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Key factors influencing the productivity performance of construction industry: A literature review

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ABSTRACT

The purpose of this paper is to identify factors influencing productivity and performance in the construction industry. The research will review the literature across 60 references from numerous countries to identify the factors affecting construction productivity generally. Then the researcher will use the mixed method approach involving qualitative and quantitative data in the stage 2 of the research to have in-depth analysis.

The findings in the research will provide insights into the key factors affecting productivity in the construction industry and other aspects of construction productivity such as: productivity definition, measurements to improve productivity performance.

Key words: Construction, contractors, New Zealand, performance, productivity

1 Introduction

1.1 Background of Study

The construction industry is considered to be one of the most important industries in the economy of every country and New Zealand is no exception. Construction is classified as one of the six individual largest sectors in New Zealand, accounting for 7.2% of total GDP according to the New Zealand Government (2014). Construction services is a large and diverse sub-sector, employing some 96,000 workers, 37% of whom are self-employed (New Zealand Government, 2014). Included are many occupations which typically are sub-contracted to both small and large building projects. These include electricians, plumbers, concreters, carpet layers, plasterers, joiners and so on according to Zuo, Wilkinson, and Seadon (2013).

Productivity plays an important role within the economy in general and within the construction industry in particular. There has been a vast amount of research into construction productivity over the last 50 years to productivity looking at a wide variety of issues (Loosemore, 2014). At the company level, improving productivity is fundamental to survival for firms because it means that they can meet their commitments to workers, shareholders, and governments while remaining

competitive (or even improve competitiveness) in the market (John & Van Dai, 2011). At the industry level, productivity improvement is essential for the health of the whole sector, as it is seen as the only valid way to pay for an increased standard of living (John & Van Dai, 2011). In the context of the construction industry, productivity improvement is particularly important because inadequate increases in productivity will mean sharper rises in construction costs, with adverse social implications and declining work for the industry (Ganesan, 1984). In New Zealand, this holds true because productivity growth in the construction sector may have significant effects on the affordability of housing in the country (Davis, 2007).

Much research is about construction productivity worldwide. However, the number of studies in the context of New Zealand is few, such as research by Carson and Abbott (2012), Chris and Malcolm (2012), Drotning, Howells, and Hazeldine (1973), Durdyev and Mbachu (2011), Saeed (2014), John and Van Dai (2011), Shahzad (2011), Shahzad (2016), Shahzad and Mbachu (2012), Will, Malcolm, and Chris (2015).

Many researchers have made observations about the productivity of the construction industry in New Zealand

and those observations have shown that the productivity trend in the context of New Zealand's construction industry is low. The figure in the report "Productivity by the Numbers: The New Zealand Experience" (Conway & Meehan, 2013) shows that productivity in the context of the construction industry in New Zealand remains flat and has sometimes decreased during the last 20 years from the 1990s until now, with the growth rate from -0.4% to just 0.9%. John & Van Dai (2011) also hold the same view, which is that productivity in the construction industry in New Zealand has tended to be flat, while neighbour Australia is experiencing a strong productivity performance during the same period (Hughes & Thorpe, 2014). Furthermore, John & Van Dai (2011) stated in their research that productivity studies into New Zealand construction have either highlighted "failure" to increase productivity or have exhorted the industry to "improve" its "poor performance" (Black, Guy, & McLellan, 2003).

Also, the number of research publications regarding factors affecting construction productivity is numerous. However, research on the factors affecting construction productivity from the perspective of contractors is sparse. Therefore, research related to productivity performance of contractors in the construction industry requires more study in the future.

The fact is that contractors are key role players contributing to the productivity and performance of the construction industry. It is clear that the success or failure of construction projects depends largely on the productivity performance of contractors because they are responsible for important activities in the construction process (de Araújo, Alencar, & Mota, 2016).

1.2 Research Aims and Objectives

The specific objectives of this research are:

- a) To explore the key factors constraining productivity and performance of the construction industry.
- b) To develop a hypothesis causal relationship of the identified factors
- c) To explore measurement of construction productivity improvement

1.3 Research Methods

In this research, the author will review the secondary data of around sixty references including journals, reports,

theses in order to identify the factors affecting the construction productivity. This step is essential for collecting data in next step to provide in deep knowledge about the contractors' productivity performance in the context of New Zealand.

2 Literature Review

2.1 Productivity Definition

There are many ways to define the term "Productivity". The common definition of productivity is by Organisation of Economic Cooperation and Development (OECD) (2001) as a ratio of a volume measure of output to a volume measure of input use. Even though there is not disagreement on this definition, there is neither a unique purpose for, nor a single definition of, productivity.

A common mathematical expression for productivity is the output divided by the input (Liou & Borchering, 1986). The concept by OCED is a relative concept which can be considered in terms of capital, investment, and labour, or other suitable inputs and outputs (Hughes & Thorpe, 2014). This concept has been cited in many articles as the common definition of the term "Productivity".

This concept has been formed as a common equation as below:

$$Productivity = \frac{Output}{Labour + Equipment + Material}$$

Equation 1: A Common Equation of Productivity (Shamil George, 2016)

However, the different analytical standpoints will comprise different meanings of productivity and, generally, the definition of productivity depends on the objectives of measurement, availability of data, and the preferences of the researchers (Chau & Walker, 1988).

2.2 Measuring Construction Productivity

Productivity, especially in the construction industry, has always been very difficult to measure and control according to John and Van Dai (2011). It is because the construction tasks are generally not simple, they are inter-dependent and are hard to quantify.

There are some methods of measuring productivity such as using labour productivity, capital productivity and multi factor productivity (MFP) and partial index measures. Two of the most common partial productivity measures

are labour productivity and capital productivity as single-factor productivity measurements (Black et al., 2003), Chia, Skitmore, Runeson, and Bridge (2012).

In the case of the New Zealand construction industry, examples of partial productivity indexes include those by Davis (2007), Janssen and McLoughlin (2008), who all estimated New Zealand labour productivity figures. In terms of total factor productivity indexes, there have been a number of main works undertaken on the New Zealand construction industry as part of economy-wide productivity estimates such as Black, Guy & McLellan (2003), Chris and Malcolm (2012).

Therefore, the following parts in the literature review will present those measurements.

Labour productivity

Labour productivity is a partial productivity measure and reflects the combined influence of a host of factors (Organisation for Economic Co-operation and Development, 2001). It is typically measured as output per person employed or per hour worked (Chia et al., 2012). Labour productivity is the most common measurement of productivity used in the construction industry (Chau & Walker, 1988). It offers a dynamic measure of economic growth, competitiveness and living standards within the economy, which can help explain the principal economic foundations that are essential for both economic growth and social development (OECD, 2008). That measurement can be illustrated by the following equation:

$$\text{Labour productivity} = \frac{\text{Volume measure of output}}{\text{Measure of input use}}$$

Equation 2: A Common Equation of Labour Productivity

The volume measure of output can be the gross domestic product (GDP) and gross value added (GVA). The measure of input can use the total number of hours worked of all persons employed of total employment (OECD, 2008). Single-factor productivity or labour productivity measures have been adopted as indicators for key government policy objectives, and as can be seen in the formula which is easy to measure and control (Crawford & Vogl, 2006).

Capital productivity

Capital productivity is usually defined as the output of, or return on, capital invested (Chia et al., 2012). The basic

measures of outputs are gross output and value-added output.

Total factor productivity

Total factor productivity (TFP) is a significant factor used to measure the development potential and competitiveness of a certain production unit (Xueqing, Yuan, Bingsheng, Yinghua, & Hui, 2013). Whilst the labour factor has been considered as the single factor input for measuring the productivity, the total factor (multi-factor) productivity measures take into account the impact of all inputs on output (Crawford & Vogl, 2006).

Economists tend to prefer estimating multi-factor production functions because the multi-factor method provides more in-depth analysis on productivity. However, the data and measurement requirements for such an approach are considerably more demanding and cannot be sure that approach will provide exact results (Crawford & Vogl, 2006).

Some agencies use the economic model in terms of dollars, because dollars are the only measure common to both inputs and outputs (EL-Gohary; & Aziz, 2014). The equation below shows the total factor productivity (TFP), which represents this type of model:

$$TFP = \frac{\text{Total Output}}{\text{Labour} + \text{Materials} + \text{Equipment} + \text{Energy} + \text{Capital}}$$

Equation 3: A Common Equation of Labour Productivity

Where;

TFP = the ratio of dollars of output to dollars of input

Those measurement methods above are included in the economic perspectives of construction productivity. However, in terms of the strategic perspectives, Shahzad (2016) has improved the productivity measurement in her study by using the measurement of time saving and cost saving.

2.3 Factors Affecting Construction Productivity

Around the world, there are very many studies about the factors influencing construction productivity, including positive impacts and negative impacts. The researchers are from not only the developed countries such as Australia, New Zealand, Singapore, USA, but also the developing countries such as Thailand, Indonesia, Malaysia, Gaza, Iran (Alghonamy, 2015; Alinaitwe,

Mwakali, & Hansson, 2007; Alwi, 2003; Chris & Malcolm, 2012; Enshassi, Mustafa, Mohamed, & Mayer, 2007; P. Ghoddousi & M. R. Hosseini, 2012; Mahamid, 2016; Makulsawatudom, Emsley, & Sinthawanarong, 2004). It is said that if all factors affecting productivity have been identified, then productivity can be forecasted effectively (Lema, 1995).

Besides the factors influencing construction productivity, many other researchers focus on the factors influencing labour productivity (Dai & Goodrum, 2012; El-Gohary & Aziz, 2014; Enshassi et al., 2007; Abdulaziz M. Jarkas, 2016; A. M. Jarkas, Al Balushi, & Raveendranath, 2015; Abdulaziz M. Jarkas & Bitar, 2014; John & Van Dai, 2011; Kadir, Lee, Jaafar, Sapuan, & Ali, 2005; Serdar & Jasper, 2011a).

Serdar & Jasper (2011b) provided a robust identification of constraints regarding construction productivity by categorizing them into external constraints and internal constraints. Those constraints are included in Figure 1 below:

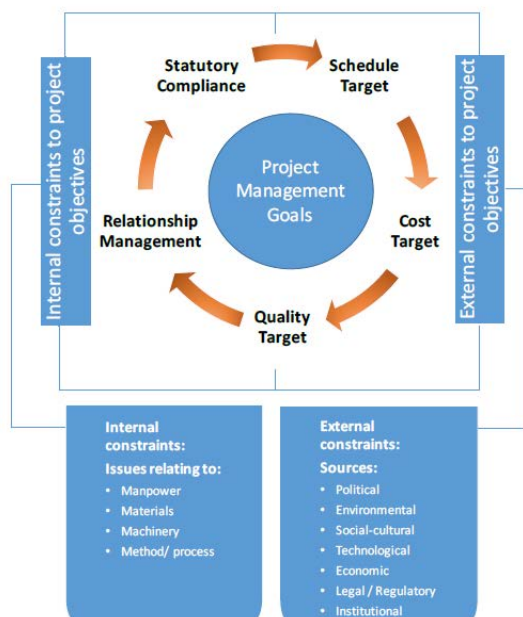
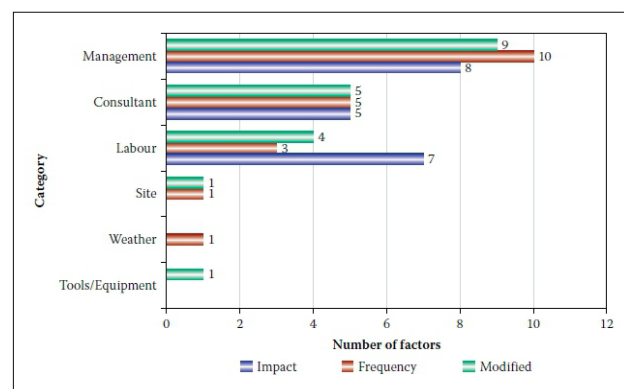


Figure 1: External and internal constraints of construction productivity [Source: Durdyev (2011)]

Hughes and Thorpe (2014) found the enabling factors in construction productivity in Australia through their review. The authors used the Likert scale and structured questionnaire to identify 47 factors affecting construction productivity in Queensland, Australia. Then, the 15 highest ranking factors have been discussed; those are:

Rework, Incompetent supervisor, Incomplete drawings, Work overload, Lack of materials, Poor communications, Poor site conditions and poor site layouts, Overcrowding, Inspection delay/Absenteeism/Work turnover/Accident, Tools and equipment breakdown, and Lack of tools and equipment. Among those factors, the two factors that have the most effect on construction productivity in Queensland are Rework and Incompetent supervisors.

Similarly, Bierman, Marnewick, and Pretorius (2016) also identified factors affecting construction productivity in South Africa. There are 51 identified factors; the authors categorized them into six groups: Management, Consultant, Labour, Site, Weather, and Tools/Equipment.



And each group has at least five specific factors. Then, in their review, the authors ranked the factors by Impact, Frequency and Modified. The results are as below:

Figure 2: Comparison between the three difference Rii values for six groups of factors [Source: Bierman et al. (2016)]

In the study of P. Ghoddousi and M. R. Hosseini (2012), researchers identified 31 factors of declining subcontractors' productivity and ranked them according to their relative importance. Those factors have been classified into seven main groups: Materials/tools, Construction method/technology, Management/planning, Supervision, Rework, Weather, and Jobsite Condition (from highest affected factors to the lowest, respectively).

Figure 2 below shows the seven groups with an

approximation of added time due to the various factors.

Groups	Maximum Time Added	Minimum Time Added
Material/tools	50	43
Construction method/technology	46	41
Management/planning	41	36
Supervision	46.5	39
Rework	33	39
Weather	48	38
Jobsite Condition	32	26

Figure 3: Approximation of added time due to factors
[Source: P. Ghoddousi and M. R. Hosseini (2012)]

Makulsawatudom et al. (2004) conducted a study to identify the critical factors influencing construction productivity in Thailand. They concluded that the top critical factors include: lack of materials, incomplete drawings, incompetent supervisors, lack of tools and equipment, absenteeism, poor communication, instruction time, poor site layout, inspection delay, and rework.

