliance requirements which often delays onsite progress and productivity.	7.35	39.71	27.94	16.18	0.00	3.12	
3) There are no specific codes of practice or standards for prefabricated products and processes in New Zealand.	10.29	19.12	14.71	30.88	0.00	2.34	
4) Unclear regulations relating to ownership of components manufactured off-site.	5.88	16.18	17.65	36.76	0.00	2.21	
5) Prefabrication & installation processes attract restrictive, onerous and costly regulations.	0.00	7.35	17.65	57.35	0.00	1.97	

[a] *Level of agreement of constraint statement: SA (Strongly agree) =5; A (Agree)= 4; SwA (Somewhat agree) = 3; D (Disagree) = 2; SD (Strongly disagree) =1.* [b] *MR = Mean rating*

The second most influential factor here is the client's preference for traditional finishes and custom made designs. These results are consistent with Becker's (2005) observation that the New Zealand clients prefer customized designs to suit their unique tastes and fashion.

The third and fourth barrier relate to the perception of poor quality associated with the past failures of the application of the technology. OSM suffers various misperceptions about its quality, which has become a negative stigma for the technology despite its numerous advantages. OSM-based construction projects are generally perceived to be of poor quality and low standards. For instance, Craig *et al.* (2006) note that a large number of buildings constructed using OSM technologies in the past have been criticized for their poor quality. Gibb and Isack (2003) conducted a market research in

UK and concluded that clients have a major role in selecting OSM as a means of construction.

The fifth barrier relates to the labour market. It should be noted that the construction process is labour intensive. It is believed that the labour market is generally reluctant to accept innovation in the construction process due to the radical changes it could introduce (Mbachu and Nkado, 2007). Obsolescence of skills and knowledge could result where there is a radical departure from the old ways of doing things. However this barrier was not considered as part of the significant constraints in New Zealand by the respondents. This might be due to the shortage of skilled labour in New Zealand.

The last barrier under this set relates to the problem of securing finances and insurance for OSM projects, though not considered as a significant barrier to the uptake of OSM in New Zealand by the majority of the respondents. This is a surprise, given that, as a result of risk implications, lenders and insurance providers often frown at the use of unpopular materials and methods notwithstanding their claimed benefits (Mbachu and Nkado, 2007).

Table 4: Constraints to uptake of OSM related to industry and market culture

	[a]Level of Agreement						
	SA	A	SwA	D	SD		
	5	4	3	2	1		
Constraints related to industry & market culture	%	%	%	%	%	[b]MR	
1) Reluctance to change by key stakeholders inhibits industry-wide adoption of OSM.	20.59	22.06	29.41	22.06	0.00	3.24	Significant (MR>2.5)
2) Clients prefer traditional finishes & custom-made designs.	5.88	30.88	26.47	27.94	0.00	2.88	
3) Perceived poor and low quality image of OSM buildings is an issue.	13.24	14.71	33.82	29.41	0.00	2.85	
4) Failures of OSM in the past make it socially unacceptable.	7.35	10.29	42.65	27.94	0.00	2.62	
5) Industry is by nature labour-intensive and the labour market is not ready for OSM.	1.47	14.71	14.71	57.35	0.00	2.25	
6) Project finance and insurance may be difficult to obtain from institutions not familiar with OSM.	1.47	11.76	27.94	38.24	0.00	2.15	

[a] Level of agreement of constraint statement: SA (Strongly agree) =5; A (Agree)= 4; SwA (Somewhat agree) = 3; D (Disagree) = 2; SD (Strongly disagree) =1.[b] MR = Mean rating.

4.3.5. Constraints Related to Supply Chain and Procurement

Supply chain is critical in the construction process as it links all the stakeholders - clients, contractors, sub-contractors, designers and suppliers. Except for one, all the subcomponents of this broad category were perceived to have significant influence on the acceptance of OSM in New Zealand construction industry.

The supply chain and procurement constraints were analysed in Table 5. The most influential constraint in this category relates to industry's lack of capacity to supply diverse varieties of OSM products due to lack of infrastructure support and resources. This result corroborates earlier findings of Scofield *et al*. (2009b) that some of the key barriers to off-site manufacture in New Zealand include a lack of production potential and insufficient marketing effort.

Table 5: Constraints to uptake of OSM related to supply chain and procurement

Subcomponent of supply chain & procurement	[a] Level of Agreement SA 5 %	A 4 %	SwA 3 %	D 2 %	SD 1 %	[b] MR	
1) Industry capacity to supply diverse varieties of OSM products is limited due to lack of infrastructure support and resources.	19.12	23.53	30.88	14.71	0.00	3.12	Significant (MR>2.5)
2) OSM requires firm control of supply chain which involves high risks especially in relation to international logistics & supply arrangements.	11.76	23.53	33.82	19.12	0.00	2.93	Significant (MR>2.5)
3) Importation of OSM products is prone to logistic, quality and compliance issues.	10.29	25.00	30.88	23.53	0.00	2.91	Significant (MR>2.5)
4) Stiff opposition from traditional suppliers against prefabrication business may limit supply capacity and large scale adoption.	11.76	22.06	19.12	30.88	0.00	2.66	Significant (MR>2.5)
5) More complex payment terms, cash flow processes and financial administration where mixed offsite and onsite components are required.	4.41	23.53	22.06	35.29	0.00	2.53	Significant (MR>2.5)
6) Apparent loss of project control during onsite operations.	4.41	7.35	19.12	50.00	0.00	2.09	

[a] Level of agreement of constraint statement: SA (Strongly agree) =5; A (Agree)= 4; SwA (Somewhat agree) = 3; D (Disagree) = 2; SD (Strongly disagree) =1.[b] MR = Mean rating.

Perhaps, this could be explained in part by Tam *et al.* (2007) argument that the setup and operation of OSM plant is quite capital-intensive and requires modern infrastructure support.

Another issue here pertains to the importation of OSM products; when these products are imported they are prone to various difficulties such as logistics, quality of components or system and compliance with the local building codes.

The fifth barrier relates to opposition from traditional component suppliers. Capacity of the industry to supply OSM products was perceived to be limited due to the strong resistance by the well established traditional material suppliers against OSM business. The Report of the Commerce Committee (2008) also highlights the fierce competition amongst the few merchant chain businesses such as Placemakers, Carters, ITM, Mitre 10 and Bunnings. These big five control the market share of material and component supplies in the New Zealand construction industry and are major influencers of the design and construction decisions; they may not allow new OSM supplier entrants a chance to flourish, especially where the material sourcing targets the Asian region on account of substantial price difference with local supplies.

The least significant barrier relates to financial issues associated with mixed use of OSM and onsite components. Respondents were of the opinion that when a combination of OSM and conventional construction approach is employed, which often will be the case with the use of OSM since not all components will be factory produced, the payment terms and project cash flows become complex resulting in difficulties to financially administrate the project. This is usually due to the requirement for multiple account system which could be quite cumbersome to follow.

4.3.6. Constraints Related to Skills and Knowledge

Table 6 presents the analysis of the relative influences of the barriers under the broad category of skills and knowledge. Majority of the survey participants believed that the most influential constraint to the uptake of OSM is the lack of skills and knowledge in the area, which is driven by poor diffusion and assimilation of the emerging skills and knowledge of the technology in the industry. The poor diffusion of skills and knowledge was seen to be largely due to the education and training in New Zealand being focussed on current traditional practices, rather than innovative ideas of the future. This finding is consistent with Goodier and Gibb (2007) harp on the need for addressing the shortage of skilled OSM suppliers and skilled labour in the UK construction industry to enlarge the market share of the technology. Lack of OSM specific skills in UK has also been pointed out as a key constraint to the improved application of the technology in the industry (Nadim and Goulding, 2009).

The second most influential constraint relates to the general lack of guidance and information on OSM available in the market and the lack of single information source on the technology. Perhaps, this corroborates the findings of Bell (2009) that propagating awareness of the technology through effective marketing is one of the key ways of improving its uptake in the industry.

Another skills related barrier influencing the application of OSM in New Zealand is the need for skilled craftsmen who can deal with the low tolerant nature of OSM and can effectively manage the interfaces of factory built components. Limited expertise of designers to handle OSM designs and lack of experienced manufacturers also minimize the application of this technology. Similar observations were made in UK (2007),where it was highlighted that to enlarge the market share of OSM there is a need to look into the shortage of skilled OSM suppliers as well as semi and multi skilled workers.

The fifth constraint relates to lack of research and development (R&D) in industry related problems. Respondents at the surveys perceived the lack of research and development in the area of OSM as influencing the uptake of this technology in New Zealand. This agree with Bell's (2009) findings, that support for research and development through grants by government and the industry is needed to test and evaluate OSM products for their quality.

The sixth constraint relates to the low IT literacy in the industry. Respondents believed that lack of IT integration and of OSM specific skills like logistic management, storage, and installation has a significant influence on the low use of OSM in the construction process.

The last constraint, which was rated as being insignificant, relates to pre-caster's inadequate qualification and lack of familiarity with OSM systems. Perhaps, the qualifications of pre-casters in New Zealand are not in doubt.

Table 6: Constraints to uptake of OSM related to skills and knowledge issues

Constraints related to skills and knowledge issues shortage	[a]Level of Agreement SA 5 %	A 4 %	SwA 3 %	D 2 %	SD 1 %	[b]MR	
1) Education & training still focussed on current traditional practices, rather than innovative ideas of the future, thereby resulting in poor diffusion of the emerging skills and knowledge of the technology in the industry.	19.12	33.82	30.88	8.82	0.00	3.41	Significant (MR>2.5)
2) General lack of guidance and information on prefabrication available in the market & lack of single information source.	13.24	35.29	32.35	13.24	0.00	3.31	
3) Lack of skills and understanding required to ensure that interfaces are managed and designed in the prefabrication technology.	8.82	36.76	32.35	16.18	0.00	3.21	
4) Requires higher onsite skills to deal with low tolerances for interfaces.	11.76	36.76	22.06	23.53	0.00	3.19	
5) Limited expertise of designers and constructors in prefabrication.	11.76	27.94	33.82	20.59	0.00	3.13	
6) Lack of R&D.	16.18	32.35	23.53	16.18	0.00	3.13	
7) May require higher levels of IT literacy which is low in smaller firms.	5.88	29.41	33.82	25.00	0.00	2.99	
8) Lack of prefabrication skills like logistic management, coordination of installation & erection.	5.88	13.24	32.35	36.76	0.00	2.53	
9) Pre-casters' inadequate qualification and non-familiarity with prefabrication.	1.47	19.12	22.06	35.29	0.00	2.21	

[a] Level of agreement of constraint statement: SA (Strongly agree) =5; A (Agree)= 4; SwA (Somewhat agree) = 3; D (Disagree) = 2; SD (Strongly disagree) =1. [b] MR = Mean rating.

4.3.7. Constraints Related to Logistics and Site Operations

The relative levels of influence of identified barriers under the broad category of logistic and site operation were analysed in Table 7.

The most significant barrier in this category is the difficulty in transporting large sized OSM components, from factory to project site due to travelling restrictions and the requirements for expensive escorts.

Table 7: Constraints of uptake of OSM related to logistics and site operations

Constraints related to logistics & site operations	[a]Level of Agreement						
	SA 5 %	A 4 %	SwA 3 %	D 2 %	SD 1 %	[b]MR	
1) Transportation of large components limited by travelling restrictions, road width, bridge load capacities, transport curfews & requirement of expensive escorts.	14.71	26.47	36.76	14.71	0.00	3.19	Significant (MR≥2.5)
2) Site constraints: limited site access for manoeuvrability & delivery on restricted sites; problem of space for carnage and onsite storage for large components.	5.88	32.35	36.76	17.65	0.00	3.04	Significant (MR≥2.5)
3) High mass prefabricated products and components result in higher transportation, storage and handling costs.	5.88	35.29	26.47	23.53	0.00	2.97	Significant (MR≥2.5)
4) Low tolerance increases problems when fitting components onsite.	5.88	26.47	32.35	29.41	0.00	2.91	Significant (MR≥2.5)
5) Logistic & stock management difficult with large components, e.g. concrete products.	4.41	23.53	19.12	36.76	0.00	2.47	

[a] Level of agreement of constraint statement: SA (Strongly agree) =5; A (Agree)= 4; SwA (Somewhat agree) = 3; D (Disagree) = 2; SD (Strongly disagree) =1. [b] MR = Mean rating.

The next most significant barrier relates to the problem of site restrictions, which constrain the use of the technology in high density areas. These restrictions could be due to ample spaces needed for cranage, component storage and manoeuvrability of associated heavy equipment on site.

4.4. Relative Levels of Impact of the Broad Constraints Groups to the Uptake of OSM

The relative levels of impact of the broad categories of the identified barriers to the uptake of OSM in the New Zealand construction industry were analysed in Table 8.

Results show that six out of the seven identified constraint categories were perceived by majority of the survey participants as being significant; the most influential being issues related to industry and market culture. Analysis of the relative levels of contribution of the broad constraint categories in constraining the uptake of the technology in Table 8 shows that industry and market culture, as the most influential barrier, contributes about 16 % of the total uptake constraints. The underlying factors within this broad category therefore deserve special attention in the effort to address the constraints and improve the uptake of the technology in the industry.

Table 8: Relative impact levels of the broad categories of constraints to the uptake of OSM

Broad constraint categories	[a]Level of impact Vh 5 %	H 4 %	M 3 %	L 2 %	Vl 1 %	[b]MR	[c] %RCI	
1) Industry & Market Culture	16.2	30.9	29.4	10.3	1.5	3.15	16%	Significant (MR≥2.5)
2) Skill & Knowledge	10.3	27.9	36.8	11.8	2.9	3.0	15%	
3) Logistic & Site Operations	7.4	19.1	50.0	10.3	2.9	2.87	15%	
4) Cost/Value/Productivity	1.5	23.5	39.7	25.0	1.5	2.72	14%	
5) Supply Chain & Procurement	4.4	20.6	36.8	23.5	4.4	2.66	14%	
6) Process & Programme	4.4	16.2	42.7	22.1	4.4	2.63	14%	
7) Regulatory	4.4	10.3	33.8	35.3	1.5	2.37	12%	
					∑	19.4	100%	

[a] Level of impact: Vh (Very high) =5; H (High)= 4; M (Moderate) = 3; L (Low) = 2; Vl (Very low) =1. [b] MR = Mean rating. %RCI = % Relative contribution index.

The key focus here is on finding ways to address the key stakeholders' reluctance to change which inhibits industry-wide adoption of OSM. This is consistent with the observation of Haas *at el.* (2000) associating the constraints to the uptake of OSM with the same set of obstacles responsible for the slow adoption of innovation in the construction industry, the key being human and institutional resistance to change.

The survey participants concurred with the recommendations of Bell (2009) that effective marketing strategies aimed at promoting awareness of the OSM merits could result in a positive industry and market culture change and hence greater industry-wide uptake of the technology.

4.5. OSM Application

OSM technology can be applied to various types of building projects and similarly various building components can be produced off-site for their on-site installation. Feedback was canvassed from participants at the questionnaire pre-test interviews on the building types and components suited to the use of OSM in the New Zealand construction industry.

Suitability of OSM for Various Building Types

Responses on the suitability of OSM technology to various types of buildings was analyzed in Table 9.

Table 9: Suitability of building types using OSM

	[a]Level of Suitability						
	VHS 5 %	HS 4 %	MS 3 %	NsS 2 %	NaaS 1 %	[b]MR	
Buildings to be built using OSM technology							
Industrial buildings	44.12	30.88	8.82	10.29	0.00	3.91	Significant (MR>2.5)
Recreational buildings (e.g. hotels)	19.12	52.94	13.24	7.35	0.00	3.62	
Office buildings	19.12	39.71	32.35	2.94	0.00	3.57	
Residential	22.06	41.18	19.12	11.76	0.00	3.56	
Commercial/ retail buildings	17.65	38.24	30.88	5.88	1.47	3.47	
Institutional buildings	19.12	35.29	26.47	11.76	1.47	3.41	
General infrastructure (e.g. stadiums)	17.65	30.88	25.00	14.71	4.41	3.21	

[a]Level of Suitability: VHS(Very highly suitable)=5,HS(Highly suitable)=4,MS(Moderately suitable)=3,NsS(Not so suitable)=2, NaaS(Not at all suitable)=1. [b] MR = Mean rating.

Results show that OSM technology can be effectively applied to all types of buildings including; industrial, institutional, residential, office, commercial and recreational buildings and to the development of general infrastructure. This finding is a positive indication of future prospects for the use of OSM in New Zealand. The finding corroborates the Australian study (CRC, 2007b), which documents evidences of successful implementation of various types of building and infrastructure projects using OSM technology in Australia. Also, Gibb (1999) reports on a variety of civil infrastructure and building projects which have been successfully implemented using OSM application in Canada, Scotland, UK, USA and Venezuela.

Suitability of OSM for Various Building Elements/ Components

Analysis of the responses on the suitability of the use of OSM technology for various building components was made in Table 10.

Table 10: Suitability of building elements/components using OSM

	[a]Level of Suitability						
	SA	A	SwA	D	SD		
	5	4	3	2	1		
Elements/ building components suitable for OSM construction	%	%	%	%	%	[b]MR	
Wall construction and components	32.35	47.06	14.71	0.00	0.00	3.94	Significant (MR>2.5)
Structural frame construction and components	30.88	44.12	17.65	1.47	0.00	3.87	
Floor construction and components	19.12	52.94	16.18	5.88	0.00	3.68	
Roof construction and components	17.65	32.35	26.47	16.18	0.00	3.29	
Foundation construction and components	1.47	2.94	19.12	51.47	17.65	1.97	
Site work construction and components (e.g. drainage, roading, etc)	0.00	5.88	10.29	39.71	33.82	1.68	

[a]Level of Suitability: VHS(Very highly suitable)=5,HS(Highly suitable)=4,MS(Moderately suitable)=3,NsS(Not so suitable)=2, NaaS(Not at all suitable)=1. [b] MR = Mean rating.

Results show that majority of the respondents believed that walls and structural frames are better productively produced off-site to optimize the value and productivity in a project. Similarly, floors and roof components built off-site can also effectively improve the speed of the construction process. However, the respondents believed that the use of OSM is not very suitable for construction of foundation and site-works due to uncertainties about the ground conditions and the requirements to make substantial changes in the design of these elements due to unique site characteristics. This indicates that notwithstanding the numerous benefits of the OSM technology, it cannot completely replace the use of conventional construction approaches in the design, and implementation of construction projects.

4.6. Improvement Measures

The third research objective was to explore the measures to improve the uptake of OSM application in the New Zealand construction industry.

During the pre-test interviews and industry-wide surveys, the research participants provided valuable feedback on how to mitigate the identified barriers constraining the uptake of OSM in the New Zealand construction industry in order to improve its application. The improvement measures suggested for different influencing constraints under each broad constraint category are discussed in the following sub-sections.

4.6.1. Measures for Addressing Constraints Related to Construction and Design Process and Programme

Respondents suggested several improvement strategies for addressing the barriers related to the construction and design process and programme.

The most recurring mitigation measure suggested here was that, given the numerous benefits of OSM, construction clients should drive the improved uptake of the technology in the industry by emphasising on the use of OSM in the briefs to the designers.

In addition, the research participants believed that an early decision on the use of OSM method of construction for a particular project can be the key solution to various design related constraints. Finalizing and freezing the project design at an early stage provides the opportunity to precisely programme the subsequent project activities. This however requires a collective agreement of the project stakeholders to use OSM technology at the onset. Awareness of OSM benefits and its effectiveness among the construction industry stakeholders can be created by various means. Respondents suggested that industry seminars and conferences can be very effective to educate all sectors of the construction industry from architects to the end-users of the project. Highlighting the current success stories of OSM projects in New Zealand can provide positive examples for its appeal and future use.

These suggested measures are somehow supported by the findings of some previous studies. For instance, Kelly (2009) emphasises that programming for OSM projects should be realistic and it is important to advance the project design at early stage and then freeze it subsequently to avoid costly changes. Kelly (2009) further suggests that project development should proceed on the basis of the parameters agreed at earlier stage to avoid any wasteful design activity.

4.6.2. Measures for Addressing Barriers Related to Cost, Value and Productivity

Transportation challenges were identified as the most influencing constraints under the broad category of cost, value and productivity. Feedback from participants at both the interviews and questionnaire surveys indicated that the key challenges in the transportation of large-sized prefab components hinged around the traffic congestion especially in the cities, long distance haul and onsite storage space. Their solutions to the problem pointed to logistic issues namely, transporting the large-sized items during off-peak hours or midnight, even spread of the manufacturing plants across the construction hubs to minimise the travelling distances, and the minimisation of the trips by using modular units rather than component-based or panelised systems. CRC (2007a) report corroborates the recommendation that locating the manufacturing plant close to the project site can significantly reduce the transportation cost and logistic problems associated with long distance supply of OSM components.

The respondents further suggested the need for improving OSM awareness through harping on its potential to deliver superior customer values. This recommendation aligns with the findings of Pan *et al*. (2005) that precise data on cost should be obtained to achieve competitive project costing, with the focus being on the "value for money", rather than the apparent project cost.

Lastly, the respondents recommended adoption of standardization of design to ensure benefit from the economies of scale in order to further improve the cost advantage of using OSM.

4.6.3. Measures for Addressing Barriers Related to Regulatory Constraints

Although the regulatory constraints were perceived by the respondents as posing no significant barrier to the use of OSM technology in New Zealand, nevertheless, they made recommendations for addressing the related barriers.

The recurring mitigation measure proffered for lack of skilled crane operators was to hire the qualified crane operators from overseas for a short-term solution and the increased training of crane operators by the Industry Training Organisations (ITOs). In addition, a number of respondents suggested that the New Zealand Immigration Service should include crane operators in their list of skills for the Migrant Visa Scheme to attract foreign crane operators.

4.6.4. Measures for Addressing Barriers Related to Industry and Market Culture

Feedback from the respondents suggested an industry-wide culture change to embrace innovative methods of construction which hold promise of moving the nation forward. They suggested a need for an industry leader to serve as a central hub to promote the use of OSM and market its benefit within and outside the construction industry. In this regard, OSM suppliers with greater knowledge and experience of the technology as well as the companies that have already used OSM can take the lead role in bringing about change.

Marketing the numerous advantages of OSM can help to change the existing mindset about the technology and mitigate the negative stigmas associated with its use such as the perception of poor quality products and suitability only as temporary building solutions.

4.6.5. Measures for Addressing Barriers Related to Supply Chain and Procurement

The most influencing supply chain issue identified in the study relate to the limited capacity of the industry to supply diverse varieties of OSM products. Mitigation measures suggested by the research participants included government intervention through guaranteed start-up funds for the OSM manufacturers and the provision of the enabling infrastructure support.

Industry members believe that the ‘Design-Built’ approach is most appropriate for OSM projects as it brings all the concerned project parties onboard at the initial stage of the project. They further suggested a need to closely coordinate the design activities with the manufacturing process as all the manufacturers are different from each other and in some cases monitoring of manufacturing process may be required by the management consultants to ensure synergy with the design requirements and development.

Further recommendations of the research participants aligned with similar measures in the NHBC (2006) report which included setting a date to freeze the project design, following a time table of all items to be delivered, following up with the manufacturers and adopting a procedure to test the quality and specifications of the products before their handing over by the manufacturers to the onsite contractors.

4.6.6. Measures to Improve OSM Skills and Knowledge

To overcome the shortage of OSM specific skills and knowledge the mitigation measures suggested by the survey participants included the review of education and training curricula to incorporate the theory and practice of OSM in New Zealand. The participants highlighted the need to equip the designers with the skills required to handle OSM projects, especially the management of interfaces. Additionally, the need to educate the contractors and other stakeholders in the industry was raised by the respondents to improve the acceptance of OSM at all levels of the industry. Another important suggestion from industry members was to invest more in the research and development of OSM and related processes to authenticate the potential of this technology.

4.6.7. Measures for Addressing the Barriers Related to Logistics and Site Operations

To manage the issues related to the logistics and site operations, the survey participants advised that the designers should adopt prefab unit sizes that lend to ease of transportation and that conform to the travelling restrictions in the delivery routes. The respondents further suggested streamlining the manufacturing process with the installation activities in such a way that components can be delivered on site only when they are needed to be installed. This can minimize the arrangements required for their storage and at the same time ensure that the construction site can stay free of congestion.

These recommendations align with Kelly (2009) observation that information regarding the site restrictions and integration of units with the existing facilities is critically important and should be introduced during the early project phases to avoid any inconvenience at any later stage.

Chapter 5. Proposition Testing and the Research Model

The purpose of this chapter is twofold. First, it presents the testing of the propositions which were developed to direct this research including the tests carried out to check their significance. Secondly, it discusses the development of research model and its application.

5.1. Test of Proposition 1

The first objective of this study was to identify the key barriers which could constrain the uptake of OSM technology in the New Zealand construction industry.

To help achieve this research objective, Proposition 1 was formulated to assume that consensus of opinions exists on the relative levels of impact of the broad categories of constraints to the uptake of OSM between the two major stakeholder groupings: the clients and client agents as the employer group, versus the contractors and the suppliers/manufacturers as the key service provider group. The proposition therefore not only directed focus on the nature of data needed to achieve the objective but also the multiple sources of evidence for testing the reliability of the feedback received. Testing of this proposition is discussed below.

Testing Method

To carry out the test of significance, the proposition was re-formulated as a hypothesis. To evaluate the level of agreement between the opinions of employer and service provider groups the Spearman's rank correlation coefficient (ρ) was used. This approach enabled the evaluation of the level of significance in the correlation between two sets of data; i.e. the opinions of the employer and those of the service providers. Zikmund (1997) recommend the use of Spearman's rank correlation coefficient to determine the degree of correlation between bi-variate sets of ranked data.

Table 11 shows the Spearman rank correlation test carried out to test the proposition. The computed Spearman rank correlation coefficient (ρ) using Equation 5 was transformed into the Student T test statistic for a more robust test, given the small sample size of the data points which were characterised by the Student T distribution than the distribution free structure assumed by the Spearman's test (Cooper and Emory, 1995).

A null hypothesis (H_0) was formulated to assume that no significant correlation existed between the opinions of the employer group and those of the service provider group, regarding the relative levels of influence of the broad categories of factors constraining the uptake of OSM technology in New Zealand. An alternate hypothesis (H_1) assumed significant and positive correlation existed between the opinions of these two groups.

Hypotheses Test

Null hypothesis (H_0):

H_0: $t \leq t_c$; (i.e. no significant correlation existed between the opinions of the two groups) (7)

Alternative hypothesis (H_1):

H_1: $t > t_c$; (i.e. significant and positive correlation existed between the opinions of the two groups) (8)

Where:

t = Student T test value obtained by transforming Spearman rank correlation coefficient (ρ), which is an indicator of the level of correlation between the two ranked groups.

t_c = Critical value of Student T test statistic, taken at 0.05 level of significance corresponding to the given degree of freedom (df = n – 2; n being the number of rows of paired ranks of variables in the two matched sets of data).

Decisions on the hypotheses

- If $t \leq t_c$, accept H_0 and reject H_1; otherwise,
- If $t > t_c$, reject H_0 and accept H_1.

Results

Results of the correlation test are shown in Table 11. The value of Spearman's rank correlation coefficient (ρ) was found to be 0.857. The equivalent/ transformed Student T- test value was 3.721; this is less than the critical value of Student T-test value of 2.015 at five percent level of significance. This led to the rejection of the null hypothesis and consequently the acceptance of the alternative hypothesis, which indicated that significant correlation existed between the opinions of the employer group and the service provider group.

Table 11: Test of Proposition 1 (correlating the opinions of the employer and service provider groups on the relative levels of impact of the broad constraint categories)

	Employer Group			Employee Group		
Broad Constrain Groups	[a] MR	[b]%RCI	Rank	MR	%RCI	Rank
Process & Programme	2.65	14%	5	2.62	13%	5
Cost/Value/Productivity	2.85	15%	4	2.59	13%	6
Regulatory	2.29	12%	7	2.44	13%	7
Industry & Market Culture	3.06	16%	1	3.24	17%	1
Supply Chain & Procurement	2.59	13%	5	2.74	14%	4
Skill & Knowledge	2.97	15%	2	3.03	16%	2
Logistic & Site Operations	2.88	15%	3	2.85	15%	3

[a] *MR = Mean rating (see Equation 2).* [b] *%RCI = % Relative contribution index.*

Objects to be ranked; $n = 7$

Spearman's rank correlation coefficient; $\rho = 0.857$

T-Score value; $t = 3.721$

Degree of freedom (n-2); $df = 5$

T-critical (at 5% level of significant) ; $t_c = 2.015$

Acceptance region; $t_{score} \leq t_{critical}$

Result; $t_{score} > t_{critical}$l

Decision: Reject H_0 and accept H_1

Conclusion

Results of Table 11 show that significant and positive correlation exists between the two sets of ranked opinions. Therefore, Proposition 1 which assumed that consensus of opinions existed between the employer group and the service provider group in their ranking of the relative levels of impact of the broad constraint categories is supported.