Similar to previous researchers, Olomolaiye et al. (1998) cited in Mahamid (2013) concluded that factors affecting construction productivity are not similar between countries and also between projects and, even for the same project, they may depend on circumstances. The researchers divided the factors affecting construction productivity into two different categories: internal factors and external factors. External factors included the nature of the industry, construction client knowledge of construction procedure, weather, and the level of economic development. Internal factors included management, technology, labour, and labour unions.

Therefore, in conclusion, from regions to regions, countries to countries, the factors affecting construction productivity have been identified and classified in some common ways such as internal factors and external factors, or by groups. Generally, the range of the total number of factors was from around 30 factors to 50 factors. The most common groups of factors affecting construction productivity are:

1. Materials/Tools/Equipment
2. Management
3. Consultants
4. Labour
5. Sites
6. Reworks

7. Construction methods/Technology
8. Weather.

2.3.1 *Materials/Tools/Equipment*

Lack of materials, tools and equipment is the significant factor constraining construction productivity. This group has been studied by many researcher such as P. Ghoddousi and M. R. Hosseini (2012), Makulsawatudom et al. (2004), Hughes and Thorpe (2014), Mahamid (2016), Lim and Alum (1995), Enshassi et al. (2007), Hwang, Zhu, and Ming (2016), and Alinaitwe et al. (2007), Ghoddouse and Mohammad (2012) identified four factors in this group: lack of proper tools and equipment on-site, the shortage of materials, materials have not arrived onsite yet, and tools/equipment breakdown due to aging or poor maintenance. Loosemore (2014) holds the same points of view to classify this group of materials/tools/equipment factors. However, the research is divided into two sub-groups as lack of materials and tools/equipment breakdown/lack of tools and equipment. Therefore, it can be seen that materials/tools/equipment are the significant factors impacting construction productivity. This group consists of many other secondary factors because the construction materials, tools and equipment are very important to the construction work. Lack of materials, tools and equipment could lead to time and cost delays, resulting in time and cost overruns. Consequently, Mahamid (2013) found that lack of materials and equipment is one of the most important factors, accounting for more than 70 percent of the importance index in the research.

The list of sub-factors in the category of materials/tools/equipment is:

- Lack of proper tools and equipment on-site
- Shortage of materials
- Materials have not arrived on-site yet
- Tools and equipment breakdown

2.3.2 *Management*

The group factor, Management, is considered as the most significant factor by many researchers such as P. Ghoddousi and M. R. Hosseini (2012), Alghonamy (2015), Enshassi et al. (2007), Bierman et al. (2016), Abdulaziz M. Jarkas and Bitar (2014), Zuo et al. (2013), and Karimian, Mbachu, and Egbelakin (2016). The factors in the management group have been mentioned in the study of

Ghoddouse and Mohammad (2012) in Iran including lack of management skills such as no construction planning. Also, the management skills for safety planning are considered as a factor in the management group. Similarly, Alghonamy (2015) stated a number of sub-factors such as poor planning and scheduling, poor site management, poor resource management, poor communications and slow decision-making. Especially, the factor of management has been studied by Bierman et al. (2016) in South Africa showing that there are about 23 sub-factors of management affecting productivity performance in the construction industry. Those same factors have been mentioned in Hwang et al. (2016) in Singapore. However, the author contributes some additional sub-factors related to the management groups: supervision, and competency of the project manager. In the research, Hwang et al. (2016) classified the factors affecting the construction productivity into groups and ranked those groups. The management factors account for an average of around 4 (the mean by ranking), which shows that the significance of management groups is equivalent to projects factors, manpower factors and technical factors. The fact is that if a project is affected by poor management skills as mentioned, it definitely faces many set-backs or failures. The list of sub-factors in this research will be indicated as below:

- Lack of construction planning
- Lack of management of safety planning
- Poor planning and scheduling
- Poor site management
- Poor resource management
- Poor communications
- Slow decision-making.

2.3.3 Consultants

The reasons related to Consultants have been analysed and there are some sub-factors under the category of group of consultants impacting on construction productivity. The studies from various countries such as: Bierman et al. (2016), Makulsawatudom et al. (2004), Mahamid (2016), Hughes and Thorpe (2014), and Alinaitwe et al. (2007). Bierman et al. (2016) have been analysed and list a number of sub-factors in this group in order to illustrate that the factor caused by consultants also has been considered as a significant factor affecting construction productivity in South Africa. The list of sub-factors is consistent with the previous studies. It includes:

- Late issue of drawings to contractors
- Delayed reply to Request for Proposal
- Late issue of specification/information to contractors
- Delayed inspection by consultant
- Complexity of design
- Incompetent drawings or design changes.

The above sub-factors can lead to time delays and cost overruns. Therefore, construction productivity is certain to be affected absolutely.

2.3.4 Labour

This group of factors has been mentioned in most studies related to construction productivity because labour plays such an important role in the construction context. Without labour factors construction projects cannot be conducted and completed. Therefore, the sub-factors included in the group of factors related to labour have been listed in many countries around the world by many researchers. These include Mahamid (2016), Jaffe, Le, and Chappell (2016), Hwang et al. (2016), Alghonamy (2015), Jarkas and Bitar (2014), Loosemore (2014), Hughes and Thorpe (2014), Zuo et al. (2013), El-Gohary and Aziz (2014), (Zuo et al., 2013), Alinaitwe et al. (2007), and Makulsawatudom et al. (2004).

According to Hwang et al. (2016), manpower refer to factors affecting labour in all construction projects. It is indicated that workers with a perception of higher productivity could deliver a better production output; workers with experience and great skills affect a project's productivity.

The list of sub-factors related in the grouping of labour and included in the research of Hwang et al. (2016) is consistent with previous studies such as those of Bierman et al. (2016), Abdulaziz M. Jarkas and Bitar (2014), and Makulsawatudom et al. (2004). It comprises:

- Motivation of workers
- Worker skill level
- Absenteeism
- Labour turnover
- Workers' experience
- Difficulty in recruitment of workers
- Level of education of the worker

2.3.5 Sites

The factors pertaining to project site have been indicated as having high impact on construction productivity. As with the other categories, this category has been analysed in many studies such as those by Bierman et al. (2016), Hwang et al. (2016), Alghonamy (2015), Hughes and Thorpe (2014), Makulsawatudom et al. (2004), Alinaitwe et al. (2007).

The list of factors has been analysed as indicated below:

- Poor site layout
- Poor site condition
- Site condition after inclement weather.
- Site congestion
- Geographical location of site.

2.3.6 Reworks/Poor Work done

According to Hughes and Thorpe (2014), reworks on construction projects can be considered as unnecessary effort of redoing a process or activity. In the construction context, the causes leading to the problem of reworks are errors, omissions, failures, changes, poor communication, and poor coordination. The authors estimated that the effect of reworks on the performance and productivity of construction projects could be the addition of around 10 percent to total project cost. According to the literature summarized by Whiteside (2006), the factor of reworks is mostly unnecessary and is avoidable.

On the other hand, the previous studies by Patrick (2000) and Love and Heng (2000) concluded that the costs caused by reworks can be quite high compared with the cost of the project. It can surge up to 25 percent of the actual construction cost. This statement is consistent with other authors such as Makulsawatudom et al. (2004), and Alinaitwe et al. (2007).

2.3.7 Weather

Ghoddouse and Mohammad (2012) conducted their research considering adverse weather and thermal conditions as one particular factor. This factor is ranked as the sixth most important ground among the seven groups and the ninth declining factor amongst the factors negatively affecting productivity. Generally, construction projects take place in an open environment, thus environmental conditions may impact upon the condition of the jobsite as well as upon the workers.

Jarkas and Bitar (2014) also hold the same opinion on the external factor affecting construction productivity. The authors pointed out that productivity losses due to snow and cold temperatures were 41% and 32% respectively. In Singapore, a heavy downpour during the monsoon season and interference from wet weather can affect construction productivity (Lim & Alum, 1995). Although it was not the top factor affecting construction productivity, it is known that in some countries with bad weather conditions, that factor can cause much damage and has significant negative impacts.

2.3.8 Construction Methods/Technology

Many researchers have analysed factors related to construction methods and technology to know their impact on construction productivity. Karimian et al. (2016), Jarkas and Bitar (2014), and Hwang et al. (2016), indicated that the construction methods or technology also have particular effects on productivity. It is clear that incomplete or unclear technical specifications will require continuous requests for clarification, inevitably leading to interruptions or disruptions in construction progress Jarkas and Bitar (2014). According to Goodrum and Haas (2002), changes in technology contribute to an increase in productivity. And Karimian et al. (2016) stated that technology can significantly influence productivity and performance in road maintenance projects.

The list of factors within this category has been indicated in the research of Jarkas and Bitar (2014), Arashpour and Arashpour (2015) and Ghoddouse and Mohammad (2012) as below:

- Utilizing traditional construction methods instead of modern technology
- Operatives do not possess the skills and experience necessary to perform the tasks
- The company is executing these types of projects for the first time
- Standardisation and specifications
- Changes in technology (Dai & Goodrum, 2012)
- Poor construction methods (Alinaitwe et al., 2007)

2.4 Summary of Literature Review

In this literature review, eight broad categories of factors influencing productivity of construction industry has been identified and reviewed. A total of 37 sub-factors within

these broad categories have been identified from various countries all over the world. The review of existing literature shows that 'materials/tools/equipment' and 'labour' are the two most significant categories, as they have been mentioned and identified in all previous studies as resulting as critical factors for construction projects.

Conclusion

This research explored the key factors affecting the productivity performance of the construction industry, then 37 sub-factors within 8 groups have been identified from country to country, project to project. Furthermore, this research also reviewed the measures to improve the construction productivity from previous researches, they are labor productivity, capital productivity and total factor productivity. Each project, each country has the own method to measure the construction productivity in the world.

The limitation of this research is only state the factors affecting productivity performance and productivity measurement as a review article. Therefore, the recommendation for further study is factors specifically affecting the contractors' productivity and the causal relationship between those factors will be completed in the next stage of the research by pilot interviews and questionnaire survey sending to various participants in New Zealand.

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Unveiling the “Bottle Brick Technology”

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ABSTRACT

This research focuses on the reuse of Post-Consumer PET Bottles or Eco-bricks in building construction. These are formed by packaging filler agents like sand, quarry dust, plastic trash, etc. within Polyethylene Terephthalate (PET) Bottles. Live experiments were done for the purpose of this particular research in the Civil Materials Testing Lab to evaluate the compressive strength and water absorption of 5 different Eco-Brick specimens with different types of mortars and in-fillers. The results of the experimentation helped in understanding the structural, aesthetic and functional aspects of PET Bottle Construction. The future prospects of this alternative technology have also been presented.

1 Introduction

1.1 Statement of Research

The use of plastic has become inevitable in our daily lives due to their excellent properties i.e. performance, shatter-resistance, value, durability, ease of usage etc. Besides their useful applications, they have also become a threat to the society due their non-biodegradability - especially the post-consumer PET (Poly Ethylene Terephthalate) Bottles i.e. drinking water and beverage bottles.

For this study, practical Civil Laboratory experiments were done to find out if post-consumer PET plastics could become a substitute for clay bricks and if architecture could still provide effective functionality and aesthetics through them.

1.2 Aims of the Study

- To understand the physical and chemical properties of PET bottles and judge whether they are viable as a building construction material.
- To analyze the quality of space and thermal environment that a PET plastic bottle environment will provide to the user.

1.3 Objectives of the Study

- Providing COST EFFECTIVE HOMES to the homeless people/Low Income groups in the country through Bottle Brick Technology.
- To suggest effective means OF REDUCING GROWING LANDFILLS.

1.4 Scope of the Study

- This research is not limited to any specific building typology.
- This study deals with the documentation and analysis of existing techniques used for construction using PET bottles.

1.5 Limitations of the Study

- This dissertation is strictly limited only to PET Plastic bottles and not to any other form of plastic.
- The project circles mainly around reuse (and not recycling) of PET Bottle waste.

1.6 Methodology of the Study

Phase 1: Structure:

- A brief overview of Plastics and their classification
- PET Bottles and their classification
- Physical and chemical Properties of PET Bottles

Tools used: Data Collection sources – Internet articles, International Journals, Brochures, Interaction with Industry Experts etc.

Phase 2: Structure:

- Live Case Study – Bamboo House India, Hyderabad
- Guidelines for PET Bottle Construction

Tools used: Literature and Live Case Studies

Phase 3: Structure:

- Structural Details and compressive strength tests of PET bottles through Laboratory Tests

- Laboratory tests to ascertain Water absorption levels with different filler agents and different mortar types

Tools used: Live experimentation – Tests in Structural Lab / Materials Lab, IS Code books, Interaction with Professors of Civil Engineering Department etc.

Phase 4: Structure:

- Thermal Comfort Analysis of PET Bottle brick buildings
- Analysis and conclusions through SWOT Analysis

Tools used: Ecotect Simulation Software, SWOT Analysis Chart etc.

2 Post-Consumer PET Bottle Construction

2.1 Classification of Plastics

The general classification of Plastics is shown below. The PET Bottles come under the category of Polyethylene.

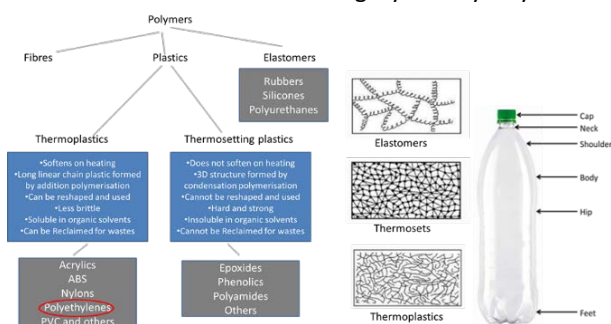


Figure 1: Classification of Plastics and sic Parts of a PET Bottle.