5.2. Test of Proposition 2

The second objective of this study was to prioritise the identified barriers in terms of their relative levels of influence as constraint factors.

To help realize this objective Proposition 2 was formulated to assume that logistics and site operation issues constitute the most significant set of factors constraining the uptake of OSM in New Zealand construction industry. This assumption was based on the findings of a number of previous studies (Pan *et al.*, 2007; Pasquire *et al.*, 2004; Tam, 2002).

Testing Method

To test Proposition 2, multi attribute analytical technique was employed based on the recommendations of Zikmund (1997) as the most appropriate method where the nature of the data and the objective to be achieved require only cross tabulation analysis without the need for statistical test of significance.

Table 12: Relative levels of contribution of the broad constraint categories as key barriers to OSM

	Level of Impact								
	Vh	H	M	L	Vl				
	5	4	3	2	1				
Constraint Groups	**%**	**%**	**%**	**%**	**%**	[a]TR	[b]MR	[c]%RCI	Rank
Industry & Market Culture	16.2	30.9	29.4	10.3	1.5	68	3.15	16%	1
Skill & Knowledge	10.3	27.9	36.8	11.8	2.9	68	3.00	15%	2
Logistic & Site Operations	7.4	19.1	50.0	10.3	2.9	68	2.87	15%	3
Cost/Value/Productivity	1.5	23.5	39.7	25.0	1.5	68	2.72	14%	4
Supply Chain & Procurement	4.4	20.6	36.8	23.5	4.4	68	2.66	14%	5
Process & Programme	4.4	16.2	42.6	22.1	4.4	68	2.63	14%	6
Regulatory	4.4	10.3	33.8	35.3	1.5	68	2.37	12%	7
						Σ	19.40	100%	

[a] TR = Total responses; [b]MR = Mean rating (see Equation 2); [c] %RCI = % Relative contribution index (See equation 4).

Table 12 presents the cross tabulation of the ranks computed from the ratings of the broad category of constraints by the respondents. The multi-attribute analysis as discussed in section 3.2.9 requires the computation of the mean rating (MR) values and the relative contribution index (RCI) values (see Equations 2 and 4, respectively). The broad categories of constraints are ranked in order of their relative levels of impact in the table.

Result

Table 12 reveals that industry and market culture was ranked highest among all the seven broad categories of constraints. With mean rating (MR) value of 3.15 and relative contribution index of 16%, this set of constraint factors was perceived as the most influencing barrier constraining the uptake of OSM in New Zealand construction industry. On the other hand, the issues related to logistic and site operations were ranked third in the other of relative levels of influence.

Conclusion

The result of the multi attribute analytical analysis as shown in Table 12 reveals that "industry and market culture" is the most significant barrier to the uptake of OSM. On the other hand, "logistic and site operations" set of constraint factors was ranked at third place. Proposition 2 is therefore not supported.

5.3. Need for the Research Model

The third objective of this research was to develop a decision support model for the methodical evaluation of the marginal value offered by the use of OSM relative to that of the conventional method of construction in terms of meeting the needs and preferences of clients in the procurement process.

The decision to choose between OSM methods of construction and the conventional construction methods is difficult in the absence of a tool which can be used to compare the value streams flowing both methods. Generally the choice between these two methods of construction is made on the basis of the outcome of a comparison of the upfront or capital development cost required for the project (Taylor, 2009). So far not much consideration has been given to the life cycle value of the project that can be achieved by the use of either of these two methods of construction. While making a decision on the method of construction, the project development cost seems to over ride consideration for the life cycle issues, especially for the developer client. Pasquire *et al.* (2004) report that there is no precise decision making tool which can be employed to know the variants of OSM systems to be employed in a project to achieve the maximum benefits. Lu and Liska (2008) also highlight the need to carry out a detailed comparison of cost impact of using OSM method of construction in place of conventional construction methods.

5.4. Structure of the Research Model

The model is structured to compare the value stream generated with the application of OSM technology to the corresponding value stream generated with the use of the conventional construction method. The comparison was carried out between the conventional system and each of the following four variants of the OSM.

1. Panelised OSM (components: roof, walls, floors, structural frame build off-site for subsequent installation on-site),
2. Modular OSM (modules manufactured off-site to be installed on-site),
3. Hybrid (mixed use of panelised and modular systems),
4. Whole building built off-site.

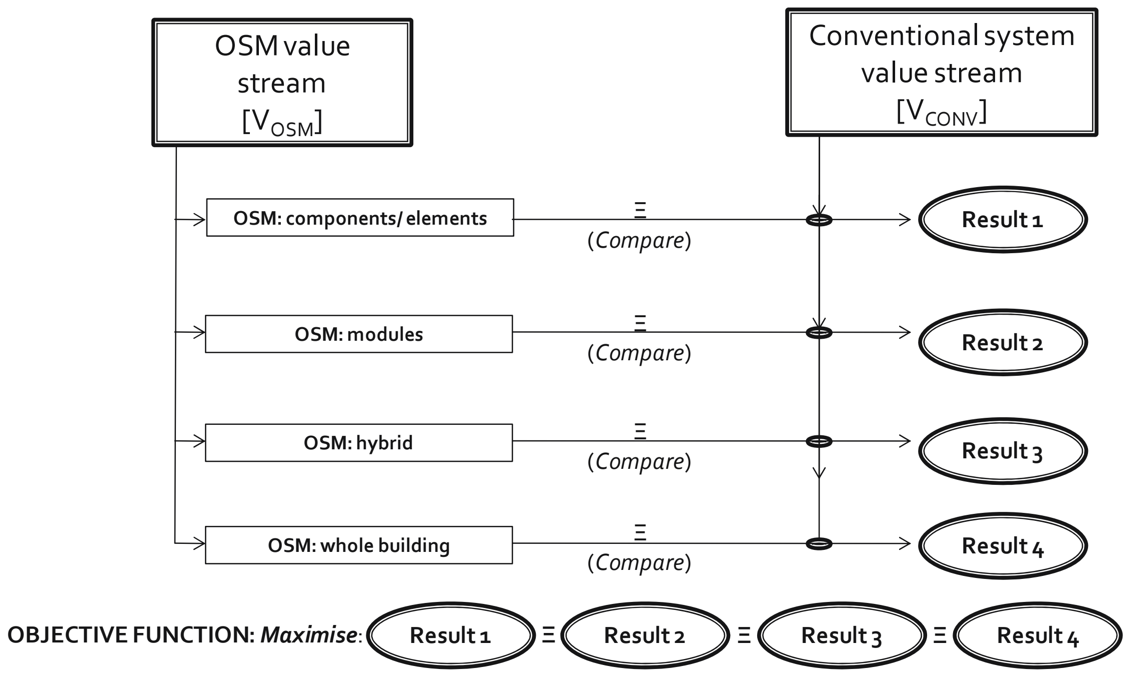

Figure 9: Structure of the research model

The structure of the decision support model is presented in Figure 9. The Figure shows that each of the four value streams resulting from the application of the OSM variants is compared to the conventional system value stream. The comparison yields the marginal value expressed in Equation 10.

$$MV_i = V_{OSM\text{-}ith\text{-}variant} - V_{CONV} \qquad (10)$$

Where:

- MV_i = Resultant marginal value of a particular variant, I, of the OSM compared to that of the conventional method.
- $V_{OSM\text{-}ith\text{-}variant}$ = Value delivered by OSM variant, I, (I = 1, 2, 3, or 4; i.e. panelised, modular, hybrid or whole building);
- V_{CONV} = Value delivered by the conventional system.

Decision Support Mechanism

All things being equal, the OSM variant which produces the highest value of MV_i is to be considered for adoption as the optimal system for maximising value delivery in the procurement process.

5.5. Phases of the Model Application

The model is structured for application in distinct phases of the procurement cycle to take into account the distinctive procurement needs and preferences of the two main categories of procurement clients: the developer on one hand and the investor/ owner-occupier on the other hand. Thus, the two phases for the application of the model are as follows:

1. Development phase (with focus on the needs of the developer client);
2. Life cycle (concerned with the needs of the investor and owner-occupier clients).

The details of the two phases of the model application are discussed in following sub-sections.

5.5.1. Development Phase Model

The structure and working of decision support model for application at the development phase is shown in Figure 10.

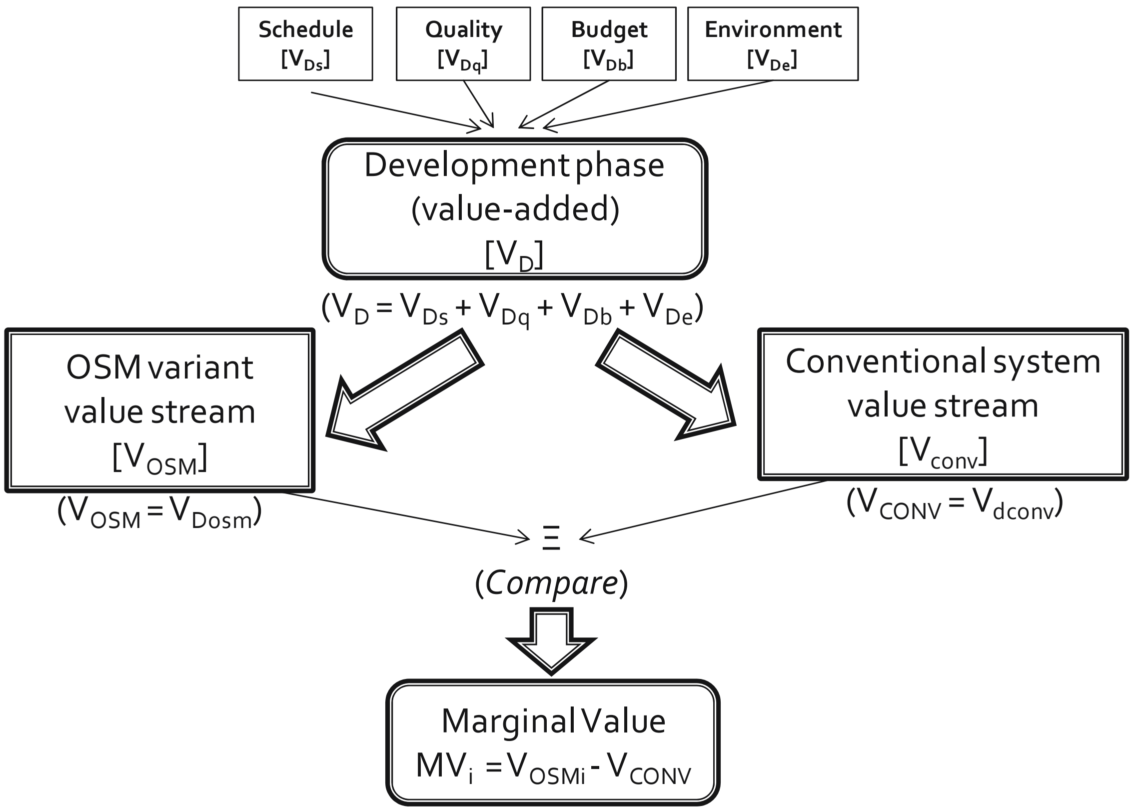

Figure 10: Structure of the model for development phase application

The development phase model takes into account the key needs and preferences of the developer client as the benchmark for comparing value delivery at this phase. These needs and preferences are usually limited to the development phase of the project. Mbachu and Nkado (2007) observe that the developer clients are seldom concerned about the issues arising during the operational phase of the project except as required by the legislation or contract such as liability during the defects liability period.

Decision Variables

The key performance indicators (KPIs) at the project development phase are used as the decision variables for the model application at this phase. Based on previous studies (CSI, 2000; Kelly, 2009; KPI, 2000; Mbachu and Nkado, 2007), the key KPIs at the development phase are as follows:

a) Schedule

b) Quality

c) Budget

d) Environment

However, the KPI Working Group (2000) adds other soft-metrics such as client satisfaction, change orders, business performance and health & safety as part of the development phase KPIs. The business performance criteria include profitability, productivity and return on capital employed. Mbachu and Nkado (2007) believe that performance of the schedule, quality and budget targets should be able to address all other aspects of performance at this phase of the procurement process.

Model for the Development Phase Application

The marginal value (MVi) of Equation 10 can be modified for the development phase to provide the model for application at this phase as follows:

$$MV_{DEVi} = \alpha V`_{Ds} + \beta V`_{Dq} + \lambda V`_{Db} + \gamma V`_{De} \quad (11)$$

$$V`_{Ds} = V_{Ds(OSM)} - V_{Ds(CONV)} \quad (12)$$

$$V`_{Dq} = V_{Dq(OSM)} - V_{Dq(CONV)} \quad (13)$$

$$V`_{Db} = V_{Db(OSM)} - V_{Db(CONV)} \quad (14)$$

$$V`_{De} = V_{De(OSM)} - V_{De(CONV)} \quad (15)$$

Where:

- MV_{DEVi} = Development phase marginal value delivered by a particular OSM variant (i) relative to the conventional approach;

- $\alpha V`_{Ds}$, $\beta V`_{Dq}$, $\lambda V`_{Db}$, and $\gamma V`_{De}$ = Development phase marginal values delivered by the OSM variant relative to the conventional system in terms of schedule performance, quality performance, budget performance and environmental performance, respectively, as the key performance indicators (KPIs) at this phase.

- α, β, λ, γ = Relative weights assigned to the schedule, quality, budget and environmental KPIs, respectively, in line with the client's preferences at the development phase; (where $\alpha + \beta + \lambda + \gamma = 1$ or unity).

It should be noted that positive marginal values offered by the OSM variant relative to the conventional system would be considered negative values for budget and schedule KPI performance in the model application. This is based on an expectation of reduction in the values of these KPIs as a desired outcome.

5.5.2. Model for Life Cycle Application

Life cycle perceptive of a project involves consideration of the development phase of the project as well as the operation and disposal phase. This perspective is more beneficial to the investor and owner-occupier clients as they are not only interested in the development phase value of the project but also the operation phase or the entire life cycle of the project (Mbachu and Nkado, 2007). Figure 11 presents the basic structure of the model for the life cycle application. The expression for its application is given by Equation 16.

Decision Variables

As the life cycle perspective of the model considers the development phase of the project as well as the operation phase, the decision variables include the key performance indicators (KPIs) at both phases. The KPIs at the development phase have been identified in section 5.5.1 as comprising schedule, quality, budget and environment, with the latter focusing largely on the scale of the carbon footprint of the development phase operations. Previous studies (Lawrence *et al.*, 2006; UNEP, 2007) identify the following as the key KPIs at the operation phase of the built facility:

Operation Phase KPIs

a) Running and Maintenance Cost

b) Maintenance Cycle

c) Environment

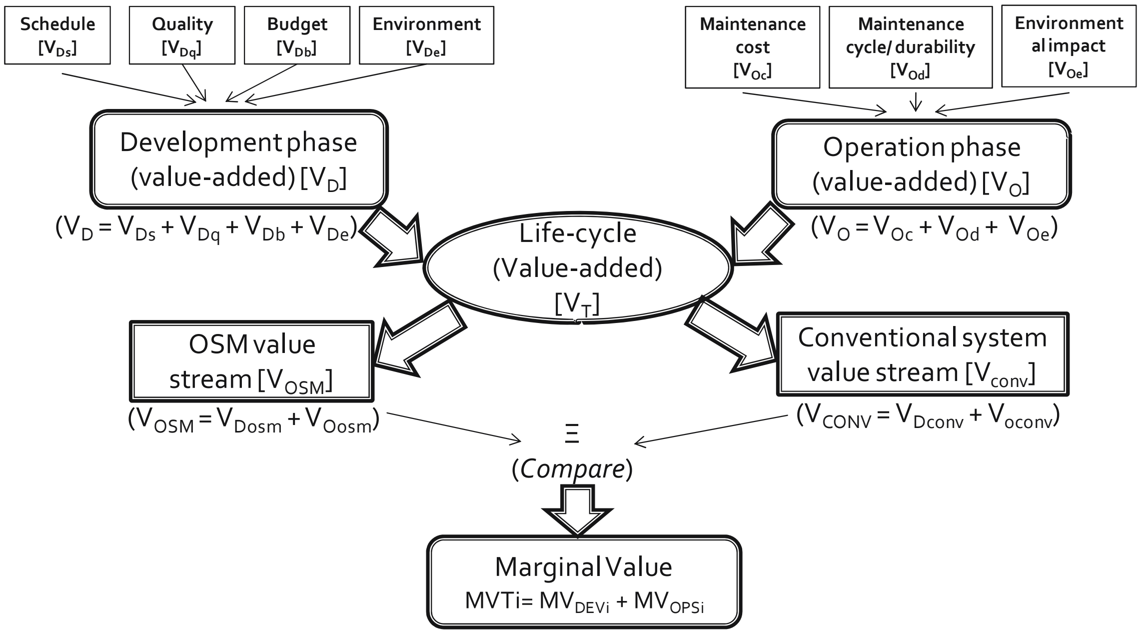

Figure 11: Structure of the model for life cycle application

The environment variable at this phase focuses on the carbon footprint of the operation phase of the built facility. UNEP (2007) estimates the development phase carbon footprint at 13–18%, while the remainder is accounted for by the operation and disposal of the built facility. The huge embodied carbon content of the operation phase is responsible for the high carbon footprint at this phase, a predominant proportion of which comes from energy use as a result of the building design, material specification, fixtures and fittings, and the behaviour of the building occupants.

Model for the Life Cycle Application

The model for the life cycle application comprises the development phase marginal value (MV_{DEVi}) of Equation 11 and the operation phase marginal value (MV_{OPSi}). The resultant marginal value (MV_{Ti}) is expressed in Equation 16.

$$MV_{Ti} = MV_{DEVi} + MV_{OPSi} \qquad (16)$$

$$MV_{OPSi} = \kappa V`_{Oc} + \tau V`_{Od} + \psi V`_{Oe} \qquad (17)$$

Where:

- MV_{Ti} = Total life cycle marginal value delivered by a particular OSM variant (i) relative to the conventional approach;

- MV_{DEVi} = Development phase marginal value delivered by a particular OSM variant (i) relative to the conventional approach as expressed in Equation 11;

- MV_{OPSi} = Operation phase marginal value delivered by a particular OSM variant (i) relative to the conventional approach;

- $\kappa V`_{Oc}$, $\tau V`_{Od}$, and $\psi V`_{Oe}$ = Operation phase marginal values delivered by the OSM variant relative to the conventional system in terms of performance on the three KPIs: running and maintenance costs, maintenance frequency and environment, respectively.

- K, τ and ψ = Relative weights assigned to the running and maintenance costs, maintenance frequency and the operation phase environment KPIs, respectively, in line with the client's and/ or user preferences at the operation phase; (where $\kappa + \tau + \psi = 1$ or unity).

As in the development phase, positive marginal values offered by the OSM variant relative to the conventional system would be considered negative values for running and maintenance costs and maintenance frequency KPI performance at this phase in the model application. Again, this is based on an expectation of reduction in the values of these KPIs as a desired outcome.

5.6. Model Application

The application of the research model was demonstrated for the modular variant of the OSM, which has been identified in a previous study (Langdon and Everest, 2004) as the future of the OSM. The model demonstration was carried out for a two floor office building project with a gross floor area of 240 m². Constraints such as insufficient data precluded the model application in relation to the whole building, hybrid and component/element variants of the OSM technology versus the conventional systems.

The selected office building was evaluated for development phase value streams as well as those of the life cycle based on the data collected as the input values of decision variables. First, consultations were made with project managers, property managers and OSM manufacturers for feedback on the required input variables. For the execution of this project using the modular OSM, the project budget was found to be NZ$ 754,000 including GST. This Figure was provided by a manufacturer of OSM buildings. The value of the schedule input was also obtained from the project manager; the estimated completion time for the project was estimated to be 13 months using the OSM modular system; this also included the time required to seek building and resource consents from the councils. Information on the cost of running and maintenance of the modular project was estimated by property managers to be NZ$ 37,700 per year. The maintenance frequency was estimated to be at a frequency of two maintenance operations required every five years.

The input for quality performance was qualitative in nature, being based on subjective assessment of experienced project managers for the development phase, and property managers for the operation phase. Qualitative assessment of quality performance was also supported by the KPI Working Group (2000), which also used a 10 point scoring system for measuring the performance of the quality indicator in all parts of the procurement supply chain. The group sees quality as “an issue that affects the project so that work needs to be redone, modified or compromised to a lower standard than originally agreed” (p.17). Though defect/ rework is the objective criterion for assessing quality, the term also encompasses wider issues which cannot be measured objectively such as incorrect information on a drawing, or non-compliance with specifications/ building code. The KPI Working Group’s (2000) scoring system for quality performance assessment was adopted, which ranged from 1 (totally defective) to 10 (apparently defect free) as follows:

- 10 = Apparently defect free;
- 8 = Few defects having no significant impact on owner;
- 5/6 = Some defects having some impact on owner;
- 3 = Major defect, having major impact on owner;
- 1 = Totally defective.

The average ratings provided by three project managers to the development phase performance on quality and environment, and the corresponding ratings provided by property managers for the operation phase performance on environment constituted the inputs for these KPIs.

The quality of the modular project option was rated 8 out of 10, the environmental performance during the development phase was rated 8 out of 10 and the environmental performance during the operation and disposal phase was rated 7 out of 10.

Corresponding objective and qualitative assessments of the KPI performance of the project based on the conventional construction method yielded the following results:

- The project budget was estimated at NZ$ 705,564; this amount includes cost of fit-outs, GST and an allowance of 30% of the total base building costs for exclusions. This value was calculated based on the cost data provided by the Rawlinsons Construction Handbook 2010. The value obtained from the handbook was first adjusted for current inflationary effects based on the current capital goods and price index (CGPI). It should be noted that similar estimation using the Department Building online calculator (DBH, 2011) provided values, which were considered too generic for unique applications.

- Regarding the project schedule, the project managers hinted that similar conventionally built project would take nine months to complete.

- The maintenance budget required each year was estimated by the property managers to be 10% of the project cost per year; this amounted to NZ$ 70,556 per annum.

- Based on the property managers' estimate, the conventionally built project would require maintenance once each year; to align this estimate with the five year baseline for the OSM modular system, this worked out to five times maintenance frequency every five years.

Ratings were made by the project and property managers for the quality and the environmental performance during the development phase, and the environmental performance during the operational phase, respectively. The average of ratings provided to each variable provided the model application input values as follows.

- The quality of conventionally built project was rated as 6 out of 10,

- The environmental performance during the development phase was rated 4 out of 10, and

- The environmental performance during the operational and disposal phases was rated 5 out of 10.

Relative Weights of the Input Variables

To factor in the clients and/ or user needs and preferences in the development and operation phases of the procurement process, relative weight was assigned to each variable used in the model as explained in the Equations 11 and 16.

The values of the relative weights for the variables were estimated in consultation with the developers for development phase application, and the investor and owner-occupier clients for the operation phase/life cycle application. The relative weights for the respective development and operation phase KPIs were established as shown in Table 13.

Table 13: Relative weights of the key performance indicators

KPI		**Relative weight**
A) Development phase:		
Budget		0.35
Schedule		0.33
Quality		0.27
Environment		0.05
	∑	1.00
B) Operation phase:		
Running & maintenance costs		0.5
Maintenance frequency/ durability		0.3
Environment		0.05
	∑	1.00

5.6.1. Development Phase Application of the Model

Evaluation of the marginal value of OSM modular variant relative to the conventional system for the development phase was made in Figure 12. The evaluation was based on the procedure set down in section 5.5.1. For better visual appreciation, the marginal values were plotted against the key performance indicators as shown in Figure 13.

Figure 13: Plots of the OSM modular system's marginal values for the KPIs at the development phase shows that the modular OSM has a negative impact on the project budget as it slightly increased the budget for the case study project by 2.4% compared to the conventional construction methods. The technology therefore was therefore perceived to be less value-adding compared to the conventional system at the development phase.

On the other hand, considerable savings on the project schedule was achieved with the use of the modular OSM, up to 22 % efficiency. Though this Figure appears to be much lesser than the 50% time saving recorded in an earlier study (BIA, 2004), it shows that the OSM modular was more value-adding at this stage than the conventional system.

The quality of the project also shows a positive value with an improvement of 9% compared to the quality of the conventionally built project.

Similarly, 5% marginal improvement was achieved by the use of OSM in respect of the environmental performance of the project at this phase. Again, this shows that the use of the modular variant of the OSM was more value-adding than the conventional system. Though this result agrees with similar findings of the KPI Working Group (2000), it could be due the perceived positive value of onsite waste reduction credited to OSM, compared to the high onsite wastage and associated carbon footprint of the conventional system. However, in terms of the embodied energy involved in the manufacture and transportation of the components for all variants of the OSM (Lawrence *et al.*, 2006), the overall environmental impact may not be significantly different from the conventional system at this phase.

Development Phase Perspective of Decision Support Model

Decision variables/Development KPIs	**OSM**	**OSM Marginal Value**	**Conventional**
Budget (costs, $)	754000	-7%	705564
Schedule (months)	3	67%	9
Quality rating (out of 10)	8	33%	6
Environment (rating out of 10)	8	100%	4

KPIs											
a) Budget			**b) Schedule**			**c) Quality**			**d) Environment**		
OSM-CONV margin	KPI rel wt	Marginal value	OSM-CONV margin	KPI rel wt	Marginal value	OSM-CONV margin	KPI rel wt	Marginal value	OSM-CONV margin	KPI rel wt	Marginal value
-7%	0.35	-2.4%	67%	0.33	22.0%	33%	0.27	9.0%	100%	0.05	5.0%

Figure 12: Evaluation of the OSM modular system's marginal values relative to the conventional system at the development phase

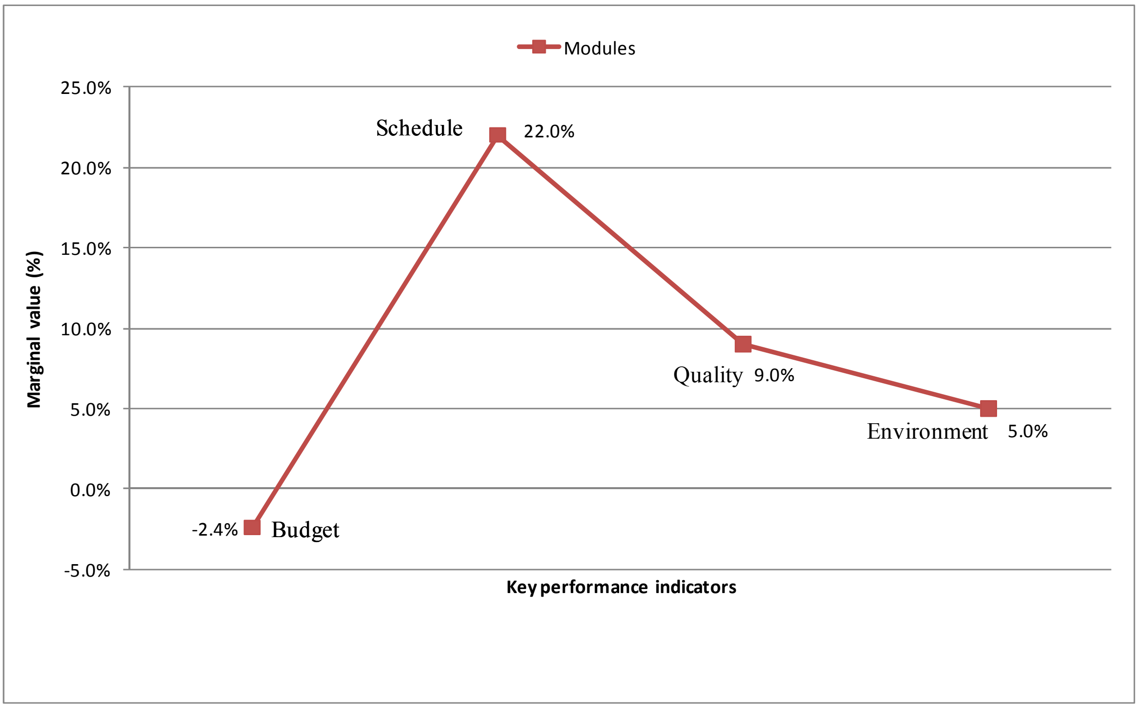

Figure 13: Plots of the OSM modular system's marginal values for the KPIs at the development phase

Overall, the use of the modular OSM was found to be more beneficial than the conventional system, even with a little higher cost of the project at the development phase. The net overall marginal value delivered at this phase was 34% relative to the conventional system. This result contrasts with the overall 22% improvement in capital value established in an earlier UK study (Langdon and Everest, 2004) for the use of OSM relative to conventional system. Also in the U.S. (BIA, 2004) found that replacing stick-built with modular construction could result in savings of 20% for 16 feet (4.88m) wide x 40 feet (12.19m) long double home, though a lesser savings of 9% was found for a slightly longer option 20 feet (6m). This was due to the cost premium associated with exceeding the maximum (i.e. 5m) width allowed for any modular unit that must be transported on the highway. Perhaps, the economies of scale enjoyed by the larger nations could be responsible for the higher development costs associated with the use of OSM compared to the conventional system.