2.2 Composition of PET

Modified ethylene Glycol + Purified Terephthalic Acid = Polyethylene Terephthalate (PET)

- The properties of post-consumer PET bottles that favor the sellers are: Strength, Thermal stability, Transparency
- The properties that attract the buyers are: Inexpensive, Lightweight, Resalable, Shatter-resistant, Recyclable

2.3 PET Bottles – Common Sizes

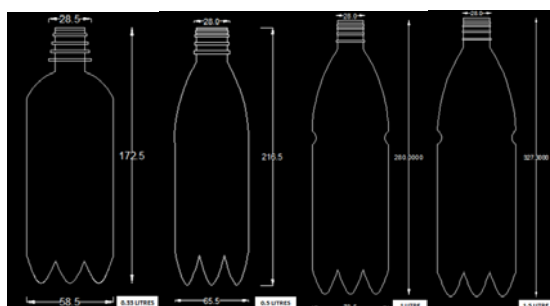


Figure 2: Specifications of different sizes of bottles.

3 Bottle Brick/Eco-brick Construction

3.1 History of Bottle brick Technology

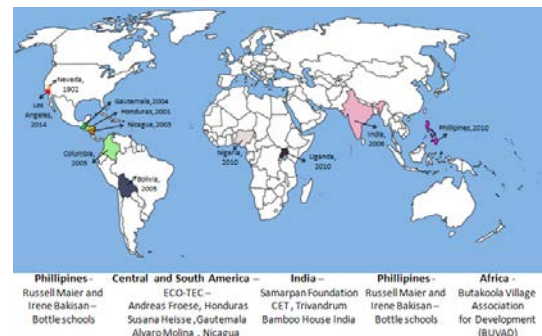


Figure 3: Idea of PET Bottle construction getting around the world. (Keiren 2016)

3.2 Live Study – Bamboo House India, Hyderabad, India

Bamboo House India was constructed by Prasanth Lingam and Aruna Lingam at Hyderabad, India in 2008.



Figure 4: Construction of PET Bottle Workshop, Bamboo House India, Hyderabad. (Prashant Lingam 2008)

Bottles filled with mud were placed in vertical and horizontal alignment for thermal insulation and strength. The couple is making plans to promote this bottle technology for mass rural housing and hopes to convince the ministry of rural development to make the government gives assistance of INR.70,000 for building a house under this program. (Prashant Lingam 2008) But a bottle house of 200-400 sq.ft. can be constructed at less than INR.50,000 in rural areas.

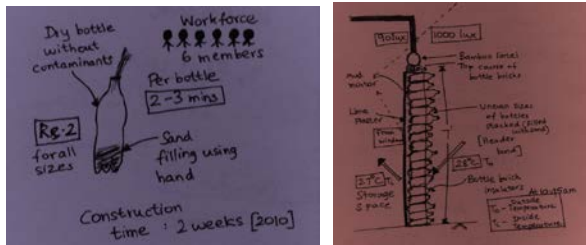
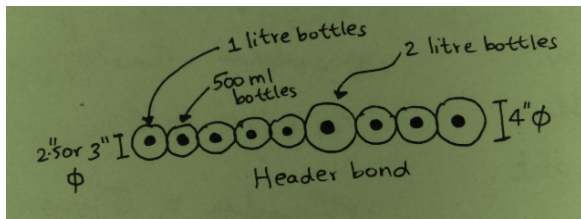


Figure 5: Details of courses of PET Bottle bricks.

- A Cement Brick costs INR.10, a red brick costs INR.7 whereas a PET Bottle brick costs INR.3 only. Only 6-8 bags of cement were used and the building has a lifespan of minimum 300 years. It is a 225 sq.ft. building built using 4000 mud brick PET and the total estimate was INR.75,000. If bricks had been used for the same size of room, the estimate would be twice than that of the former. Major features of the building include :
 - Bamboo beams and columns in order to avoid steel reinforcement
 - Plastered with mud and cow dung, and then with cement
 - Plans to promote the idea under the Indira Awaas Yojana
 - Single storey structure - walls painted with Traditional Indian Kolam Designs
 - There are no problems during rainy season



Figure 6: View of the Exposed PET Bottle Brick Wall.

3.3 The Building System

Pet Bottle construction - Foundation

Maximum depth of excavation of PET Bottle foundation (Single storey structure) = 0.6 m

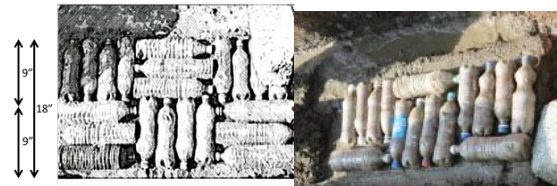


Figure 7: PET Bottle Brick Foundation.(Ramaraj 2014)

Pet Bottle construction – Masonry

Type 1 Horizontal Placement

- ½ litre bottles for 9" wall (Ramaraj 2014)
- 1 litre bottles for 12" wall (Excluding plaster thickness)

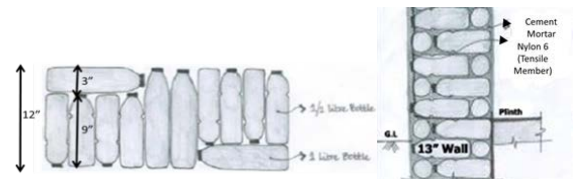


Figure 8: PET Bottle brick Masonry – Horizontal Stacking.

Type 2 Vertical Stacking

- ½ litre bottles for 4.5" wall (Excluding plaster thickness)

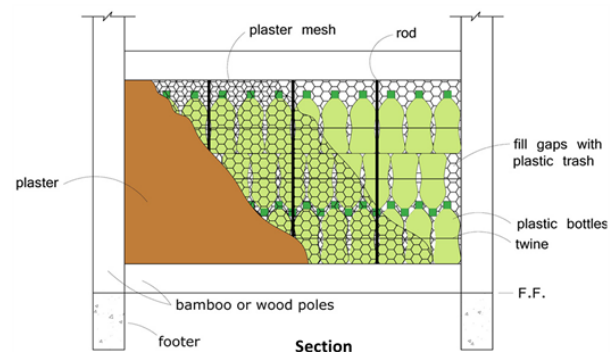


Figure 9: PET Bottle brick Masonry Type 3 - Vertical Stacking.

Pet Bottle construction – Columns

Each column generates a hollow centre 4"-8" (10-20 cm in diameter) to hold the reinforced concrete.

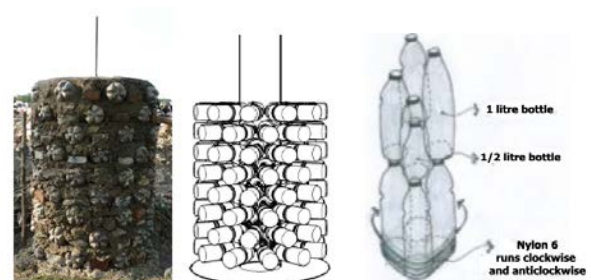


Figure 10: PET Bottle Columns by radial arrangement.

Pet Bottle construction – Mortar Ratios

If the site has only clay soil, clay mortar can be used in the walls and columns, without the addition of cement. If the site has sandy soil, the ratios of soil to cement are: 1:6, 1:10, 1:15, and 1:20. The Lime mortar ratio is 0.5: 8: 1 (cement: soil: lime). In case of wet climate, at every 4th row, the workers apply a stronger mortar Mixture of soil-cement to protect the wall from rain and weathering agents.

Pet Bottle construction – Mortar Consumption

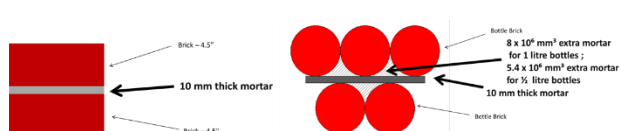


Figure 11: Volume of Mortar Consumed for Brick and Bottle Brick construction respectively.

The following values and mathematical expressions were derived based on extensive study:

- Volume of mortar needed for brick construction = 253000 mm³
- Volume of mortar needed for bottle brick construction =
For 1 litre bottles = 253000 mm³ + (8 x 10⁶ mm³) (x-2)
For 1/2 litre bottles = 253000 mm³ + (5.4 x 10⁶ mm³) (x-2)
 Where, x = Number of bottles in a single course
- Cost increases by 4.2 times in bottle brick construction. Hence, the triangular gaps between the bottles have to be filled by building wastes, stones etc.

PET Bottle construction – Service Lines



Figure 12: Service Lines amidst PET Bottle. (Keiren 2016)

Service lines (electric and plumbing) must be planned before construction starts, so that gaps can be left at proper places in the masonry to insert the service lines. Sometimes, they are held by the ropes that hold the bottle caps in place.

3.4 Common Filler Agents in Bottle Bricks

Table 1: Various In-fillers for PET Bottle Bricks and their pros and cons. (Shilpi Saxena 2013)

Filler / Property	River Sand	Quarry Dust	Inorganic Trash
Economy	Expensive	Cost = Less than ½ of cost of river sand	Free of cost (Used covers, Wrappers etc.)

Ease of filling	Dry sand can be filled quickly than wet sand	Quite simple as sand	Laborious
Time required for filling	Quick filling	Quick filling	Needs more time for filling compared to the other fillers
Procurement	From river beds – Transport charges	Has to be obtained from quarries – Transport Charges	Available locally – No transport charges
Workers needed (With respect to time of completion of project)	Less	Less	Comparatively More
Weight of the bottle	Very Heavy	Heavy	Light weight

4 Structural Aspects of PET Bottle Construction

4.1 Live Experimentation of Bottle Brick Technology

Operative Experimentation included evaluation of Compressive Strength and Water Absorption of PET Bottle brick blocks with Different Filler Agents and Different types of Mortar for the purpose of this research.

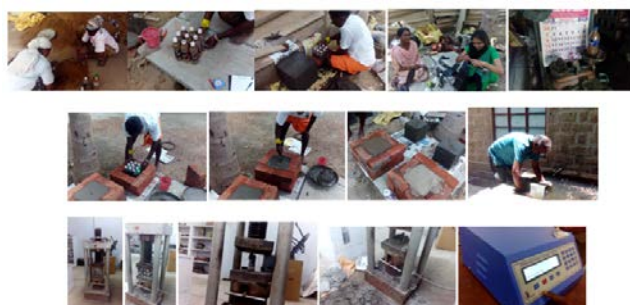


Figure 13: Live Experimentation - Making five specimens – 3 types of mortar and 3 types of in fillers.

The table below shows the schedule of rates of building materials used very frequently in the Indian Market.

Table 2: Schedule of Rates as on July 3rd, 2015. (LiveChennai 2015)

Items	Frequency	Cost (INR.)
Brick	1 Load	17,000
Fly Ash bricks	1 Load	19,500
River sand	1 Cubic feet	50-55
Cement	50 kg	400
Supervisor	Daily Pay	550
Man worker	Daily Pay	400
Woman Worker	Daily Pay	300
Carpenter	Daily Pay	550
Plumber	Daily Pay	500
Commercial Hard plywood	18 mm	58
Steel	1 kg	40,000 (avg.)
Paint	1 litre – White color	225.5

Note:

1 Load = 3000 stones, 1 unit = 100 cubic feet

1INR = 0.021 NZD

1NZD = INR 47 (Approx.)

- One Brick of size 23 cm x 11 cm x 7.5 cm = INR. 5.60
- One fly ash brick of size 24 cm x 11.5 cm x 90 cm = INR. 6.50
- One plate of mortar (38 cm diameter) = 11000 cm³
- Rate of bricks increases by INR.2 during monsoon season and decreases by INR.2 in summer.

The table below quantifies the various resources involved in the experimentation.

Table 3: Results from the experimentation performed for this research.

Filler or Mortar/ Property	3 Different Filler Materials + Cement Mortar			3 different Mortars + Bottles filled with river sand		
	River Sand	Quarry Dust	Inorganic Trash	Cement Mortar	Lime Mortar	Mud Mortar
Procurement	River sand from Trichy	Quarry dust from Trichy	Trash bags from home – 43 x 48 cm	Cement from Madurai	Lime from Madurai	Mud From the site
Ease of filling	Dry sand can be filled quicker than wet sand	Quite simple as sand	Tedious	Dry sand can be filled quicker than wet sand	Dry sand can be filled quicker than wet sand	Dry sand can be filled quicker than wet sand
Time required for filling 1 bottle	45 secs. (avg.)	1 min 45 secs. (avg.)	3 mins 45 secs. (avg.) – 20 bags	45 secs. (avg.)	45 secs. (avg.)	45 secs. (avg.)
Time required for preparation of mortar	5 mins	5 mins	5 mins	5 mins	6 mins	8 mins
Time required for plastering	4 mins	4 mins	4 mins	4 mins	6 mins	10 mins
Workers needed	3	3	3	3	3	3
Weight of a single bottle	0.675 kgs.	0.896 kgs.	0.120 kgs.	0.675 kgs.	0.675 kgs.	0.675 kgs.
Rate of one bottle brick	INR.2.13	INR. 1.45	INR1	INR.2.13	INR.2.13	INR.2.13
Mortar ratio (Cement : Sand)	1 : 6	1 : 6	1 : 6	1 : 6	0.5 : 1.5 (Lime : Sand)	0.5 : 0.5 : 1.5 (Cement : Lime : Mud)
No. of bags of cement / lime / mud used respectively for filling 9 bottles	0.25	0.25	0.25	0.25	0.5	0.5
Total cost for making the 3 x 3 bottles block	INR.119.17	INR.113.05	INR.109.00	INR.119.17	INR.73.05	INR.69.17

4.2 Water Absorption Test

Aim

To determine the water absorption capacity of the Bottle brick as per IS: 3495 (Part II) – 1992

Procedure

The dry weight of the specimen blocks were taken as W₁. The specimen blocks were placed in an immersion tank for 24 hours. Then, the weight of the blocks were measured again to find the wet weight after wiping out the traces of water with a cloth W₂. The water absorption capacity of the blocks were determined using the formula:

$$100 (W_2 - W_1)$$

Water absorption rate =

$$W_1$$

IS: 3495 (Part II) -1992: More the water absorption capacity, weaker the brick and vice-versa.

The water absorption rates of normal clay bricks are:

1st class brick: Not more than 20 % by weight

2nd class brick: Not more than 22% by weight

3rd Class brick: Not more than 25% by weight

Table 4: Water Absorption Test Results.