5.6.2. Operation Phase and Life Cycle Application of the Model

Figure 14 shows the evaluation of marginal values delivered by the modular OSM relative to the conventional construction method at the operation and life cycle phase of the case study project.

The operation and disposal phase decision variables were added to the earlier development phase results to obtain the overall life-cycle marginal values as provided by Equation 12.

Figure 15 summarises the development and operational phase marginal values achieved for modular OSM technology relative to the conventionally constructed option of the case study project. The results for the operation phase application of the OSM modular system show 23% reduction in running and maintenance cost, 18% reduction in maintenance frequency and 8% improvement on environmental impacts. The overall marginal value delivered at the operation phase was 49.3%.

Although these results are too high compared to the findings of earlier studies, for instance, the 30% improvement was reported (BIA, 2004) as the overall life-cycle value delivered by the modular system compared to the stick-built approach.

Operation Phase Perspective of Decision Support Model

Operation phase KPIs	OSM	OSM Marginal Value	Conventional
Annual maintenance costs ($/yr)	37700	47%	70556
Maintenance frequency (No/ 5yr)	2	60%	5
Environment (rating out of 10)	7	40%	5

Operational KPIs								
a) Maintenance Budget			b) Maintennce Frequency			c) Environment		
OSM-CONV margin	KPI rel wt	Marginal value	OSM-CONV margin	KPI rel wt	Marginal value	OSM-CONV margin	KPI rel wt	Marginal value
47%	0.5	23.3%	60%	0.3	18.0%	40%	0.2	8.0%

Figure 14: Evaluation of the OSM modular system's marginal values relative to the conventional system for the operation phase/ life cycle

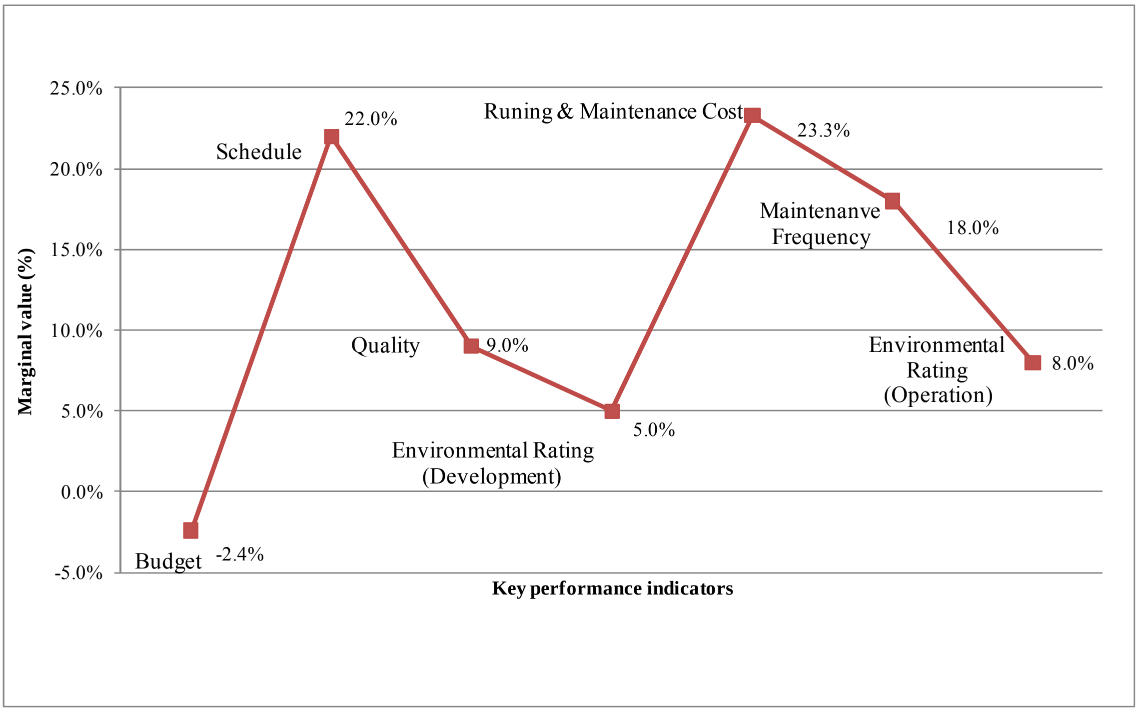

Figure 15: Plots of the OSM modular system's marginal values for the life cycle KPIs

5.6.3. Conclusion of Model

The application of the model for the development and life cycle phases of the procurement cycle has been demonstrated using the modular versus conventional systems. Overall results showed that the use of modular variant of the OSM resulted in an increase of about 2.4% in the project budget over the cost for the conventional stick-built system at the development phase. This result is a departure from the findings of earlier studies that the use of OSM technology has a positive impact on project development budget with a potential for comparative reduction of up to 6% (MHC, 2011), 30% (BIA, 2004) or 15% (Langdon and Everest, 2004). Perhaps, the small size of New Zealand could be responsible for the inability of the industry to leverage economy of scale to deliver buildings at a reduced cost compared to the traditional system.

The good news is that the use of the modular variant of OSM delivers superior value on other KPIs over and above the corresponding value achievable using the traditional system. The model application shows that employing the OSM technology at the development and operational phases of the procurement cycle results in value improvement of up to 34% and 49%, respectively. This is in agreement with (MBI, 2010b) report, which anticipates value improvement in the use of the technology of about 30% - 50% compared to the traditional system.

The improvement in the quality of built project for both development and operational phases was found to be 9%. This finding agrees with (CSI, 2000) report that OSM technology provides a superior quality to compared to the conventionally built project.

The extent of reduction on the environmental impact of construction activities and the operation of the built facility also shows a positive trend when evaluated for the development and operation phases. The development phase application of the model showed a reduction of 5% in carbon footprint, while 3% reduction was noted for the operational phase. MHC (2011) reports that the use of OSM may not have any significant improvement in the reduction of the embodied energy compared to the traditional construction system, rather, the reduction in site waste and material wastage is the driving force behind the use of OSM. The Report shows a reduction in wastage to be 5% or more when conventional construction process is replaced by the OSM technology. Embodied energy which is the energy spent in the extraction of the raw materials from non-renewable sources, manufacturing and transporting of the finished product to site is the key issue here, which OSM may not have an answer to.

The life cycle perspective shows a significant benefit of using modular OSM in terms of running and maintenance requirements. The budget required to carry out annual maintenance is reduced by 23%; in addition, there is an annual reduction of 18% in the frequency of maintenance by the use of OSM compared to the traditional stick-built system.

5.7. Summary

Research propositions were formulated to enhance the achievement of the objectives set for research. The testing of the propositions showed that one out of the two key propositions was supported by statistical evidences. The proposition 1, which states that consensus of opinions exists on the relative levels of impact of the broad categories of constraints to the uptake of OSM between the two major stakeholder groupings i.e. the clients and agents as the employer group, versus the contractors and the suppliers/manufacturers as the service provider group was supported. Proposition 2 which assumed that logistics and site operation issues would constitute the most significant group of factors constraining the uptake of OSM in New Zealand construction industry was not supported. The cross tabulation analysis employed in the test of the proposition revealed that industry and market culture is the most significant set of barriers to the uptake of OSM.

The decision support model was developed to provide a methodical approach to the evaluation of the marginal value delivered by the use of OSM relative to the conventional system as a basis for an informed decision making process in the selection of a suitable method of construction with a view to maximising value addition at both the development and life-cycle phases of the procurement process. Application of the model was demonstrated using the modular variant of the OSM versus the conventional stick-built system. The methodology developed could be replicated in studying other variants of the technology and for other settings.

Chapter 6. Conclusions and Recommendations

This chapter presents the conclusions drawn from the research findings and the recommendations put forward for improving the uptake of OSM in the industry. The chapter also highlights the key contributions of the research to knowledge and recommendations for further research.

6.1. Conclusion

OSM or prefabrication of building components could be leveraged to improve the reported low productivity trend in the New Zealand (NZ) construction industry. This study is focused on identifying the key constraints to the uptake of prefabrication in the NZ construction industry and the improvement measures. Using the modified version of an Australian study (CRC, 2007) as a starting point, seven broad categories of constraints were found relevant in the New Zealand context as being responsible for the low uptake of the technology in industry. In their decreasing order of relative levels of contributions, the broad categories are as follows: industry and market culture (16.2%), skills and knowledge (15.5%), logistics and site operations (14.8%), cost/value/productivity (14), supply chain and procurement (13.7%), process and programme (13.6%), and regulatory (12.2%). The latter was found to be insignificant on account of low impact rating. Overall, industry and market culture, skills and knowledge, logistics and site operations, and cost/value/productivity account for 61 percent of the constraints to the uptake of the technology in New Zealand. The key constraints underlying these four broad categories are as follows:

1. Industry and market culture: Reluctance to change by key stakeholders.
2. 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.
3. Logistics and site operations: The legal restrictions on the transportation of large components and the requirement for expensive escorts.

4. Cost/value/productivity: High transportation and handling costs, especially where there is a need for long distance haulage and the use of heavy cranes for high rise construction.

Mitigation measures as suggested by the survey participants focused on addressing the key constraints in each broad category having a significant impact on the uptake of the technology in the industry. In addition, it was found that increased awareness campaign, more research and greater client involvement in the promotion of the use of the technology at the design stage could contribute to improved uptake of the technology in the New Zealand construction industry.

Overall, it is argued that if the key stakeholders in the industry could aim to proactively address the identified constraints to the uptake of prefabrication in line with their relative levels of impact, greater uptake of the technology could be achieved in a more cost-effective manner. Consequently, the technology could be leveraged to significantly improve productivity and performance in the New Zealand construction industry.

To enable a methodical evaluation of the marginal value achievable by the use of a variant of OSM over and above that of the traditional stick-built system at the design and life-cycle phases of the procurement process, a decision support model was developed. The model incorporates the key performance indicators (KP1s) underlying clients' value system at the development and operational phases and compares the extent to which each variant of OSM delivers each value criterion relative to the conventional system. The sum of the marginal values at each phase of the procurement system provides the rationale basis for choosing either the OSM variant or the conventional system based on the approach that delivers the highest marginal value.

The model application to real life project was demonstrated using the modular variant of the OSM compared to the conventional stick-built system. Results of the model application at the development phase shows that the OSM was more beneficial to the client than the conventional system with an overall marginal value of 34% relative to the conventional construction approach. Individual results showed 22% improvement in the completion time for the project, 9% improvement in quality and 3% reduction in the carbon footprint at the development phase. However, the technology was found to be 2.4% more expensive than the traditional stick-built system. This result contrasts with the findings of previous studies which point to cost reduction at this phase with the use of the technology. This could be due to the small size of New Zealand which constrained the leveraging of economy of scale to achieve significant cost savings as in other countries with large population.

Results of the model application at the operation and life-cycle phases also show that the technology achieved superior value compared to the conventional stick-built system. The overall marginal value achieved by the modular OSM application at the operation phase was 49% compared to the traditional stick-built system; this comprised 23% reduction in the running and maintenance costs, 18% reduction in the maintenance frequency of the structure and fabric, and an annual 8% reduction in the carbon footprint.

Overall, the use of modular variant of the OSM was found to deliver superior value to clients compared to the conventional system at the development, operational and life-cycle phases of the procurement process.

6.2. Contributions to Knowledge

The key contributions of this study to existing stock of knowledge include the identification and prioritisation of the key barriers to the uptake of OSM, measures for improving the uptake of the technology and a decision support model for evaluating the marginal value delivered by a particular variant of OSM compared to the conventional stick-built system.

Identification and Prioritisation of the Key Barriers to the Uptake of the OSM

The study has contributed to knowledge by providing a more structured approach to identifying and segregating the broad categories of the key barriers to the uptake of OSM technology in New Zealand in a meaningful and more manageable way relevant to the unique New Zealand context.

This study has also prioritized the barriers to the uptake of OSM according to their relative levels of influence. Establishing the relative importance of each broad category of constraints is a key gap in the literature which has been filled. This will greatly benefit the construction industry operators by providing an optimal or cost effective approach for disbursing scarce resources to addressing the key barriers which could result in significant improvement in the uptake of the technology.

Measures for Improving the uptake of OSM Technology

This research has also contributed to exploring further the measures for addressing the identified barriers with a view to improving the uptake of OSM technology. These measures if properly applied are likely to enhance the adoption of OSM methods of construction in New Zealand construction sector leading to improved productivity of the New Zealand construction industry.

Development of Research Model

One of the reasons behind clients' and designers' reluctance to use OSM is the absence of knowledge of the extent of value addition that could be achieved by the use of the technology compared to the tried and tested traditional stick-built system. Comparative value analysis between both systems has been largely based on cost without due consideration given to other equally important variables such as quality and environmental impacts; this has been largely due to a lack of a methodical approach for a more holistic analysis. This study has bridged this gap by providing and demonstrating the application of a decision support model which can be used as a methodical approach for evaluating the marginal value delivered by the OSM over and above the value stream flowing from the conventional system. The model applications at the development and operational phases also provide distinct methodical approaches for value assessment for the benefit of the short-term procurement interest clients such as developers and the long-term procurement interest clients such as property investors and owner-occupier clients, respectively.

6.3. Recommendations for Future Research

The study reveals that industry and market culture is the most significant set of barriers to the uptake of OSM in New Zealand construction industry. This indicates a need to carefully look into the aspects of the culture of the industry and the market in New Zealand which are constraining the construction industry to adopt this innovative technology and to address the challenges and risks associated with the use of OSM. A careful evaluation of the real and perceived risks associated with OSM and the corresponding mitigation measures will provide the opportunity to expose and address the issues and ensure greater uptake of the technology in New Zealand. Further in depth research into the other identified barriers with significant levels of impact is also needed.

This research focused on OSM application in relation to buildings. There is a need to examine in detail the suitability of OSM for various civil engineering projects including carrying out financial analysis, risk estimation and sustainability measurement.