Filler or Mortar/ Property	3 Different Filler Materials + Cement Mortar			3 different Mortars + Bottles filled with river sand		
	River Sand	Quarry Dust	Inorganic Trash	Cement Mortar	Lime Mortar	Mud Mortar
W ₁	34.5 kgs.	30 kgs.	23.5 kgs.	34.5 kgs.	29 kgs.	29.5 kgs.
W ₂	36 kgs.	31.4 kgs.	24.8 kgs.	36 kgs.	x	30.5 kgs.
Water absorpti on rate	4.347 %	4.66 %	5.53 %	4.347 %	Failed	3.38 %
Results	Less than 20 %	Less than 20 %	Less than 20 %	Less than 20 %	x	Less than 20 %

4.3 Compressive Strength Test

Aim

Also called the crushing strength test, this was done to know the compressive strength of the bottle bricks.

Procedure

The cast specimens were are taken to laboratory for testing and examined one by one. Each specimen was put on a crushing machine and heavy pressure was applied till it broke. The ultimate pressure at which it crushed was taken as the axial load in KN. Then the surface area bearing the stress was calculated in mm². (**STANDARDS 2005**). All these were done under the guidance of Civil Engineering and Architecture Professors.

The compressive strength of bottle bricks were calculated using the formula:

**Maximum load at failure in N =
Compressive strength in N/mm²**

Surface area of the bed face in mm²

Clay Brick's minimum compressive strength according to **BIS: 1077-1957 =**

$88.55 \times 10^3 \text{ KN}$

$\text{-----} = 3.50 \text{ N/mm}^2$

$230 \times 110 \text{ mm}^2$

Nowadays, bricks are prepared to bear greater stresses – 200 KN or more → i.e., more than 7.9 N/mm^2 compressive strength and are graded as A.

Table 5: Compressive strength test results of the Bottle bricks.

Filler or Mortar/ Property	3 Different Filler Materials + Cement Mortar			3 different Mortars + Bottles filled with river sand		
	River Sand	Quarry Dust	Inorganic Trash	Cement Mortar	Lime Mortar	Mud Mortar
Applied pressure	41.9 x 10^3 N	44.4 x 10^3 N	51.6 x 10^3 N	41.9 x 10^3 N	Failed	24.9 x 10^3 N
Surface area	250 x 250 = 62500 mm^2	250 x 250 = 62500 mm^2	250 x 250 = 62500 mm^2	250 x 250 = 62500 mm^2	250 x 250 = 62500 mm^2	250 x 250 = 62500 mm^2
Compressive strength	0.6704 N/mm^2	0.7104 N/mm^2	0.8256 N/mm^2	0.6704 N/mm^2	Failed	0.3984 N/mm^2
	Heaviest block – Fair compressive strength	Intermediate weight – Decent strength	Lightest weight – Maximum strength	Exhibits fair compressive strength	Failed in water absorption	Very less compared to cement mortar

4.4 Comparing the Lab Test results (of this research) with the works of other researchers

Following is a comparison between comparative strengths of Plastic bottle bricks obtained from the tests conducted for this particular study with those of another researcher from Curtin University, Australia who has already performed similar experiments, but focusing only on those bottle bricks with plastic trash as in filler.

Table 6: Compressive strength of Eco-bricks with Plastic trash in filler of different weights. (Source: Parakshi, 2014)

Specimen	Compressive Force (kN)	Area (m^2)	Strength (MPa)
1	35.1	0.0136	2.59

2	34.6	0.0136	2.55
3	39.3	0.0136	2.90
4	40.1	0.0136	2.96
5	35.3	0.0136	2.60
6	38.9	0.0136	2.87
7	34.5	0.0136	2.55
8	36.1	0.0136	2.66
9	36.3	0.0136	2.68
10	38.0	0.0136	2.80

Vikram Pakrashi, in his Paper “Experimental characterisation of polyethylene Terephthalate (PET) bottle eco-bricks ARTICLE in MATERIALS AND DESIGN (2014) says, the weight of Eco-brick was observed to hold a nearly good relationship with load at failure and with specific strength equivalent to basic concrete cubes. (Pakrashi 2014)

From the compressive Strength test results below, we see that, the 500 ml eco-bricks filled with inorganic trash are SUITABLE FOR SINGLE STOREY NON LOAD BEARING WALLS AND SMALL STRUCTURES WHEN COMPRESSIVE STRENGTH $> 1.5 \text{ N/mm}^2$. (Raut 2015)

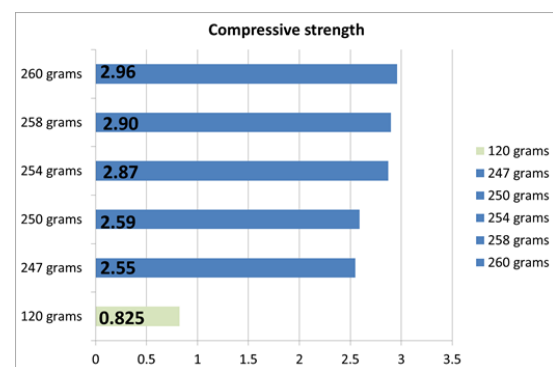


Figure 14: Comparing Lab Test results with works of other researchers. (■ = Pakrashi results, ■ = this research's Results)

Inference: “Strength is doubled as bottle weight is doubled”

Compressive Strength α Weight of the bottle

Testing of One litre Bottle Bricks

This experiment was done under the guidance of Krishna G Lodha, a final year Civil Engineering student in Nasik, Mumbai.

Inference: “Strength is doubled as bottle size is doubled”

Compressive Strength α Size of the bottle





Figure 15: Compressive Strength of 1 litre Bottle Bricks (Lodha 2014)

(From top left to bottom right, in order:

1. One litre PET Bottles + Bond Ash (low density)
2. Filling time – 2 hours to fill two bottles
3. Wires for binding
4. A 15 litre oil can for mould purpose, 1:6 cement mortar mix
5. Universal testing Machine - Compressive strength was found out to be 5.95 N/mm² - twice the strength of a normal brick!!
6. Bottle Bricks after crushing)

Building Bottle homes worldwide with Horizontal header bond stacking strategy

Urban Housing Shortage in 2015 = 1.6 billion units

Minimum floor size of a single storey housing unit (height = 10') = 225 sq.ft. (15' x 15')

1 sq.ft. = 16 bottles (½ litre bottles)

Global Statistics of PET Bottle Waste Generation

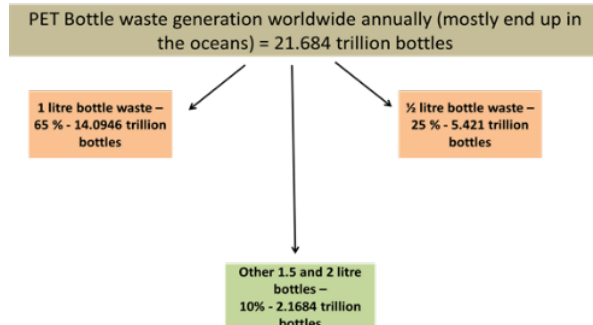


Figure 16: Annual PET Bottle waste Statistics globally. (Hotz 2015)

Surface area of 4 walls of the unit = 150' x 4 units = 600 sq.ft.

Surface area of minimum 2 windows (each of size 3' x 4') and a door (3' x 4') = 45 sq.ft.

Therefore, total surface area of masonry excluding openings = 555 sq.ft.

Total no. of bottles needed for the 4 walls of 1 housing unit = 555 x 16 = 8880 bottles

So, 1.6 billion units need = 1,600,000,000 x 8880 = 1,420,800,000,000 = 14.3 trillions

Available number of ½ litre Pet Bottle waste in the oceans = 5.421 trillions

Therefore, ½ litre post-consumer PET bottles in the oceans can solve housing issues 37.9 % of the existing issues (606.4 million housing units). Similarly, 1 litre post-consumer PET bottles in the oceans can solve housing issues 176% more than the existing issues (2.816 billion housing units).

Building Bottle homes in India

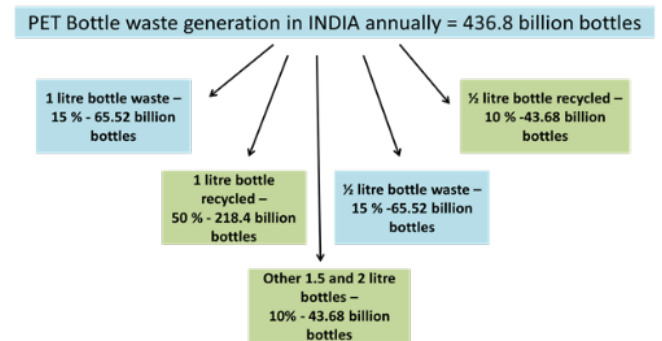


Figure 17: Annual PET Bottle waste Statistics in India. (Mumbai 2015)

Urban Housing Shortage in India = 60 million units

By calculating in a similar method used above, ½ litre post-consumer PET bottles can solve 12.29 % of India's housing Shortage (roughly 19.674 million housing units) and 1 litre post-consumer PET bottles can solve 21.86 % of India's housing Shortage (roughly 19.674 million housing units).

5 Analysis of Thermal Comfort by a Bottle Brick building

5.1 Simulation of a 5 m x 5 m Single storey building in Ecotect Software

Location: Tiruchirapalli, India (Tropical Semi-Arid Climate)

From the Psychrometric Chart data of Tiruchirapalli, we understand that the comfort zone temperatures are in the range 26°C- 32°C.

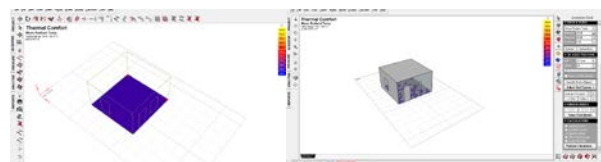


Figure 18: Thermal Comfort Analysis Grid.

For the purpose of this particular research, a 5 m x 5 m house was created in Ecotect Software. The weather data for Tiruchirapalli was loaded. The climate zone is tropical semi-arid.

Simulation was done for two massing types.

- 300 mm Brick cavity Walls
- 230 mm walls of Bottle Bricks filled with Plastic trash

(Mojtaba Valinejad Shoubi 2013)

Simulation of a 5 m x 5 m Building in Ecotect Software – Brick cavity Wall - Location: Tiruchirapalli, India

Generation of Average Inside and Outside Temperature with Brick Cavity wall massing

Peak noon time – Temperature difference between inside and outside temperatures = - 4.2°C

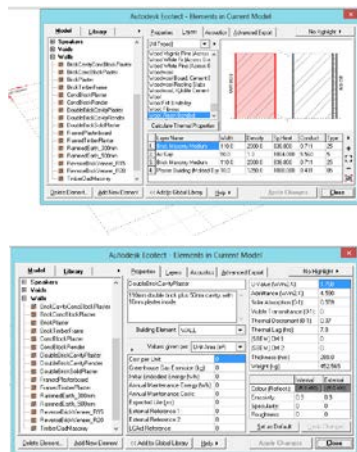


Figure 19: Input of the Layers of the Wall Section – Brick Cavity Wall.



Figure 20: Graph + Results showing Inside and Outside Temperature Report (Brick Cavity wall Building).

Simulation of a 5 m x 5 m Building in Ecotect Software – Bottle Brick

With plastic trash in filler- Location: Tiruchirapalli, India

Generation of Average Inside and Outside Temperature with Bottle brick with Plastic trash wall massing

Peak noon time – Temperature difference between inside and outside temperatures = -1.6°C

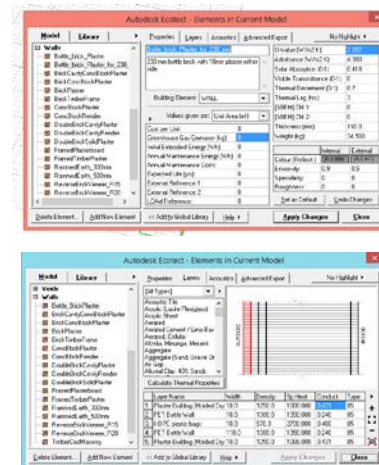


Figure 21: Input of the Layers of the Wall Section – Plastic Trash Filled Bottles.



Figure 22: Graph + Results showing inside and Outside Temperature Report (Plastic Trash Filled Bottle Building).

6 SWOT Analysis of PET Bottle Construction

6.1 Procurement of PET Bottles for building Construction – Pros and Cons

Most of the bottles obtained from the landfills are in crushed state. All may not be in the same shape and size. A jute sac can hold 200-300 crushed bottles, out of which the probability of good ones to the total is 1: 4 (50 – 75). Pressure blowers are needed in order to quickly blow up the bottles to their original shape.



Figure 23: Procuring PET Bottles from Landfills and Pressure blowing them to gain original shape.

6.2 Structural Aspects of PET Bottles in Building Construction -Pros and Cons

Drilling holes, Hammering nails, alterations such as plumbing and wiring are tough.

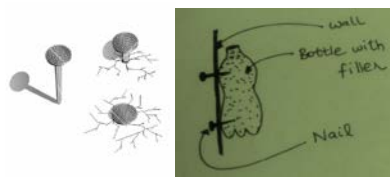


Figure 24: Drilling and hammering in PET Bottle Walls.

Self - Interlocking Polli bricks to achieve all Bonding types

Post-consumer PET bottles are recycled and converted to the interlocking bottles as shown below to facilitate construction purpose.

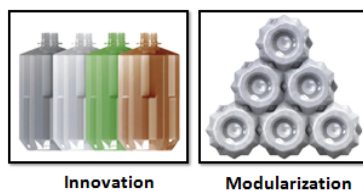


Figure 25: Self- Interlocking Polli-Bricks.(Miniwiz 2015)

These polli-bricks have a translucent skin and allow the natural light to pass through. They have good thermal and sound insulation features and can also withstand hurricane force winds. These can be mainly used for walls, greenhouses, roofs, etc.

6.3 Seismic Test at CSIR

Samarpan Foundation,India has applied for a patent for PET Bottle construction using Nylon – 6 fish net (High impact strength and resistant to chemicals) under Patents Act -1970 and Design Act -2000. The eco-brick houses could tolerate a 9.8 Richters on the Seismic Scale.



Figure26: Seismic investigation of PET Bottle construction at CSIR, India.(Foundation 2006)

The houses built using this simple technology are ideal for hot climate because the bottle bricks are heat buffers and the also are filled with sand giving more insulation. This technology is also ideal for terrorist prone regions like Kashmir because the bottle bricks are bullet proof and the bullets get stuck to the bottles filled with sand.

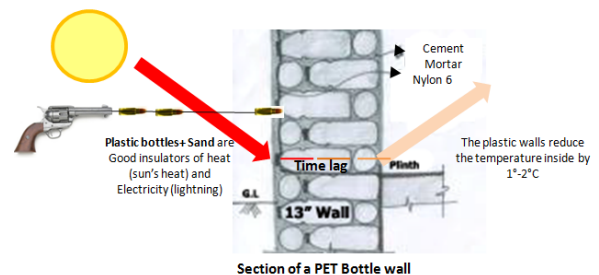


Figure 27: Bullet Proof PET Bottle Shelters.

6.4 Maintenance of PET Bottle Buildings - Pros and Cons

The major maintenance issues are:

- Formation of spider webs and honey combs in the exposed bottle brick works.
- Bottle caps of bottles in an exposed work should always be sealed. If they are opened, the bottle's contents might spill out and reduce the strength of the masonry.(Saraswat 2013)
- Also, the bottles should not contain any leftover food particles or beverage or water. Otherwise, they might attract insects.

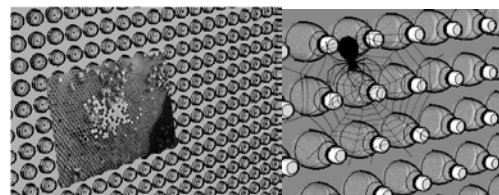


Figure 28: Bee hive and Spider Web formations in Exposed PET Bottle Walls.

6.5 Demolition of PET Bottle Buildings -Pros and Cons

The prototype bottle house built by Samarpan Foundation, India on a farm site was demolished in 4 hours in contrast to the hour it would take to demolish a regular construction with steel in the RCC slab.

This further evidences the tensile strength and impact tolerance of structures constructed with Nylon-6 fish net and PET bottle bricks. When demolished, bottles are deformed, yet do not shatter. They can be reused based on their condition.



Figure 29: Demolition of PET Bottle Brick Building.
(Foundation 2006)

Demolition rate per sq. ft. = INR. 2000

The figure shows a Prototype Bottle Brick house in India (6.5 m x 5 m) being demolished.

6.6 Resale Value of PET Bottles Buildings -Pros and Cons

Resale value of PET bottle houses will be lesser than the cost of construction, as the material is already being reused. After 40 years, the rates of depreciation will be 40% if the condition of the building is good, 50% if the condition is above average and 60% depreciation if the condition is just alright. Builders estimate the lifetime to be a minimum of 60 years, when cement plastering is done.

PET Bottle construction is only an alternate construction technique, mainly to provide housing for the people of poor nations. We do not know if the middle and upper middle class people will take up this idea as this is a new idea. Resale of PET bottle structures is only a far sighted idea.

7 Future Prospects of Bottle Brick Technology

7.1 Bottle Brick filling machines

Bottle packaging machines for filling sand or other filler agents in bottle bricks might be used in future for quick filling.



Figure 30: Bottle Brick Filling Machine.

- Rate of new bottles = INR. 0.50
 - Rate of used bottles = INR 1 to INR. 2
- Probably, the rates of used bottles might increase to the rate of a clay brick or more than that if people start using it extensively for construction purposes.

8 Conclusion

"Home is a notion that only nations of the homeless fully appreciate and only the uprooted comprehend."

-Wallace Stegner

- PET bottles are the new and alternative 'vernacular building materials' and the bottle brick technology is an effective way of getting rid of growing landfills.
- Moreover, they have good compressive strength and are good enough for constructing single and double storey structures. Efforts are being made by certain organizations to construct a triple storey structure.
- This practice provides employment opportunity for the unemployed - rag pickers in the landfills and the construction laborers in the site (as the bottle bricks are made in-situ).
- PET Bottle bricks have sound technical, structural, utilitarian and aesthetic values. Their potential can be explored in almost all parts of the building like walls, floors, roofs, in fillers and even columns.
- Besides architecture, they have a bright chance of becoming an integral part of Landscape architecture, interior design, roads, circulation pathways etc. either in a direct or indirect form.
- Awareness should be created amongst the builders by constructing many PET bottle-brick prototype structures.
- This construction practice does not require any special skill or knowledge. The poor people can be builders and specialists by themselves and also use their creativity during construction. This technique has a lot of flexibilities.
- Thermal comfort is achieved at a very cheap price. This idea can become a great success if the government housing schemes adopt the idea and instigate further research to propagate it.

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Development of a multiple-criteria decision assessment framework for adaptive reuse case study building selection

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ABSTRACT: A number of theoretical methodologies for the selection of best adaptive reuse alternatives have been reported from empirical evidence. However, these frameworks have their distinct weaknesses when applied in the selection process for optimal adaptive reuse alternative. This paper therefore focuses on developing and testing an integrated multiple-criteria decision assessment framework for the selection of best adaptive reuse alternative from two case study buildings, in New Zealand, toward achieving sustainable town-centre living.

1 Introduction

Most government recognised heritage buildings around the world are usually considered as assets that are essential for the development of local tourism, due to the historical and socio-cultural values they possess (Bedate, Herrero, & Sanz, 2004; Pedersen, 2002). Also, these buildings play a key role in the socio-economic and cultural development of a society (CPWD, 2013) by providing a physical link and progression of cultural evidence to the past (Goodwin, Tonks, & Ingham, 2009). However, most heritage buildings located in seismic active regions of the world are usually prone to earthquakes due to the non-consideration of earthquake actions in their design (Dizhur et al., 2011; Egbelakin, Wilkinson, Potangaroa, & Ingham, 2013; MBIE, 2016). New Zealand's Building Amendment Act for earthquake-prone buildings (EPBs) (MBIE, 2016), EPB owners to strengthen their buildings to a minimum requirement of 34% NBS rating within a specified timeframe (NZSEE, 2016), otherwise, the buildings will be demolished. Consequently, there is a renewed interest to preserve historical earthquake-prone buildings towards achieving urban seismic resilience and sustainability (Bullen & Love, 2011a; Langston & Shen, 2007).

The growing perception that it is cheaper to convert older buildings for newer functions rather than demolishing and rebuilding them, is one of the major factors that contribute to the vast interest in the adaptive reuse approach (RM Ball, 2002; Pearce, DuBose, & Vanegas, 2004). The adaptive reuse trend has been clearly projected by Kohler and Hassler (2002), Bullen and Love (2011b), Gallant and Bickle (2005), Douglas

(2006), and RM Ball (2002). Other studies have identified that performance upgrading of older buildings through adaptive reuse usually have a tremendous influence on the sustainable development of a built environment (Bromley, Tallon, & Thomas, 2005; Rohrer, 2001). The Adaptive Reuse approach focuses on repurposing an existing building to enable it to function as a contemporary building while preserving its useful features (Bookout, 1990; Douglas, 2006; Wilkinson, James, & Reed, 2009). In a quest to minimise the social and economic costs of developing a sustainable urban area, the adaptive reuse approach may be beneficial to governments, communities, building owners, and developers (Bullen & Love, 2011a; Wilkinson et al., 2009). Several cities have started to realise that an essential aspect of any successful urban regeneration strategy is the reuse of heritage buildings (Rick Ball, 1999; Yakubu et al. 2017).

However, during an adaptive reuse selection process, some disparities may exist between the objectives of built heritage preservation, economic sustainability, seismic resilience, and building usability. Most especially between different stakeholders with conflicting perception about the adaptive reuse approach. For example, heritage building owners, developers, building professionals, heritage advocates, and the government, have varying adaptive reuse concerns. While the government, architectural historians and heritage advocates are concerned about preserving historical features of heritage buildings, structural engineers will be concerned about life safety. On the other hand, the building owners and developers will consider time as

money throughout the adaptive reuse process. Therefore, in order to select the most suitable adaptive reuse alternative, multiple factors should be considered by the decision-makers. Consequently, the decision-making process for the selection of an optimal adaptive reuse case study building is usually a difficult task.

A number of theoretical methodologies for the selection of best adaptive reuse alternatives have been reported (Bullen & Love, 2011c; Ferretti, Bottero, & Mondini, 2014; Hsueh, Lee, & Chen, 2013; Ishikawa et al., 1993; Langston, Wong, Hui, & Shen, 2007; Saaty, 1980, 1996). However, these frameworks have their distinct weaknesses when applied in the selection process for optimal adaptive reuse alternative. This paper therefore focuses on developing and testing an integrated multiple-criteria decision assessment framework for the selection of best adaptive reuse alternative from two case study buildings, in New Zealand, towards achieving a sustainable town-centre living.

2 Literature review

This section aims at introducing the concepts of adaptive reuse of existing buildings, multiple-criteria decision assessment frameworks (MCDAFs), and description of the fundamental ideas of some of the frameworks related to the adaptive reuse selection process.

2.1 Adaptive reuse concept

The adaptive reuse approach is very important in the development of a community's sustainability strategy. In an effort to support the sustainability of a built environment, a broader revitalization strategy would be that most buildings of historical and cultural significance should be reused and adapted instead of being demolished (Ball, 1999; Bullen & Love, 2011b; Wilkinson, James, & Reed, 2009). The benefits of adaptive reuse have been identified to improve the economic, social, and environmental performance of existing buildings (Bullen, 2007), including heritage buildings (Bullen & Love, 2011b; Yung & Chan, 2011). However, building owners and property developers may still show reluctance in embracing this strategy. (Bullen & Love, 2010) highlighted the reasons for this reluctance to be as a result of some perceived problems relating to increased maintenance, health and safety, building design inefficiencies, increased rental returns, uncertainty, and commercial risk.

The following factors have been suggested to be considered before an existing building is redeveloped for the purpose of adaptive reuse (Bullen & Love, 2010,

2011a, 2011c; Itard & Klunder, 2007; Shipley, Utz, & Parsons, 2006):

- The structural layout and capacity of the building to handle the required adaptation functions and spaces;
- The architectural assets of the building;
- The existence of hazardous constituents;
- Market inclinations;
- The heritage value of the building;
- The energy value of the roof, windows, and walls of the existing building;
- The provision of a well secured and safe environment by the existing building;
- The potential for the existing building to meet health safety, building, and accessibility requirements;
- The state of the building's plumbing, electrical and mechanical systems, including their modification capability; and
- The safety and convenience of the existing building's location.

2.2 Multiple-criteria decision assessment frameworks (MCDAFs)

The issue of decision-making involves a process of choosing from different important alternatives based on different criterion of preference (Saaty, 2004; Vaidya & Kumar, 2006). The MCDAF techniques usually address problems that have predefined alternatives, and can be ranked by decision makers (Tsfamariam & Sadiq, 2006). The aim of using the MCDAF techniques is towards enhancing the degree of coherence and conformity in the decision process, usually done by cross-adapting the value objectives and applied systems of the decision makers (Carlsson & Fullér, 1996). Also, MCDAFs allow decision-makers to choose more preferable alternatives from a pool of feasible options, based on specific criteria. The MCDA method could be defined as a general term for the combination of formal approaches for individual or group decision-making processes that consider multiple criteria (Belton & Stewart, 2002). The MCDA techniques have been reportedly used by mainstream property and construction sectors and other asset and design management applications, to handle issues of selecting best existing buildings for redevelopment opportunities (Langston, 2012). The selection of heritage EPBs for adaptive reuse is a distinctive multiple criteria decision-making problem, involving managerial first choices among different building performance criteria (Yang & Lee, 1997). The characteristics of some MCDA techniques are further discussed in the next section.

Analytic Hierarchy Process (AHP)

The AHP (Saaty, 1980) which falls under the utility theory (Carlsson & Fullér, 1996), is a widely applied approach for handling decision-making problems that have multi-criteria characteristics, through reducing the multi-dimensional problems to a one-dimensional form (Saaty, 1980). This approach is based on the principles of rank order expectations, homogeneous elements, reciprocal judgements, and hierarchic structure (Saaty, 2005). Furthermore, the AHP approach encompasses disintegrating a problem that is unstructured and complex into a group of components arranged in a multiple levelled hierarchy (Saaty & Rozanne, 1987). This approach usually signified by a hierarchy, is relatively measured with absolute balances of both intangible and tangible criteria on the basis of judgement from experts and knowledgeable people (Saaty, 1990).

The AHP has a key feature of quantifying the subjective judgements made by decision makers, through assigning corresponding mathematical values to alternatives, on the basis of the relative vitality of the alternatives being considered (Yang & Lee, 1997). A conclusion may then be reached through a synthesis of the judgements in order to determine the general priorities of the variables (Saaty, 1994a). The determination of decisions using the AHP approach could be done either by applying a lone number for the finest results or by using a prioritized vector that could order the diverse probable outcomes.

Previous studies have identified the major steps in applying the AHP approach to decision-making. These steps include (Saaty, 1994a, 1994b):

- i. Decomposing the problem into elements and sub-elements, down to the lowest hierarchal level;
- ii. Using a Pair-wise comparison procedure to measure each element's relative importance at a specific level, and
- iii. Synthesizing the priorities through computing each element's priority weights at each level repeatedly, until a decision is reached by total composite weights.

However, the AHP has received several criticisms as a result of its application of an unbalanced judgement scale and its inefficiency in handling the intrinsic imprecision and uncertainty in the comparison of alternatives (Deng, 1999). The eigenvalue method used in the AHP has been argued to have a great fundamental weakness, because of the order presentation violation of the derived priority vector (e Costa & Vansnick, 2008). Furthermore, although the AHP is aimed at capturing the knowledge of the expert about a particular alternative,

this approach does not have the capacity to reflect the thinking style of humans (Kahraman, Cebeci, & Ulukan, 2003). The exact value applied when expressing the opinion of a decision-maker in the assessment of alternatives (T.-C Wang & Chen, 2007), and the assumed independent nature of d decision criterion (H.-J. Wang & Zeng, 2010), are also significant limitations of the AHP.