It is further recommended that the methodology developed in this study for the application of modular variant of OSM should be followed in further studies relating to other variants of the technology. The further studies should investigate the value addition achievable by comparing the three variants of OSM with the conventional system. Findings of such further studies for the development phase might be an improvement over the plots shown in Figure 16; the plots were the outcome of a shallow analysis based on scanty data available for the panelised/components and whole building variants of the OSM compared to the traditional system.

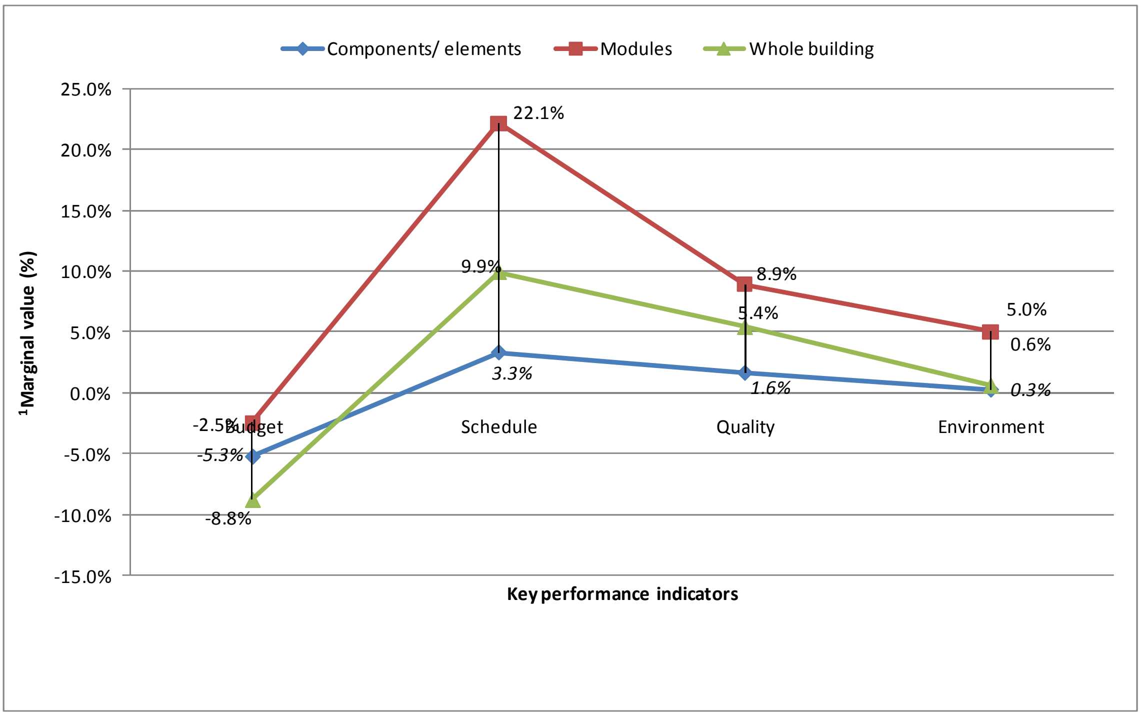

Figure 16: Plots of the marginal values of the OSM variants for the KPIs at the development phase

References

Arif, M. and Egbu, C. 2010. Making a Case for Offsite Construction in China. *Engineering, Construction and Architectural Management,* 17(6)**,** 536-548.

Azman, M. N. A.,Ahamad, M. S. S.,Majid, T. A. and Hanafi, M. H. 2010. *The Common Approach in Off-site Construction Industry*. *Australian Journal of Basic and Applied Sciences,* 4(9)**,** 4478-4482.

Barker, K. 2003. *Review of Housing Supply: Securing our Furure Housing Needs*. London, UK: HMSO.

Barret, J. and Weidmann, T. 2007. *A Comparative Carbon Footprint Analysis of On-Site Construction and an Off-Site Manufactured House*. Stockholm, Swedan: Stockholm Environment Institute

Becker, P. 2005. *StepChange - Innovation, Attitude and Business Benefits*. London, UK: DTI & TRADA.

Bell, P. 2009. *Kiwi Prefab: Prefabricated Housing in New Zealand.* Masters Dissertation, Victoria University of Wellington.

BIA 2004. Going Modular: Reducing Housing Costs in Philadelphia with Modular Construction. Building Industry Association.

Blismas, N. and Wakefield, R. 2007. *Drivers, Constraints and the Future of Offsite Manufacture in Australia*.

Blismas, N.,Wakefield, R. and Hauser, B. 2009. *Concrete Prefabricated Housing via Advances in Systems*. *Engineering, Construction and Architectural Management,* 17(1)**,** 99-110.

CACPUCI 2009. *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry*. Washington DC: National Research Council.

Chiang, Y. H.,Chan, E. H. W. and Lok, L. K. L. 2006. *Prefabrication and Barriers to Entry - A Case Study of Public Housing and Institutional Buildings in Hong Kong*. *Habitat International,* 30(482-499.

Committee, C. 2008. Inquiry into housing affordability in New Zealand. Report of the Commerce Committee. Wellington, New Zealand: The House of Representatives.

Cooper, D. R. and Ermory, C. W. 1995. *Business Research Methods,* 5th Edition, Chicago, USA, Richard D. Irwin Inc.

CRC 2007a. *Off-site Manufacture in Australia: Current State and Future Directions*. *CRC Construction Innovation.* Canberra, Australia: Cooperative Research Centres.

CRC 2007b. *Offsite Manufacture in Australia - Final Report*. *In:* Fussell, T. (ed.). Canberra, Australia: Cooperative Research Centre for Construction Innovation (CRC).

CRC 2007c. *Offsite Manufacture in Australia: Case Studies*. Canberra, Australia: Cooperative Research Centres.

CSI 2000. *Value and Benefits Assessment of Modular Construction*. The Steel Construction Institute.

Davis, N. 2007. *Construction Sector Productivity: Scoping Report*. Wellington, New Zealand.

DBH 2008. Briefing for the Minister for Building and Construction. Department of Building and Housing.

DBH 2009. *Report of the Building and Construction Sector Productivity Taskforce*. Wellington, New Zealand: Department of Building and Housing.

DBH 2011. Quick Calculator: Online Total Estimate for Building Cost.

Degeest. 2011. *Pre-built vs On-site* [Online]. Available: http://www.degeest.com/09/benefits.html [Accessed 1 May 2011 2011].

DoL 2009. Cranes - Approved Code of Practice for - Includes the Design, Manufacture, Supply, Safe Operation, Maintenance and Inspection of Cranes. *In:* Labour, D. O. (ed.).

Gibb, A. G. F. 1999. *Off-site Fabrication,* Scotland, UK, Whittles Publishing.

Gibb, A. G. F. and Isack, F. 2003. *Re-engineering through Pre-assembly: Client Expectations and Drivers*. *Building Research and Information,* 31(2)**,** 146-160.

Goodier, C. and Gibb, A. 2007. *Future Oppertunities for Offsite in the UK*. *Construction Management and Economics,* 25(10.

Gurdjian, P. and Andonian, A. Year. Key Levers for Productivity Improvement in Armenia. *In:* Armenia 2020 Conference, 2003 Yerevan. Mckinsey Report.

Haas, C. and Fagerlund, W. R. 2002. *Preliminary Research on Prefabrication, Pre-assembly, Modularization and Off-site Fabrication in Construction*. Austin, USA: University of Texas at Austin.

Haas, C.,O'connor, J. T.,Eickmann, J. A. and Fagerlund, W. R. 2000. *Prefacbrication and Preassembly Trends and Effects on the Construction Workforce*. Austin, USA: Center for Construction Industry Studies, The University of Texas at Austin.

Hampson, K. and Brandon, P. 2004. *Construction 2020 : A vision for Australia's Property and Construction Industry*. . Brisbane, Australia: Cooperative Research Centres (CRC).

Industry, C. O. a. T. P. a. C. O. T. U. S. 2009. *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry*. Washington, D.C.: The National Academies Press

Jaillon, L. and Poon, C. S. 2008. *Sustainable Construction Aspects of Using Preabrication in Dense Urban Environment: a Hong Kong Case Study*. *Construction Management and Economics,* 26(953-966.

Jaillon, L. and Poon, C. S. 2009. *The Evolution of Prefabricated Residential Building Systems in Hong Kong: A Review of the Public and Private Sector*. *Automation in Construction,* 18(239-248.

Jaillon, L. and Poon, C. S. 2010. *Design Issues of Using Prefabrication in Hong Kong Building Construction*. *Construction Management and Economics,* 28(1025-1042.

Jaillon, L.,S., P. C. and Chiang, Y. H. 2009. *Quantifying the Waste Reduction Potential of Using Prefabrication in Building Construction in Hong Kong*. *Waste Management,* 29(309-320.

Jailon, L. and Poon, C. S. 2009. The evolution of prefabricated residential building systems in Hong Kong: A review of the public and private sector. *Automation in Construction,* 18(239-248.

Kamarazaly, M., Aishah. 2007. *Outsourcing versus In-house Facilities Management: Framework for Value Adding Selection.* Masters Masters, Massey University.

Kelly, R. 2009. *Your Guide to Specifying Off-site Manufacture. Maximising Value and Minimising Risk.*

KPI 2000. KPI Report for the Minister for Construction. London: Department of the Environment, Transport and Regions. KPI Working Group.

Langdon, D. and Everest 2004. Cost model: Off-site manufacture.

Lawrence, L.,Green, J. and Lee, S. 2006. Carbon Footprint of Construction Capstone Project. University of Washington Program on the Environment.

Love, P. E. D. and Irani, Z. 2004. *An Exploratory Study of Information Technology Evaluation and Benefits Management Practices of SMEs in the Construction Industry*. *Information & Management,* 42(227-242.

Lu, N. Year. *The Current Use of Offsite Construction Techniques in the United States Construction Industry*. *In*, 2009 Seattle, WA. 946-955.

Lu, N. and Liska, R. W. 2008. *Designers' and General Contractors' Perceptions of Offsite Construction Techniques in the United State Construction Industry*. *International Journal of Construction Education and Research,* 4(3)**,** 177-188.

Luo, Y. 2008. *Decision supportfor prefabrication strategy selection on building systems.* PhD, The Pennsylvania State University.

Lusby-Taylor, P.,Morrison, S.,Ainger, C. and Ogden, R. 2004. Design and Modern Methods of Construction. *The Commission for Architecture and the Built Environment (CABE), London*.

Mbachu, J. 2008. *Conceptual Framework for the Assessment of Subcontractors' Eligibility and Performance in the Construction Industry*. *Construction Management and Economics*, 26(471–484.

Mbachu, J. 2009. *Improving Construction Project Delivery Through Automation and Robotics*. *6th International Conference on Construction Project Management (ICCPM).* Jeju, Korea.

Mbachu, J. and Nkado, R. 2007. *Factors Constraining Successful Building Project Implementation in South Africa*. *Construction Management and Economics,* 25(1)**,** 39-54.

MBI 2010a. *Improving Construction Efficiency & Productivity with Modular Construction*. Charlottesville, USA.

MBI 2010b. *Permanent Modular Construction*. California, USA: Modular Building Institute.

MHC 2011. *Prefabrication & Modularisation: Increasing Productivity in the Construction Industry*. Massachusetts, USA: McGraw_Hill Consctruction.

MUHEC 2010. *Code of Ethical Conduct for Research, Teaching and Evaluations Involving Human Participants*. *In:* University, M. (ed.).

Murray, N.,Terrence, F. and Aouad, G. 2003. *A Virtual Environment for the Design and Simulated Construction of Prefabricated Buildings*. *Virtual Reality,* 6(244-256.

Nadim, W. and Goulding, J. S. 2009. *Offsite Production in the UK: The Construction Industry and Academia*. *Architectural Engineering and Design Management,* 5(136-152.

Naoum, S. G. 2007. *Dissertation Research and Writing for Construction Students,* 2nd Edition, Oxford.

Ngowi, A. B.,Pienaar, E. and Mbachu, J. 2005. *The Globalisation of the Construction Industry — A Review*. *Building and Environment,* 40(135 - 141.

NHBC 2006. *A Guide to Modern Methods of Construction*. London. UK: NHBC Foundation.

Pan, W.,Gibb, A. and Dainty, A. 2005. *Offsite-MMC in Housebuilding – Perspectives and Practices of Leading UK Housebuilders*. Loughborough University.

Pan, W.,Gibb, A. F. and Dainty, A. R. J. 2007. *Perspective of UK Housebuilders on the Use of Offsite Modern Methods of Construction*. *Construction Management and Economics,* 25(2)**,** 183-194.

Pasquire, C.,Blismas, N.,Aldridge, G. and Gibb, A. 2002. *Innovation Through Standardization and Pre-assembly: Issues for Benefit Measurements*. *10th Symposium Construction Innovation and Global Competitiveness.*

Pasquire, C.,Gibb, A. and Blismas, N. Year. Off–site Production: Evaluating the Drivers and Constraints. *In*, 2004.

Phillipson, M. 2003. *Defining the Sustainability of Prefabrication and Modular Process in Construction. Current Practice and Potential Uses of Prefabrication.* Department of Trade and Industry.

POST, P. O. O. S. a. T. 2003. *Modern Methods of House Building*. London, UK: Parliamentary Office of Science and Technology POST.

Rivard, H. 2000. *A Survey on the Impact of Information Technology on the Canadian Architecture, Engineering and Construction Industry*. *ITcon,* 5(

RSE, P. N. F. A. 2009. *Construction and Demolition Waste*. Hong Kong.

Scofield, R.,Wilkinson, S.,Potangaroa, R. and Rotimi, F. 2009a. *Driving Innovative Offsite Construction Techniques in New Zealand* [Online]. Auckland: Heavy Engineering Research Association (HERA). Available: http://www.hera.org.nz/Folder?Action=View%20File&Folder_id=105&File=Driving%20Innovative%20Offsite%20Construction%20Techniques%20in%20NZ.pdf [Accessed 20-02-2011 2011].

Scofield, R., Potangaroa, R. and Bell, P. 2009b. *Offsite Unplugged: The Potential for Offsite Production in New Zealand*. Available: http://12219-portal.memberconnex.com/Folder?Action=View%20File&Folder_id=105&File=Offsite%20Unplugged.pdf.

Stanleygroup. 2011. *Reasons to Go Modular* [Online]. Auckland, New Zealand. Available: http://www.stanleygroup.co.nz/page/137-modular [Accessed 1 May 2011 2011].

Statistics, N. 2005. *UK 2005: The Official Yearbook of the United Kingdom of Great Britain and Northern Ireland*. London: Office for National statistics.