Analytic Network Process (ANP)

The application of the ANP (Saaty, 1996) has gained an increasing use in recent years (Lin, Lee, Chang, & Ting, 2008). This feedback system approach provides a widespread analytic framework that can solve corporate, governmental and societal decision problems (Cheng, Li, & Yu, 2005). The ANP is a broad decision-making tool that is capable of incorporating all relevant criteria that would lead to a decision, usually signified by a network (Saaty, 1996). The ANP usually begins with the AHP, providing a better generalized decision-making framework without assuming the independence of greater-level elements from lesser-level elements, and of elements that fall within their individual levels (H.-J. Wang & Zeng, 2010). Most decision related issues cannot be hierarchically structured due to the dependence and interaction of greater-level elements on lesser-level elements (Saaty, 1996).

The ANP models a network arrangement that reduces the unidirectional and hierarchical assumptions in the AHP approach in order to create interdependent relationships in the framework (Cheng et al., 2005). The interdependencies contained in an ANP framework for different criteria levels is usually represented graphically with an arc or a reciprocal arrow, and with a looped arc if the interdependencies fall within the same analytical level (H.-J. Wang & Zeng, 2010). The structure of the feedback does not contain the maximum-to-minimum hierarchy, but resembles a network with cycles that connects the components of the elements, sinks and source nodes (Saaty, 1996). Most often in practice, the decision problems that involve feedback are usually challenging. This is as a result of the need to determine the importance level of the elements of a network and decision alternatives, including justifying the validity of findings (Saaty, 2008).

Applying the ANP in the selection of heritage buildings for adaptive reuse will involve adopting the following steps (H.-J. Wang & Zeng, 2010):

- i. Identifying the multiple criteria that should be considered, and then drawing a relationship that will show the level of interdependence among each

- criterion;
- ii. Determining the level of impact between the criteria and representing the responses numerically; and
- iii. Determining the general prioritization of the reuse alternatives of the heritage buildings.

Nevertheless, a limitation of the ANP is the issue of 'Rank Reversal' from the perspective of mathematical operations. Although there are other existing techniques that could aid reducing this rank reversal problem (Saaty & Takizawa, 1986), the development and application of fuzzy set approaches have been suggested to improve this problem (Meade & Sarkis, 1998).

Fuzzy-Delphi Method (FDM)

The FDM (P.-T. Chang, Huang, & Lin, 2000; Ishikawa et al., 1993; Kaufmann & Gupta, 1988; Murray, Pipino, & van Gigh, 1985) is suggested to be an appropriate tool that can be used as a construct (P.-T. Chang et al., 2000), when handling the issues of uncertainty and ambiguity that may occur in survey techniques and responses (Sackman, 1974). This technique is an effective and efficient group communication approach that evades major psychological distractions pertinent to round-table deliberation, designed to systematically elicit decisions from selected experts (Helmer & Helmer-Hirschberg, 1983). A key strength of the FDM is the anonymous merging of ideas from different experts, using iterations and structured feedback responses, in order to avoid group domination when reaching a consensus (P.-T. Chang et al., 2000; Ono and Wedemeyer, 1994). Also, the fuzzy logic addresses the artificial uncertainty and ambiguity by representing the level of preferences with ratios or explicit numbers (Hsueh, Lee, & Chen, 2013).

I. S. Chang, Tsujimura, Gen, and Tozawa (1995) developed a broader FDM procedure for the purpose of giving estimated time intervals of activities in multiple criteria assessment problems. This procedure necessitates the participants of a decision-making process to give an optimistic, pessimistic, and moderate estimate of alternatives in several rounds of surveys (Kaufmann & Gupta, 1988). Based on this three-point estimate, the mean is calculated from the formed triangular-fuzzy numbers (TFNs), and then revealed to the individual experts as feedback information. The FDM process will only be completed if a particular criterion (value) is satisfied by the fuzzy intervals between the TFN estimates of all distinct experts and the group average of all the survey items (P.-T. Chang et al., 2000). A dissemblance index (Kaufmann & Gupta, 1991) is used to

determine the fuzzy interval between the TFN estimates of each expert and the group average. However, the limitation of this approach is that it only makes use of the popularly applied system of fuzzy numbers (i.e., TFNs), and also, at some point in the survey rounds the participants would find it difficult to find the moderate point (P.-T. Chang et al., 2000).

Multiple-Attribute Value Theory (MAVT)

The MAVT (Ferretti, Bottero, & Mondini, 2014) is being presented to address decision issues relating to finite and discrete set of alternatives requiring evaluation. It also addresses decision issues based on conflicting objectives, and performances measured by one or more criteria (Keeney & Raiffa, 1976). The MAVT focuses on constructing a means of linking each alternative with real numbers in order to establish a preference order for the alternatives, and also making this order consistent with the judgements of the decision makers (Ferretti et al., 2014). This process works on the assumption that; for every decision issue, there is an existence of an actual value function that represents the decision-maker's preferences (Van Herwijnen, 1999). This actual value function is then used to convert each alternative option's evaluation based on considered criteria, into a single value. From this approach, the best alternative will be the one that has the best value (Van Herwijnen, 1999).

The MAVT efficiently represents the actual issues of a territorial system (Ferretti et al., 2014). For instance, applying the MCDAF to a structured participative procedure will enable the decision-makers to be more aware of the variables at stake while building the model, therefore learning about the issues in the process of solving them (Abastante, Bottero, Greco, & Lami, 2012). Also, the MAVT permits the inclusion of new alternatives at any stage of a decision-making process without altering the ranking of alternatives, and re-elicitation of preferences (Ferretti et al., 2014).

Furthermore, the MAVT could be seen as a compensatory procedure because, it can aggregate the performance of the best alternative across all the attributes, for the establishment of an overall assessment (Ferretti et al., 2014). This implies that the MAVT technique can allow the compensation of a criterion's weak performance, by another criterion's strong performance. Furthermore, the MAVT supports the process of evaluation under the weak sustainability theory (Costanza & Daly, 1992), which assumes that complete substitution of alternatives could be effectively permitted between natural capital and man-made

capital.

The main limitation of this approach is the requirement of a focus group consisting of experts for the model development. This is because the conflicting objectives of these actors in the decision arena and the manner at which their feedbacks are aggregated and imputed into the framework (Ferretti et al., 2014) may affect the final evaluation results. However, if the values functions is probably shifted to utility functions, the uncertainty of decision-makers' risk attitudes and predictions may improve this weakness (Ferretti et al., 2014).

Adaptive Reuse Potential (ARP) Framework

The ARP framework (Langston, Wong, Hui, & Shen, 2007) provides an avenue for the identification and ranking of existing buildings with high adaptive reuse potential. This method is capable of transforming the old-fashioned decision-making procedures, to better sustainable strategies, practices and outcomes. The ARP Framework requires the estimated present age (in years), and the projected physical life (in years) of the existing buildings. The obsolescence factors (economic, social, functional, physical, technological, and legal) of the buildings are also required to be assessed (Langston et al., 2007).

The useful life (L_u) of an existing building proposed for adaptive reuse purposes could be expressed as (Langston & Shen, 2007):

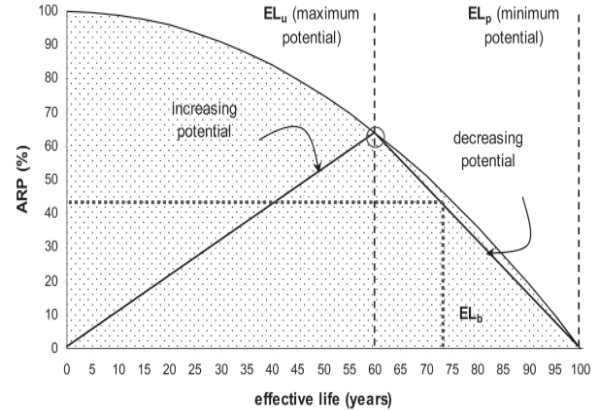
$$L_u = \frac{L_p}{(1 + \sum_{i=1}^6 O_i)^{L_p}} \quad (1)$$

Where: L_u = useful life of heritage EPB (years)

L_p = physical life of heritage EPB (years)

O_i (i.e., O_1 to O_6) = obsolescence: physical, economic, technological, functional, legal, and social obsolescence (% per annum).

From Equation 1, useful life is taken as the discounted physical life, by applying the typical discount rate method to sum up the obsolescence factors on a yearly basis (Langston & Shen, 2007). A proposed algorithm makes use of the information gotten from the obsolescence, useful life, and physical life assessments to produce a reuse potential index, expressed in percentage. Existing buildings that have higher indexes will have the highest potentials for adaptive reuse, while the buildings that do not have any index at all; will not (Langston & Shen, 2007). Figure 1 summarizes this algorithm.



Source: (Langston & Shen, 2007)

Figure 1: Concept of the ARP Framework

From figure 1, existing buildings with ARP values higher than 50, between 20 to 49, and between 1 and 19 will reflect a higher, moderate, and low adaptive reuse potentials respectively (Langston & Shen, 2007). Furthermore, ARP values higher than 85 would strongly suggest redevelopment activities to commence on the existing building (Langston & Shen, 2007). The effective useful life (EL_u), the effective physical life (EL_p), and the effective building age (EL_b) parameters, are calculated correspondingly by multiplying the useful life, the physical life, and the building age by 100, and then dividing by the physical life of the existing building. The feasible ARP zone (y) is represented by the shaded portion below the curve (Equation 2), taking a negative exponential form.

$$y = 100 - \frac{x^2}{100} \quad (2)$$

Equations 3 and 4 imply the lines of increasing and decreasing ARP respectively.

$$ARP_{(increasing)} = \frac{100 - \frac{E(L_u)^2}{100} \cdot EL_b}{EL_u} \quad (3)$$

$$ARP_{(decreasing)} = \frac{100 - \frac{E(L_u)^2}{100} \cdot (100 - EL_b)}{100 - EL_u} \quad (4)$$

However, there is an argument that the adaptive reuse process must consider social, economic, and environmental benefits in order to adequately interpret the significance of the ranked heritage EPBs (Heath, Oc, & Tiesdell, 2013). It is important to practically consider incorporating the benefits of heritage buildings and social costs, into the development and evaluation of the adaptive reuse strategy. Although the process of identifying the value for money for adaptive reuse

implementation is mostly linked to monetary return, focusing on only monetary matters will create a decision-making bias (Langston et al., 2007).

2.3 Conceptual Framework Development

A conceptual framework was developed for this study to incorporate multiple criteria quantitative and qualitative functions, and fuzzy interpretation functions for the selection of best adaptive reuse alternative from two case study buildings, in New Zealand. The framework has four major phases (refer to Figure 2). The first phase illustrates four priority aspects that will contribute towards achieving a sustainable town centre living in New Zealand. The priority aspects are measured by interlinked sets of criteria as shown in the second phase. Some barriers that could influence the specified sets of criteria are presented in the third phase, while the fourth phase entails the possible interventions that could address the identified barriers in the third phase.

Priority Aspects and Criteria

As depicted in Figure 2, the four priority aspects of the conceptual framework (i.e., seismic resilience, sustainability, built heritage preservation, and building usability) are discussed in the subsequent subsections.

- Seismic Resilience

The purpose of seismic resilience is to recover or maintain functionality, and create adjustments that can accommodate thriving and learning while reducing the adverse effects of future earthquake occurrences (Smith, Brown, & Saunders, 2016). A community could be considered as seismic-resilient if it possesses the capacity to absorb and minimise the disruptive and adverse effects of an earthquake, and respond effectively to the earthquake event (Bruneau et al., 2003). According to Mileti (1999), a seismic-resilient community could be described as an area that can withstand an extreme seismic event with a tolerable degree of losses, and can consistently handle mitigation actions through achieving a tolerable degree of protection.

- Sustainability

The concept of sustainability encompasses three underpinning key factors, which are the economic, social and environmental well-beings (Berke & Conroy, 2000; Campbell, 1996; Lele, 1991). The reconciliation and interaction within these key elements are essential to the pursuit of sustainability. A strong economy, for instance, provides for the wealth, happiness, and health of individuals. Likewise, a healthy, diverse, and productive

environment improves living standards and supports life. Accordingly, the social well-being provides an acceptable living standard (Prescott-Allen, 2001; Williams, 2002). However, in New Zealand, the consideration of cultural well-being is usually governed by legislation (Saunders & Becker, 2015). The integration of all the well-beings, therefore, becomes the focus of any sustainability challenge.

- Built Heritage Preservation

Heritage buildings provide a physical link and progression of cultural evidence to the past (Goodwin et al., 2009). In a fast growing urbanizing world, these heritage values viewed as public goods (Navrud & Ready, 2002), could aid the significance of a town's cultural heritage and unique competitiveness (Yuen, 2005). The Heritage New Zealand Pouhere Taonga Act 2014 is based on the following working principles (HNZPT, 2014):

(a) that historic locations have long-lasting worth in their own right, and provide evidence of the origins of the nation's distinct society;

(b) that the process of identifying, safeguarding, preserving, and conserving New Zealand's cultural and historical heritage should—

- Address all relevant cultural values, disciplines, and knowledge.
- Address the possible loss or alteration of substantial cultural heritage value.
- Protect the preferences of current and future generations.
- Be fully investigated, documented, and noted, where culturally suitable.

(c) that value exists in individuals, Tangata Whenua, societies, corporations, local authorities, and central government agencies, working together towards New Zealand's cultural and historical heritage; and

(d) the relationship between the culture and traditions of Māoris and their ancestral lands, sites, water, wāhi tapu, wāhi tūpuna, and other taonga.

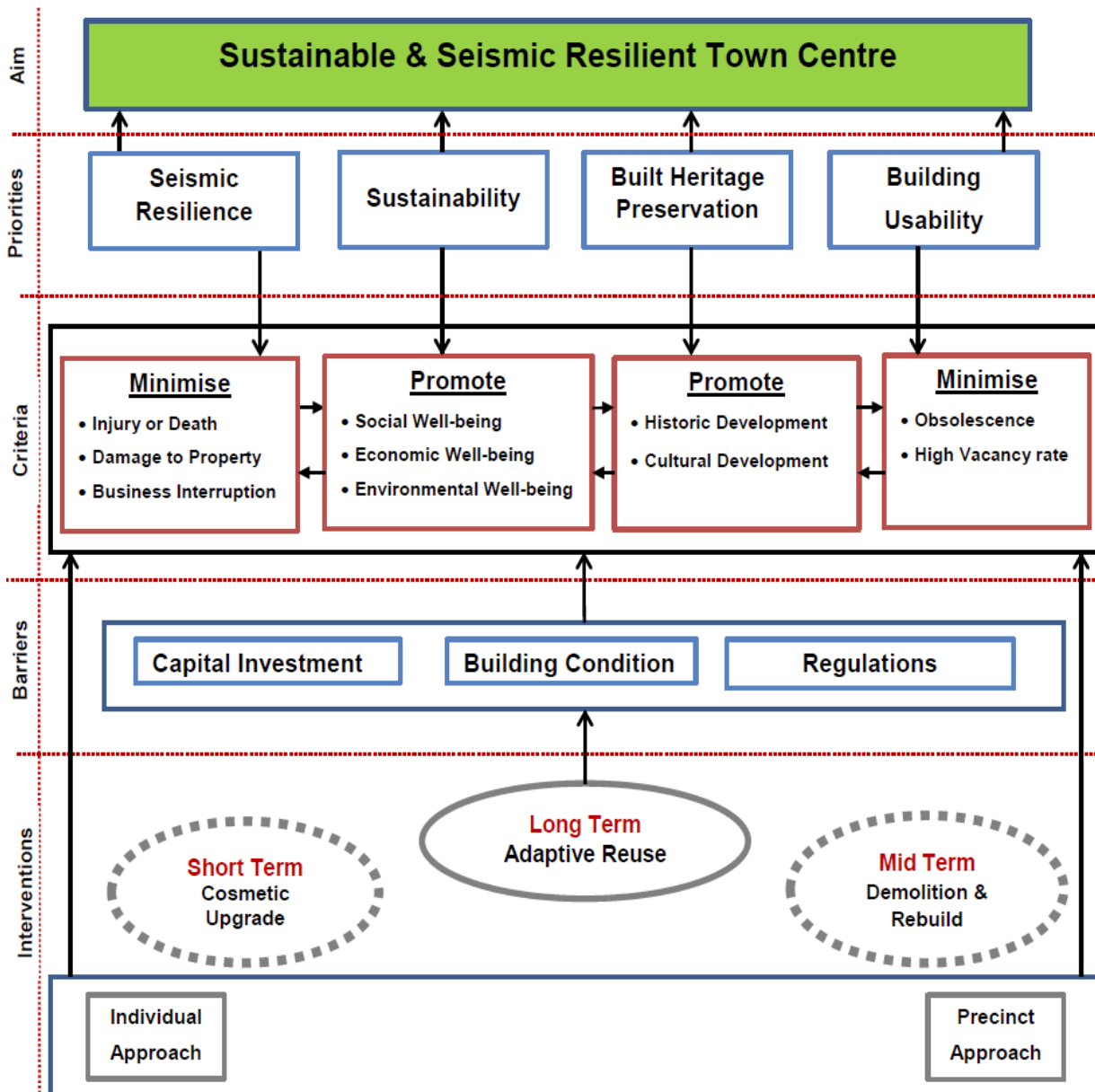


Figure 2: Conceptual Framework for a sustainable and Seismic Resilient Town Centre

- **Building Usability**

The constant shifting demand for existing buildings in the property market is due to the impacts of the ineffectiveness, and the natural decay of the systems and fabrics of these buildings (Petersdorff et al., 2006). Most building owners may decide to either redevelop or demolish their existing buildings on an economic basis, as a response to the declining usability of these buildings (Pearce, DuBose, & Vanegas, 2004). A reduction in the vacancy rate and obsolescence of existing buildings could potentially increase building demand. Consequently, this increase will optimise the value of these buildings by acknowledging their residual usability (Ellison, Sayce, & Smith, 2007).

Barriers

Some barriers that could likely influence the specified sets of criteria (refer to figure 2) towards achieving a sustainable and seismic resilient town centre are discussed in Table 1 under three broad categories (Bullen & Love, 2011c).

Table 1: Barriers influencing achieving a Sustainable and seismic resilient town centre

Barriers	Description
Capital Investment	There is usually lack of investors for building redevelopment projects, due to concerns regarding poor building aesthetics and marketability, lack of incentives, low occupier demand, high retrofit cost, and uncertainty about the future value of the land.
Building Conditions	Usually, only buildings located in strategic sites are considered to attract investment returns from potential investors. Other factors such as a building's residual service life, its existing functionality, structural integrity, internal layout and space utilization have also been identified.
Regulatory Requirements	Deficient central and local governance towards embracing existing building redevelopment innovations will serve as a detrimental impact to sustainable urban development. For instance, the use of legislation as a mechanism to mandate earthquake retrofit projects could also be considered a barrier to sustainable development. Compliance to building code requirements (i.e., disabled and fire access regulations), planning requirements, health and safety requirements, and heritage requirements, often significantly act as barriers to sustainable redevelopment projects.

Table 2: Possible interventions to the identified barriers

Interventions	Description
Cosmetic Upgrade	Although a typical minor maintenance routine aimed at upgrading an existing building's outward appeal is usually done per five year interval (Douglas, 2006), the building will require major maintenance at some point (Wilkinson & Remoy, 2011). Also, the structural integrity of the building is not likely to be considered during the cosmetic maintenance process. Moreover, there is a possibility of the intervention costs surpassing the benefits from the cosmetic maintenance, especially in depressed property markets.
Demolition and rebuild	This intervention creates opportunities for a best fit with the needs of both current and future users of the existing buildings. However, apart from waste of resources, rebuilding a technically efficient structure will conflict with the objectives of sustainable development. Also, the longer reconstruction time will lead to delay in investment return.
Adaptive Reuse	The conversion of a buildings existing use to other new uses will sustain a durable and beneficial use of the existing building and its location. This intervention is cheaper than demolition, and there are also possible high financial and social benefits from embracing this intervention (Bullen, 2007; Bullen & Love, 2010).

Interventions

This paper suggests possible interventions that could be used to address the identified barriers above. The three suggested interventions include: cosmetic maintenance, demolition and rebuild, adaptive reuse (Remøy & van der Voordt, 2014). Table 2 summarises these interventions.

3 Research method

A focus group interview was conducted with relevant stakeholders, using the case study approach to explore the best selection of adaptive reuse alternative from proposed buildings. The case study area is Whanganui, located on the west coast of North Island in New Zealand, and has a Mainstreet (i.e., Victoria Avenue) famous for its heritage building precincts. These collections of heritage buildings possess original pre-1935 architectural designs. With a population of roughly 42,153 people and a population density of 0.18 persons per hectare, Whanganui has experienced a steady decline in population since the 2006 Census at a rate of 1.1%.

3.1 Case Study Buildings

Two case study buildings (figures 3 and 4) were proposed by Whanganui local council for an optimal adaptive reuse selection. Also, table 3 shows a comparative analysis of the two buildings.

Building A



Figure 3: Thains Building

Building B



Figure 4: Wakefield Chamber

Table 3: Comparative characteristics of the two case study buildings

Building	Year of Build	Ownership	Location Characteristics	Earthquake -prone
A	1930s	Private	• Corner building • Mainstreet entrance (i.e., gateway building)	• Yes • <34% NBS
B	1929	Government	• Corner building	• Yes • <34% NBS

3.2 Data Collection

A focus group interview aimed at selecting the best building alternative for an adaptive reuse feasibility study in Whanganui was chosen as the best data collection approach due to the provided opportunity of testing assumptions and gathering beliefs and opinions from selected stakeholders (Krueger & Casey, 2014). The focus group interview was conducted with relevant stakeholders representing different portfolio, and from different professional backgrounds. A total of 22 participants were selected for the interview. The participant mix comprised a combination of structural engineers, quantity surveyors, architects, estate valuers, building owners, property developers, legal representatives, heritage representatives, and local government council representatives. Table 4 presents the profile of the focus group interview participants.

Table 4: Profile of Focus Group Interview Participants

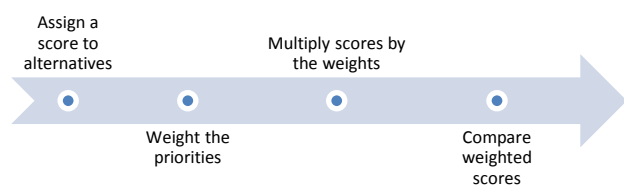
Category	Frequency	(%)
Building professionals	4	18.2
Building owners	6	27.3
Local council representatives	7	31.8
Heritage representatives	4	18.2
Legal Representatives	1	4.5
Total	22	100%

3.3 Testing the MCDA Framework

The focus group participants were engaged in order to explore the applicability and validity of the MCDA framework. For anonymity purposes, a total of 22 participants were randomly grouped into four categories, with each group having a unique colour code. The groups were colour-coded into blue, green, purple, and red groups, and had a minimum and maximum of 5 and 6 participants respectively.

Weighting and Scoring

The validation exercise involved the application of weights to each priority aspects and their criteria, and also applying scores to the alternative case study buildings. The essence of the weighting and scoring technique was to allocate a number to separate alternatives, priorities, and criteria in order to reflect the value judgement of the decision makers (Belton, 1990; Belton & Stewart, 2002). The weights allocated to a specific criterion reflect its relative importance in the decision making process, and are an essential aspect of generating learning outcomes from the MCDAF process (Belton & Stewart, 2002; Wright & Goodwin, 2009). The scores indicate the relative importance of separate alternatives for each criterion. Figure 3 demonstrates the weighting and scoring process for decision making.



(Source: Resilient organisations, 2016)

Figure 3: The weighting and scoring process

The MCDAF follows a linear additive statistical principle for the weighting and scoring process. The linear additive model is the most frequently applied MCDA technique. This method has been adopted for this research due to the independent nature of the criteria, and also, uncertainty is not incorporated into the model (Belton & Stewart, 2002; Triantaphyllou, 2000). However, depending on the time and available resources, the developed MCDAF could apply different scoring techniques from other several MCDA variations. Accordingly, a three-stepped process was used to score the alternative buildings, and weight the priority aspects and criteria, as proposed in the linear additive statistical

approach (Belton, 1990; Wright & Goodwin, 2009).

Steps for Weighting and Scoring

The first step involves the use of a local scoring system (i.e., between 0 to 10) to compare the alternative case study buildings on how well they will fulfil each criterion, with 10 being the most likely and 0 the least likely (Belton, 1990). Since only two alternative buildings were proposed for this study, once the highest score of 10 is assigned to one of the buildings for each criterion, automatically the second building scores 0. Appendix 1 demonstrates the scoring process. The second step involves determining a weight that will indicate the relative importance of each priority aspect and criteria within the framework, to the decision makers. The third step involves allocating points totalling 100 to individual criterion within each separate priority aspect. However to get the actual weight for each criteria under a priority aspect, the weight for that particular priority aspect was multiplied by the weight of each criteria and divided by 100. Appendix 2 demonstrates this weighting process. The workshop facilitators guided each group to support the group leaders.

Selection of the preferred alternative Buildings

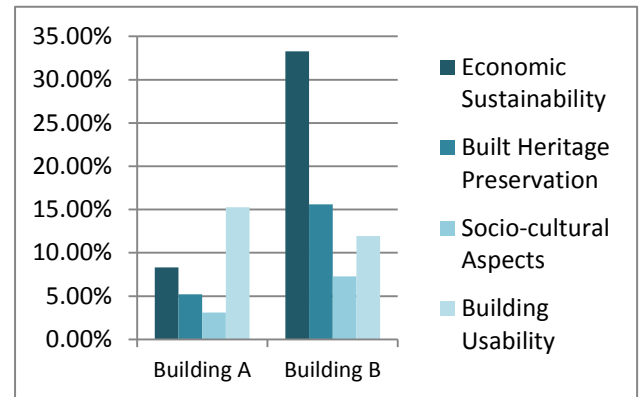
A decision on agreed alternatives is the final step in the MCDA, after the scoring and weighting processes. The information required to make a final decision originates from a decision matrix which presents the results from the weighting and scoring processes. The decision matrix presents the total scores at the bottom (refer to appendix 3). The result is a performance matrix which involves assigning a weight to a criterion, and then multiplying that criterion by its score relative to each alternative building. The total weighted score of the MCDA was then achieved through comparing the total weighted scores for each alternative. Accordingly, the total weighted score for each alternative was converted to percentage by dividing by the total possible score for the priority area. Although bearing in mind that the criteria for each score was different, the alternative with the highest total score (i.e., in percentage) was the preferred choice.

3.4 Presentation of Findings

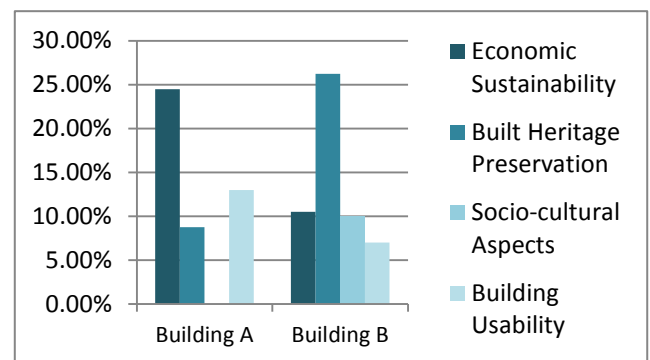
The development and testing of the MCDA with the focus group participants enabled the selection of the best case study building for the implementation of an adaptive reuse feasibility study in Whanganui. From the two buildings that were presented (Buildings A and B),

Building B was preferred by all four (Blue, Green, Red and Purple) focus groups. A breakdown of the decision-making process for each group is summarised below.