Stevens, B. 1992. Architectural and structural precast concrete. *Australian Concrete Technology*, 269-291.

Tam, C. M. 2002. *Impact on Structure of Labour Market Resulting from Large-Scale Implementation of Prefabrication*. *Advances in Building Technology,* 1(5.

Tam, V. W. Y.,Tam, C. M.,Zeng, S. X. and Ng, W. C. Y. 2007. *Towards Adoption of Prefabrication in Construction*. *Building and Environment,* 42(10), 3642-3654.

Tatum, C. B.,Vanegas, J. A. and Williams, J. M. 1986. *Constructability Improvement Using Prefabrication, Preassembly, and Modularization* Construction Industry Institute, Constructability Task Force, United States

Taylor, S. 2009. *Off-Site Production in the UK Construction Industry- A Brief Overview*. London, UK: Construction Engineering Specialist Team:HSE.

UNEP 2007. *Building and Climate Change: Status, Challenges and Opportunities,* Paris.

Wilson, M. W. Y. 2006. *Prefabrication for Hong Kong's Construction Industry: A study of Barriers and Oppertunities.* Master of Science, The University of Hong Kong.

Yau, W. M. W. 2006. *Prefabrication for Hong Kong's Construction Industry: A Study of Brriers and Oppertunities.* Master Thesis, The University of Hong Kong.

Zikmund, W. G. 1997. *Exploring Marketing Research,* 6th, Dryden Press.

APPENDICES

Appendix A: Low Risk Notification

MASSEY UNIVERSITY

16 August 2010

Wajiha Shahzad
1/43 Woodward Road
Mount Albert
AUCKLAND 1025

Dear Wajiha

Re: Improving Productivity in the New Zealand Construction Industry through Offsite Manufacture of Components: Key Areas of Application, Merit, Constraints and Prospects

Thank you for your Low Risk Notification which was received on 11 August 2010.

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)

cc Dr Jasper Mbachu
School of Engineering and Advanced Technology
Albany

Prof Don Cleland, HoS
School of Engineering and Advanced Technology
PN456

Massey University Human Ethics Committee
Accredited by the Health Research Council

Te Kunenga ki Pūrehuroa

Research Ethics Office, Massey University, Private Bag 11222, Palmerston North 4442, New Zealand
T +64 6 350 5573 +64 6 350 5575 F +64 6 350 5622
E humanethics@massey.ac.nz animalethics@massey.ac.nz gtc@massey.ac.nz
www.massey.ac.nz

Appendix B: Survey 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

<u>Research Survey</u>

Improving productivity in New Zealand construction industry through off-site manufacture of components: Key areas of application, merits, constraints and prospects

By:
Wajiha Mohsin Shahzad

SECTION I : FACTORS CONSTRAINING UPTAKE OF OSM IN NZ CONSTRUCTION INDUSTRY

1 Off-site manufacture (OSM) is defined as the manufacture of the key building components in places other than construction site for their on-site assembly. Listed below are statements about some of the factors constraining the uptake of OSM technology in New Zealand construction industry with particular emphasis on commercial buildings, as adapted from the Australian study (Cooperative Research Centre for Construction Innovation, 2007). These factors have been broadly categorised into 7 constraint groups ranging from process & programme to logistics & site operations. For each statement under each group, please indicate your level of agreement or disagreement with each suggested factor as a restraint or barrier to the uptake of OSM in New Zealand, using the five point rating scale provided as follows:

***Level of agreement**: 5=Strongly agree; 4 =Agree; 3=Somewhat agree; 2=Disagree; 1=Strongly disagree*

	Constraints to the uptake of off-site manufacture (OSM) in New Zealand construction industry	Level of agreement					No Idea
		5	4	3	2	1	
A	***PROCESS & PROGRAMME***						
i	Traditional design in New Zealand is not suited to OSM						
ii	OSM requires longer planning time which could affect any time saving advantage.						
iii	Using OSM requires high use of IT in construction industry						
iv	Overall advantage of integrated supply chain can only be possible if facility is designed for OSM at the outset.						
v	After commencement OSM does not allow easy or inexpensive design changes						
vi	Knock-on effects of problems in the manufacture process can be significant and could cascade into wider problems downstream; e.g. mismatch of design assumptions with onsite conditions.						
vii	***Other constraints? Please specify:***						
B	***COST/VALUE/PRODUCTIVITY***						
i	OSM is often perceived to be more expensive compared to traditional methods.						
ii	Requires high internal set-up cost for factory production.						
iii	Cranage costs can be higher due to handling of large sized components.						
iv	Higher transportation cost where long distance hauls are required.						
v	***Other constraints? Please specify:***						
C	***REGULATORY***						
i	Handling and cranage of large sized components leads to enormous safety compliance requirements.						
ii	Crane Operators need to be trained and certified under H&SE Act 1992						
iii	There are inadequate codes of practice or standards for OSM products and processes in New Zealand.						
iv	Unclear regulations relating to ownership of components manufactured off-site						
v	OSM manufacture & installation processes attract restrictive, onerous and costly regulations.						
vi	***Other constraints? Please specify:***						
D	***INDUSTRY & MARKET CULTURE***						
i	Labour market is not ready for OSM.						
ii	Clients prefer traditional finishes & custom-made designs.						
iii	Conservative approach: reluctance to change by key stakeholders - contractors, suppliers & professionals - may inhibit industry-wide adoption of OSM.						
iv	Perceived poor and low quality image of prefabricated buildings						

W. Shahzad Page 1 of 4

	Constraints to the uptake of off-site manufacture (OSM) in New Zealand construction industry	Level of agreement					No Idea
		5	4	3	2	1	
D	***INDUSTRY & MARKET CULTURE (CONT'D)***						
v	Negative stigma from past attempts of the application of OSM may limit acceptance.						
vi	Project finance and insurance may be difficult to obtain from institutions not familiar with OSM technology.						
vii	***Other constraints? Please specify:***						
E	***SUPPLY CHAIN & PROCUREMENT***						
i	OSM requires firm control of supply chain which involves high risks especially in relation to international logistics & supply arrangements.						
ii	Industry capacity to supply diverse varieties of OSM products is limited due to lack of infrastructure support and resources.						
iii	Importation of OSM products is prone to logistic, quality and compliance issues.						
iv	Apparent loss of project control during onsite operations.						
v	More complex payment terms & cash flows processes and financial administration where mixed offsite and onsite components are required.						
vi	Stiff opposition from traditional suppliers against new entrants to OSM business may limit supply capacity and large scale adoption.						
vii	***Other constraints? Please specify:***						
F	***SKILL & SHORTAGE***						
i	Limited expertise of designers and manufacturers in the OSM technology.						
ii	Lack of skill and understanding required to ensure that interfaces are managed and designed in the OSM technology.						
iii	Education & training still focussed on current traditional practices, rather than innovative ideas of the future.						
iv	Requires higher onsite skill to deal with low OSM tolerances for interfaces.						
v	May require higher levels of IT literacy which is low in smaller firms.						
vi	Pre-casters' inadequate qualification and familiarity with OSM systems.						
vii	Lack of OSM specific skills like logistic management, coordination of OSM installation & erection skills.						
viii	Generally lack of guidance and information on OSM available in the market & lack of single information source.						
ix	Lack of R&D in OSM.						
x	***Other constraints? Please specify:***						
G	***LOGISTICS & SITE OPERATIONS***						
i	Logistic & stock management difficult with large components, e.g. concrete products.						
ii	Site constraints: limited site access for manoeuvrability & delivery on restricted sites - access of cranage, scale of facility/structure and size of components.						
iii	Transport of large components limited due to constraints of road width, bridge load capacities, transport curfews & requirement of expensive escorts.						
iv	Low tolerance increases problems when fitting components onsite.						
v	High mass OSM products and components results in higher transportation, storage and handling costs.						
vi	***Other constraints? Please specify:***						

2 From your experience, how would you rate the relative levels of restraint offered by the constraint groups to the uptake of off-site manufacture (OSM) in New Zealand construction industry? The rating scale is as follows:
***Level of restraint of constraint groups to uptake of OSM**: 5= Very high; 4 = High; 3 = Moderate; 2 = Low; 1 = Very low.*

	Constraint Groups	Levels of restraint to OSM					No Idea
		5	4	3	2	1	
a	**Process & Programme**						
b	Cost/Value/Productivity						
c	Regulatory						

W. Shahzad Page 2 of 4

	Constraint Groups	Levels of restraint to OSM					No Idea
		5	4	3	2	1	
	(Cont'd):						
d	Industry & Market Culture						
e	Supply Chain & Procurement						
f	Skill & Knowledge						
g	Logistic & Site Operations						

3 For the following building types, please rate their suitability for OSM if the application is to maximise value and productivity in the NZ construction industry. Five point rating scale is provided as follows:
***Level of suitability of OSM application to building types**: 5=Very highly suitable; 4=Highly suitable; 3=Moderately suitable; 2=Not so suitable; 1=Not at all suitable*

	Building types	Level of suitability					No Idea
		5	4	3	2	1	
a	Industrial buildings						
b	Office buildings						
c	Commercial/ retail buildings						
d	Institutional buildings						
e	Residential						
f	Recreational buildings (e.g. hotels)						
g	General infrastructure (e.g. stadiums)						

Other? Please specify:

h ______________________________

4 For the building type(s) above where you think OSM is suitable to use, please rate the following element types in terms of their suitability for offsite manufacture and supply as against onsite production, if the aim is to maximise value and productivity. The five point rating scale is provided as before:
***Level of suitability**: 5=Very highly suitable; 4=Highly suitable; 3=Moderately suitable; 2=Not so suitable; 1=Not at all suitable*

	Elements/ building components	Level of suitability					No Idea
		5	4	3	2	1	
a	Roof construction and components						
b	Wall construction and components						
c	Floor construction and components						
d	Structural frame construction and components						
e	Foundation construction and components						
f	Site work construction and components (e.g. drainage, roading, etc)						

Other? Please specify:

g ______________________________

5 Please could you provide at least one piece of advice on how to improve uptake of off-site manufacture of products and components in the NZ construction industry? (*You can provide your advice below or attach separate sheet, if need be*)

____

____

____

SECTION II : DEMOGRAPHIC BACKGROUND

1 Please indicate your professional affiliation.

- ☐ NZIOB
- ☐ RMBF
- ☐ Property Council of New Zealand
- ☐ ADNZ
- ☐ Other (please specify): ______________
- ☐ NZIA
- ☐ NZIQS
- ☐ BIF
- ☐ IPENZ

2 Please indicate your professional status or official designation in your organization.

- ☐ Engineer
- ☐ Planning/Design/Construction
- ☐ Project Manager
- ☐ Other (please specify): ______________
- ☐ Architect
- ☐ Superintendent
- ☐ Building Official
- ☐ Consultant

3 Please indicate your length of experience with projects utilizing OSM products and components.

- ☐ < 5 yrs
- ☐ 11 - 15 yrs
- ☐ 21 - 25 yrs
- ☐ 5 - 10 yrs
- ☐ 16 - 20 yrs
- ☐ > 25 yrs

W. Shahzad Page 3 of 4

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

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Appendix C: Sample 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; wajiha.mohsin@gmail.com

Dr Wayne Sharman
Strategic Business Development & Contract Manager
Building Research Association of New Zealand
Wellington.

Date: 9th August 2010

Dear Dr Sharman

Research Survey: Improving productivity in New Zealand construction industry through off-site manufacture of components: Key areas of application, merits, constraints and prospects.

Off-site manufacture (OSM) of building components for on-site assembly is a relatively modern method of construction compared to the traditional construction methods. OSM offers prospects for productivity improvement in the construction process by providing solutions to the prevalent problems of delays, defects, and environmental impacts. However, the uptake of OSM in New Zealand construction industry is not encouraging in spite of its well recognized benefits. The low uptake of the technology is indicative of some inherent shortfalls or serious constraints. Identification of the key barriers to OSM uptake in New Zealand and innovative ways of addressing them can contribute to the productivity improvement. This is the key objective of a Masters research in the School of Engineering & Advanced Technology (SEAT), Massey University. The outcome of the study will include development of model for determining the extent of improvement in productivity and value-for-money that could be achieved by the use of OSM in place of conventional systems.

To meet the objectives of the research, a questionnaire has been carefully designed and it will take 10 – 20 minutes to complete. 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.

Kindly return the filled questionnaire using the enclosed stamped & addressed envelope or fax it to the address indicated. If you will be interested in the key findings of the study, please fill the attached Summary Request Form; the form could be faxed separately should you desire anonymity.

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

Yours sincerely,

____

Wajiha Mohsin Shahzad
(Researcher)

Appendix D: Survey Notification in the Property Council of New Zealand Newsletter

HOT PROPERTY Edition 235—2010/22

REGIONAL ROUNDUP

Property Council New Zealand

EVENTS 2010

CANCELLED
10 November
Wrap it Up
Wellington

17-19 November
Conference 2010
Christchurch

22 November
Bay of Plenty Branch
AGM
Tauranga

2 December
End of year celebration
Christchurch

Shared vision for Wellington?

Wellington Mayor Celia Wade-Brown's vision for Wellington is one where the economy, buildings and the environment all work together to create an efficient but compact city, with the ability to easily move goods and services through the city and region, without compromising a sense of place, she told the Wellington Branch executive this week.

"There's not a huge difference in the vision by the Property Council—it's more about the mechanisms to get there and we are constrained on some things by government legislation," she said .

Branch President Ian Cassels said the meeting was a positive start to working with a new Mayor and councillors. "The Wellington Branch was pleased to host Ms Wade-Brown and that she was receptive to an open discussion.

"What we are imploring Ms Wade-Brown to accept, is that Wellington, like no other city in the country, heavily depends on its office space, businesses and workers to contribute to the city's economy and rate base.

"Right now, the office sector is not very healthy, painting a worrying picture of Wellington's ability to grow."

He said the branch executive was pleased to talk to Ms Wade-Brown about the importance of the airport and international flight connectivity, initiatives to promote Wellington to potential businesses and encouraging a connected CBD. The branch intends to hold further discussions about the city council's heritage and earthquake policies.

For news, updates and event information, check www.twitter.com/voiceofproperty and follow us.

Construction industry survey

Please participate in Massey University Master's research student of the School of Engineering and Advanced Technology, Wajiha Shahzad's survey. Her research is entitled, *Improving productivity in New Zealand construction industry through off-site manufacture of components: Key areas of application, merits, constraints and prospects.* Assist Wajiha by completing the survey online: http://www.surveymonkey.com/s/CSTWLYN or by clicking here for a participant letter, survey questionnaire and to request key findings.

Property Council Retail Lease up for review

The Property Council Retail Lease will be reviewed, after discussions at a recent New Zealand Council of Shopping Centres meeting. The Council of Shopping Centres will drive the review, engaging a team of legal experts. The retail lease will then be peer reviewed before being launched. Property Council research analyst Gabriela Slezakova said the lease will be electronically available, accessible to read and amend through Property Council's website.

Corporate Sponsors

225 1785-2010 Rider Levett Bucknall

Brookfield Multiplex

Property Council Membership is due for renewal in April 2011!

Are your clients, colleagues and friends Property Council members? Refer them to our website, www.propertynz.co.nz or email sheree@propertynz.co.nz for more information on the benefits of membership. Discounts are available for those who join from now until April.

HEAD OFFICE	BAY OF PLENTY	WAIKATO	WELLINGTON	AUCKLAND	SOUTH ISLAND
P O Box 1033	P O Box 2475	P O Box 335	P O Box 6719	P O Box 1033	P O Box 4170
Auckland	Tauranga 3140	Hamilton 3240	Wellington	Auckland	Christchurch
(09) 373 3086	(07) 542 2925	(07) 210 1535	(021) 710 961	(09) 373 3086	(021) 053 7927

Appendix E: Survey Notification in the PrefabNZ Newsletter

PrefabNZ.com

The Hub for Prebuilt Construction

_5 November 2010

Welcome to PrefabNZ – the hub for pre-built construction:

- a **catalyst** for prefab collaboration,
- a front-door-**portal** for prefab information and
- an **incubator** for prefab innovation.

Nelson

The PrefabNZ Behind-the-Scenes tour of the **Nelson Marlborough Institute of Technology (NMIT) Arts and Media building is on Friday November 12th** (12-5pm). This is the world's first multi-storey pre-stressed timber building. See http://www.nmit.ac.nz/schools/artsmedia/artsandmediabuilding.aspx. Speakers at this event include:

- Laurie Halkett (Pine Manufacturers Assoc.)
- Pamela Bell (PrefabNZ)
- Andrew Irving / Jeremy Smith (ISJ Architects)
- Carl Deveraux (Aurecon)
- Jason Guiver (Hunter Laminates)
- Michael Cambridge (Organic Building)
- Scott Gibbons (Gibbons Contracting)
- Andrew La Grouw (La Grouw Builders)
- Dave Strachan (Strachan Group Architects)
- Gary Caulfield (Stanley Modular)
- Michael Newcombe (Canterbury University)
- Helen Richards (Powered Living)
- And Martin Goss (Mtech Consult UK)

NMIT building rendering – Irving Smith Jack Architects

Mtech Consult

Martin Goss of Mtech Consult UK is speaking at the Nelson event. He is the founder of Mtech Consult, an organisation that is providing technical guidance and advice for businesses and governments in the UK and overseas in the offsite and prefab sector. An article of interest: http://www.mtech-consult.co.uk/editorial/why-do-we-build-so-wastefully/

Welcome

The PrefabNZ family is growing, including architects, manufacturers, designers, engineers, researchers, consultants and contractors:

- Litecrete Systems (Wilco Precast),
- Craig Maxwell,
- High Performance Houses Ltd,
- Dixon Wild Architects,
- Concept Design,
- Neil Cudby Ltd,
- Modular Housing Solutions,
- Renelle Gronert (Auckland University),
- Cladding Systems (Overclad),
- Constructing Excellence,
- Artelier,
- Pete Bossley Architects,
- Geoff Monckton & Associates,
- Michael Newcombe (Canterbury University),
- MaximPanel 2007 Ltd,
- JS Betz Consulting Ltd,
- Portabuild 2007 Ltd,
- PLB Construction Group Ltd,
- DesignHQ Ltd,
- Kaynemaile Ltd, XLT Ltd
- Advanced Architectural Products
- Winstone Wallboards

All PrefabNZ members will have their own directory listing on the new www.prefabnz.com website, currently in development, scheduled to go live in early December.

info@**prefab**nz.com

Survey

Please take the time to look at this 10 minute survey http://www.surveymonkey.com/s/7LWH8LW – it is part of Wajiha Shahzad's Master of Engineering research programme at the School of Engineering and Advanced Technology (SEAT), Massey University. The research is on 'Improving productivity in the NZ construction industry through offsite manufacture of components' and the study is supported by BRANZ. This research will be important to identify key development barriers and to develop a decision support model for determining the extent of improvement in productivity and value-for-money that could be achieved by using prefab and offsite over traditional methods.

Wajiha Shahzad, Massey University

Projects

Tell us about your prefab projects. You can submit your events, info, news, images and ideas to the newsletter and website. Get in touch info@prefabnz.com for the case study template.

Case: High Performance Houses

Doug Robinson of Wanaka's Salmond Architecture kindly showed off the new High Performance House nearing completion on site at Riverstone Terraces near Albertown. This is very exciting as it incorporates German timber structurally insulated panels (SIPs). The panels make up the walls and roof, and were installed in a matter of hours by hand and hi-ab. The Kingspan Tek-panels are made of CFC-free oriented strand-board (OSB) injected with closed-cell urethane, eliminating the need for adhesives. More info at http://www.tek.kingspan.com/uk/introduction.htm

The super-insulation (RV5) and air-tightness of the wall construction (30min fire-rating) is compensated with a two-way heat transfer system that changes 3 air-cycles each hour. The 236 square metre house (incl. garage) is being built by Scott Pickett of Kiakaha Developments and will be sold once completed.

High Performance House exterior

High Performance House interior

SIPs detail

Collaborate

PrefabNZ is working to bring you collaborative project opportunities. If you have something in mind and need partners, then let us know so we can be the catalyst. This is a great chance to connect, inspire, create and collaborate.

info@prefabnz.com

Appendix F: Survey Notification in the IPENZ Newsletter

Applicants who are already undertaking management training are also eligible to apply.

Please send applications to:
The Scholarship Officer
New Zealand Federation of Graduate Women Wellington Branch
PO Box 2006
Wellington 6140

Applications close 15 February 2011.

▲ back to contents

Master's Researcher Seeks Survey Participants

My name is Wajiha Shahzad, a Master's research student at the School of Engineering and Advanced Technology, Massey University. My research is entitled, "Improving productivity in New Zealand construction industry through off-site manufacture of components: Key areas of application, merits, constraints and prospects". The aim of this study is to identify the key barriers to off-site manufacture (OSM) uptake in the industry and innovative ways of addressing them with a view to improving wider application of technology. The outcome of the study will also include development of a model for determining the extent of improvement in productivity and value for money that could be achieved by the use of OSM in place of conventional systems.

Relevant Members of IPENZ are invited to participate in the research by completing the survey questionnaire, and I would appreciate your help in making the research possible. The questionnaire takes about 10–15 minutes to complete. Participation in this survey will contribute to the development of the building and construction industry of New Zealand. All responses will be treated in strict confidence and will be used solely for this research. I undertake to provide each participant a summary of the key findings of the study if they are interested.

Participants can complete the questionnaire online at www.surveymonkey.com/s/78x5swy

Participation in the survey is voluntary with no obligation to participate. Please complete the survey by 10 November 2010.

Wajiha Shahzad
School of Engineering and Advanced Technology, Massey University, Auckland
Cell: 021 0278 1661
Fax: 09 443 9774
Email: w.m.shahzad@massey.ac.nz

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Appendix G: Sample Interview

Question 1: In what ways do you think Off-site manufacture (OSM) of components for on-site assembly can improve productivity in the New Zealand construction industry?

Answer: There is a general lack of skilled tradesmen onsite, which requires close quality control. Component made on site usually turned up improperly made. At the same time, on-site construction requires increasing workforce.

Discussion:

a. Off-site manufacture can help overcoming the problems associated with lack of skilled tradesmen.
b. Components built in factories are made properly under factory environment.

Question 2: To which areas of construction or building do you believe the technology could be most productively applied in the industry? Any particular reasons for this?

Answer: OSM can be productively applied to all kinds of buildings including commercial, residential and educational buildings; however, it is better suited to commercial and educational buildings due to repetition of elements.

Question 3: What do you perceive as the main barriers to the improved uptake of the technology in the New Zealand construction industry?

Answer: New Zealand has a "Do It Yourself" (DIY) attitude and this approach inhibits manufacturers. In general New Zealand construction industry is very traditional and this is not an adventurous industry.

Discussion:

People should realize benefit of OSM in terms of faster job completion as parallel activities are taking place on-site and off-site. This speeds up the project completion. Precast panels used for cladding is one good example of speeding up the project completion. Similarly when a wall is being constructed on site, factory built windows are brought to site and installed quickly, compared to the traditional approach where each window is made on –site, prolonging the overall project completion time.

Question 4: What would you advise as the innovative ways of addressing the barriers or of improving the uptake of the technology in the industry?

Answer:

- Drivers for innovation,
- A starting voice is needed.

This will not happen overnight, there must be ways of expressing OSM in market. Big companies (like Fletcher Construction Company and Mainzeal) need to celebrate OSM and innovation.

Discussion:

It can be like, if big construction companies will start adopting OSM, smaller companies will also follow the market trend. Or it can be like if smaller construction companies are able to set examples of success with OSM, bigger companies will definitely think of utilizing benefits of OSM.

Question 5: In the next 5 to 10 years, how do you foresee the prospects for greater industry-wide adoption of the technology? What reasons inform your foresight in this respect?

Answer: There is absolute potential of OSM in New Zealand, it is a complete lottery. The basic thing is Designer's understanding of processes. For example complete bathrooms are available in market for their installation; they have everything in them including floors but the Designer needs to know the process of bringing the floor of readymade bathroom to an appropriate level for its proper working. Similarly, ready to install kitchens are becoming very common.

Diminishing skills is another reason, which will promote OSM.

Discussion:

Example of a carpenter who makes a coffee table with nice finishes and smooth corners but if someone else will make the same coffee table that might serve the purpose but will not have nice finishes and corners. Here OSM comes to rescue the diminishing skills.

Question 6: Overall, what general comments can you make about the topic of OSM in the context of the New Zealand construction industry?

Answer: There is not much use of OSM in New Zealand construction industry, New Zealand is not experienced in OSM.

R&D is required in some areas of building; Windows and window flashing, roofing systems and interfaces to overcome the problem of leakage.

Discussion:

Small construction companies can potentially promote OSM, as they have few projects in hand and they are very particular about deliverables. On the other hand big companies have a different approach, if one of their project is behind the schedule and others are on time, they usually don't bother.

The building of Albany Senior High School, is a 5 level building completed by Arrow Builders. Precast cladding panels were used for this building and the building was ready much earlier of the scheduled time.

Even though big companies realize the benefits of OSM but risk associated with anything that is new, keeps them going traditional way.

Appendix H: Cost Estimation for Research Model

COST ESTIMATION

TWO LEVEL OFFICE BUILDING IN AUCKLAND

Gross Floor Area = $240m^2$

Cost Estimate for Modular:	
Details	**Cost in NZ$**
1 Module 60m2	116000
4 Modules	464000
Total value	580000
Stairs & sundries 30%	174000
Total (Modular Cost)	754000
Cost Estimate for Conventional:	
Details	**Cost in NZ$**
GFA m2	240
Rate (Base rate + Fitouts)	2115
Total Value	507600
Exclusions 30%	152280
GST 15%	76140
CGPI adgustment 6%	30456
Total (Conventional Cost)	705564

Appendix I: Abstract of Paper Accepted for Publication in the Proceedings of the PAQS Conference 2011

OFF-SITE MANUFACTURE OF COMPONENTS AS A MEANS OF ENHANCING PRODUCTIVITY IN THE NEW ZEALAND CONSTRUCTION INDUSTRY: KEY UPTAKE CONSTRAINTS AND IMPROVEMENT MEASURES

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ABSTRACT

Off-site manufacture (OSM) is the prefabrication of building components off-site and their subsequent assembly on-site. With the reported poor performance of the New Zealand construction industry, the technology could be leveraged to improve productivity in the construction process. This paper aims to identify the key constraints to the adoption of the OSM technology and explores measures to improve its uptake in the construction industry. Through a nation-wide survey of consultants, contractors, employers and manufacturers, feedback was received and analysed using the multi-attribute analytical technique. Results show that the key constraints to the adoption of OSM in New Zealand could be segregated into six broad categories; in decreasing order of relative influence, these are:1) industry and market culture; 2) skills and knowledge; 3) logistics and site operations; 4) cost, value and productivity; 5) supply chain and procurement; and 6) process and programme.. In each broad category, the relative levels of impact of the underlying constraints to the uptake of the technology were reported. The outcome of the study is expected to provide insights on the cost-effective measures for addressing the constraints with a view to improving the uptake of the technology and hence the leveraging of the numerous benefits for improving productivity in the New Zealand construction industry.

***Key Words**: Modularisation, New Zealand Construction Industry, Off-site Manufacture, Prefabrication, Productivity.*

Appendix J: Abstract of Journal Article Submitted for Publication in the International Journal of Project Organization and Management

Shahzad, W.M. and Mbachu, J.I. (2011) 'Prefabrication as an on-site productivity enhancer: Analysis of impact levels of the underlying constraints and improvement measures in New Zealand construction industry.

Title: Prefabrication as an on-site productivity enhancer: Analysis of impact levels of the underlying constraints and improvement measures in New Zealand construction industry

Author(s): Shahzad, W.M and Mbachu, J.I.

Journal: International Journal of Project Organization and Management

Publisher: Inderscience

Abstract: Prefabrication of building components could be leveraged to improve the reported low productivity trend in the New Zealand (NZ) construction industry. Despite the numerous known benefits of prefabrication, the uptake of the technology in the industry has been discouragingly low. This paper aims to identify the key constraints to the industry-wide uptake of prefabrication and the improvement measures. Through a nation-wide survey of consultants, contractors, employers and manufacturers, feedback was received and analysed using the multi-attribute analytical technique. Results show that the broad categories of constraints to the adoption of prefabrication in NZ are (in order of decreasing impact and relative contributions): industry and market culture (16.2%), skills and knowledge (15.5%), logistics and site operations (14.8%), cost/value/productivity (14%), supply chain and procurement (13.7%), process and programme (13.6%), and regulatory (12.2%). The subcomponents of the broad constraint categories and their relative levels of impact on the uptake of the technology were reported, Mitigation measures for the key constraints were discussed.

Keywords: constraints; construction industry; modularization; New Zealand; off-site manufacture; OSM; prefabrication; productivity; productivity improvement; project management.