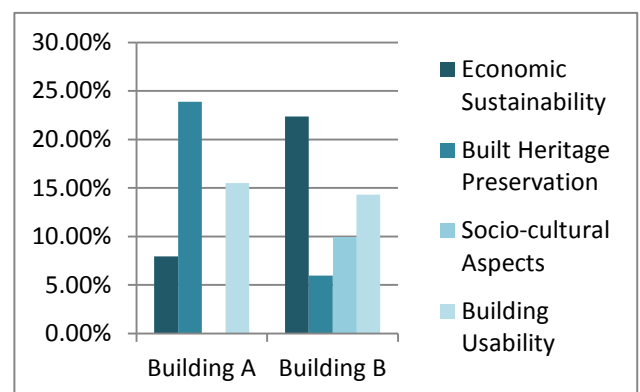
Blue Group		
Priority	Total Standardised weighted Score for each Building	
	Building A	Building B
Economic Sustainability	8.32%	33.26%
Built Heritage Preservation	5.20%	15.59%
Socio-cultural Aspects	3.12%	7.28%
Building Usability	15.28%	11.95%
	31.91%	68.09%



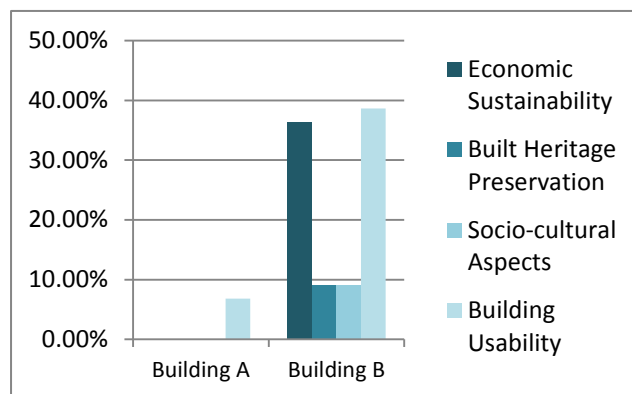
Green Group		
Priority	Total Standardised weighted Score for each Building	
	Building A	Building B
Economic Sustainability	24.50%	10.50%
Built Heritage Preservation	8.75%	26.25%
Socio-cultural Aspects	0.00%	10.00%
Building Usability	13.00%	7.00%
	46.25%	53.75%



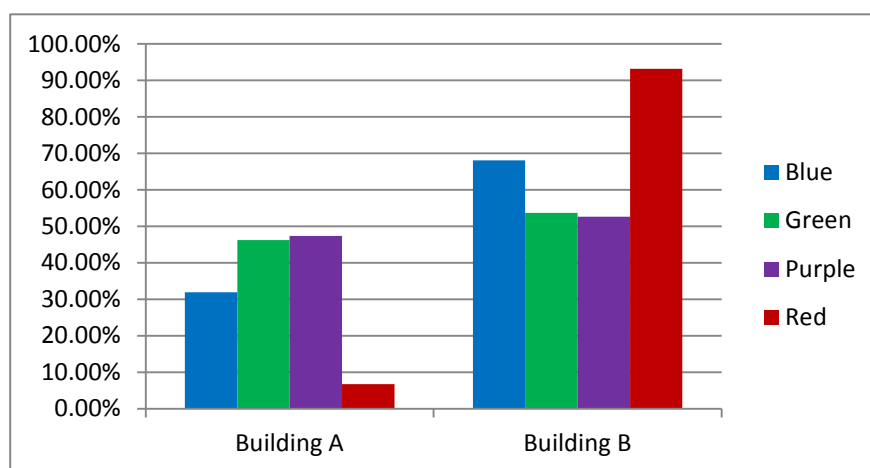
Purple Group		
Priority	Total Standardised weighted Score for each Building	
	Building A	Building B
Economic Sustainability	7.96%	22.39%
Built Heritage Preservation	23.88%	5.97%
Socio-cultural Aspects	0.00%	9.95%
Building Usability	15.52%	14.33%
	47.36%	52.64%



Red Group		
Priority	Total Standardised weighted Score for each Building	
	Building A	Building B
Economic Sustainability	0.00%	36.36%
Built Heritage Preservation	0.00%	9.09%
Socio-cultural Aspects	0.00%	9.09%
Building Usability	6.82%	38.64%
	6.82%	93.18%



All Groups		
Group	Total Standardised weighted Score for each Building	
	Building A	Building B
Blue	31.91%	68.09%
Green	46.25%	53.75%
Purple	47.36%	52.64%
Red	6.82%	93.18%
Mean Score	33.09%	66.91%



4 Conclusion

The proposed alternative case study buildings were critical to the MCDA process as a result of the discussion around them being specific to the impacts the buildings might have towards achieving a seismic resilient and sustainable town centre. Accordingly, the criteria and priority aspects were detailed in order to induce the participants to engage deeply with their opinions. The use of case study buildings that are well-known to the participants helped to generate a solid impression for the real-world issues and inferences based on their own experiences. These kinds of experiences are usually way better than what the workshop facilitators would have created and conveyed within a short period.

The standardised scores were essential in order to roughly provide advice on how each alternative case study buildings performed in relation to the separate priority areas. Overall, building B was preferred by all four groups as the optimal case study building that will be most suitable for the implementation of the adaptive reuse strategy for Whanganui. However the preference of the priority aspects varied for all groups. The blue and purple groups for instance preferred to benefit economic sustainability from implementing the adaptive reuse strategy on building B. The green group on the other hand preferred to achieve built heritage preservation from the adaptive reuse process on building B. The red group preferred to achieve building functionality from adapting building B for new uses.

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Sustainable Refurbishment for School Buildings in New Zealand: A Literature Review

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ABSTRACT

Building refurbishment is challenging and an effective solution should be sought to expand their service life and the comfort of their users. The school buildings in New Zealand (NZ) are no exception as they are increasingly in need of maintenance and refurbishment due to their ages and evolving teaching and learning requirements. Based on a review of recent successful refurbishment projects, this paper identifies critical lessons from these projects in several countries which can be adopted in developing a sustainable refurbishment strategy of school buildings in NZ. Findings include three groups of lessons in terms of reasons, process and barriers in the projects that assist stakeholders to prepare a suitable refurbishment plan in their school buildings. Recommendations are that the owners and consultants should take advantage of the information technology such as 3D scanning and Building Information Modeling in planning and implementing their refurbishment projects as well as overseas findings and recommendations.

Key words: *Building refurbishment, energy efficiency, school buildings, New Zealand*

1 Introduction

Buildings are long-lived products, which are typically designed to last sixty years (Shah, 2012) and many buildings have existed for much longer than the designed lifespan as a consequence of being well maintained and refurbished (Meeus, 2012). Therefore, the key concern of sustainable development must be considered over the life cycle of buildings in consideration of maintenance and refurbishment (Kohler, Knig & Kreissig, 2010). According to Meeus and Shah (2012), in developed countries, 70% of current building stock will exist in the period 2030 to 2050 and the largest environmental, economic and social impacts of built environment act through these existing buildings rather than new ones. Thus, sustainable refurbishment is becoming increasingly recognized as an effective solution for existing buildings. Indeed, sustainable refurbishment extends the life of existing buildings, enables the buildings to have functional adaptations and energy efficiency measures which could reduce environmental impacts and life cycle cost of the buildings (Bhuiyan et al., 2015).

Refurbishment means 'to refurbish again' and 'refurbish' is 'to restore to freshness of appearance or good condition' or 'to polish' (Steven & Shephard, 2009). Many researchers state that refurbishment of a building refers to "upgrade, major repairs work, renovations, alterations, conversions, extensions, and modernization

of existing building" (Quah, 1988; Ali, Noordin, & Rahmat, 2005). Its aim is to provide "modification and improvements to an existing building in order to bring it up to an acceptable and current condition" (British Standard 15643-1, 2010). When a building has come to the end of its service life, or fails to perform its expected functions, partial refurbishment and whole refurbishment can be alternatives instead of demolition (Ali, Kamaruzzaman, & Salleh, 2009). Therefore, refurbishment offers the most potential for improving both physical and functional aspects of existing buildings. In addition, sustainable refurbishment gives significant advantage in value for money. For example, includes lower lifecycle cost, operating cost of the buildings and reduction of energy use, which will reduce impacts on the environment. It also prevents the building from degradation and protects the existing community of the buildings (Okakpu et al., 2014).

Among existing buildings, schools are in the domain of public buildings, and account for a fair percentage of occupant floor space. For instance, school buildings attribute around 20% of the entire non-residential floor space in Europe (Iruregi et al., 2017). As such, providing a conducive environment for education is an important factor, to be considered in the sustenance of schools. School buildings provide, first and foremost, services for studying and teaching that are comfortable and high indoor environment quality. However, the services

quality of school assets may not be ensured over their life span, while Trachte & De Herde (2015) believed that the lack of the comfort and quality have negative influences on students' performance and effectiveness of studying. This is why school buildings have an urgent need of suitable maintenance and refurbishment plans.

Considering environment and economic aspects, school stakeholders should balance between cost-effective actions and environmental impacts of the refurbishment plans. This means school buildings are maintained and refurbished in sustainable manner. However, to achieve these in each school building will depend on different parameters and priority of the refurbishment strategy. In New Zealand, although the Ministry of Education issued national school property strategy 2011-2021 to set out the goals of sustainable upgrading existing schools, it is not yet clear how to plan and deliver sustainable refurbishment projects of these buildings.

This paper identifies key lessons of sustainable refurbishment from lessons learned in school building refurbishment projects in several countries. These factors may provide appropriate benchmark for best practice in NZ. To achieve this, previous studies were critically analyzed based on the following three objectives:

Objective (1) is to provide adequate information in deciding when and why a building required refurbishment. Objective (2) is to identify important factors to consider during the refurbishment process, while Objective (3) is to investigate common issues that can limit the sustainable refurbishment of school buildings. The results of this critical review may be considered recommendations for a strategy for assessment of refurbishment of NZ school properties to meet sustainable development goals of the Ministry of Education NZ.

2 School Buildings in New Zealand

In NZ, the total number of schools in NZ has reduced. Compared to 1996, the number of schools has reduced by 251 schools over last 20 years. While the number of schools in Auckland is increasing, schools in other regions are decreasing (see Figure 1). There are 2,529 schools with over 17,000 buildings and 38,000 classrooms serving approximately 750,000 students (Ministry of Education, 2017).

Considering the age of these buildings, it can be said that a significant number of school buildings will soon require extensive refurbishment in order to expand their service

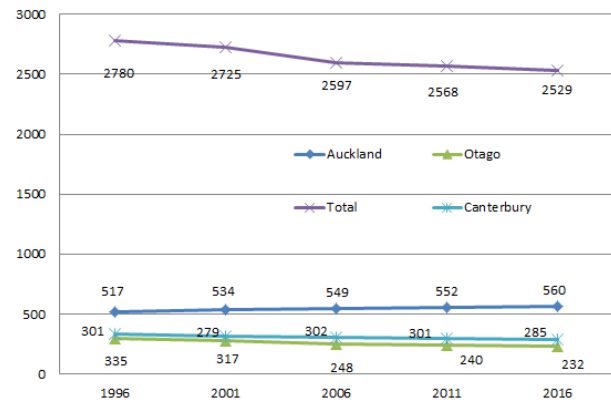


Figure 1: Number of Schools in New Zealand 1996-2016.
Source: (Ministry of Education, 2017)

life. According to New Zealand Ministry of Education (2011), 70% of school buildings are between 30-100 years old, and the average age of state school buildings is 42 years as shown in Figure 2 (Ministry of Education, 2017). Therefore, partial or whole refurbishment of existing school buildings in NZ is inevitable.

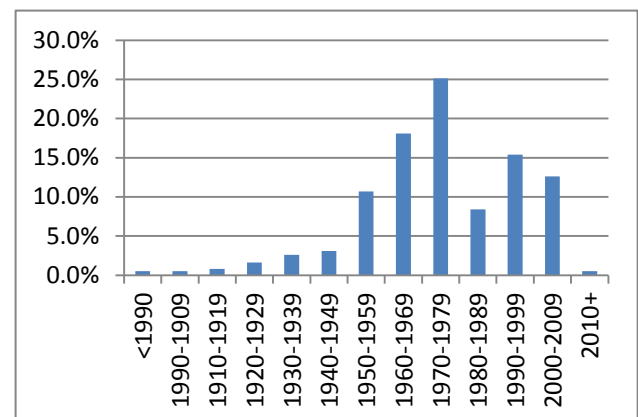


Figure 2: Year Built of School Buildings.

Source: (Ministry of Education, 2017)

In 2011, Ministry of Education (2017) published a report on NZ school property strategy 2011-2021, which focuses on three strategic goals: 1) School property is well-managed, 2) School property is fit for purpose and 3) A high-performing portfolio of schools. One of the priority areas to achieve the second goal is to maintain the condition of school property, and in particular, to ensure the maintenance of schools' assets over life expectancy. The key initiative is a maintenance program for school buildings to be well maintained and supporting teaching and learning activities.

In terms of environmental sustainability, NZ uses Green Star certification to rate the sustainability of buildings.

Based on a number of criteria, the rating achievable ranges from 1-star to 6-star (New Zealand Green Building Council, 2017). The highest rating achievable for schools is six-star green building, which is a “New Zealand Excellent Standard”. When schools are assessed, energy use and indoor environmental quality are the most important categories with significant weighting (Bound & Flemmer, 2014). Hence, an effective refurbishment of any school should meet the expectation of the Green Star.

Over the years, NZ government has invested extensively in the refurbishment of schools across the country. Annually the Ministry of Education spends around \$170 million on existing state school operations to ensure that they are in good condition which can optimally support teaching and learning (New Zealand Ministry of Education, 2017). Since 2014, there have been over 60 refurbishment projects for which the Ministry of Education offered tenders (New Zealand Government Electronic Tenders, 2017). Approximately 80% of school building refurbishment tenders are offered for the refurbishment of classrooms, block buildings (including teaching areas, offices, toilets), and some bids for the renovation of libraries, sports centers, laboratories, and infrastructure. In 2015, the value of building consents for education buildings have surpassed one billion NZD a year, with 30% for the refurbishment of existing school buildings (Statistic NZ, 2016). While the school property assets and facilities are well maintained, they also need to be continuously improved to support future education.

3 Problem Statement

Refurbishment issues often arise when the building performance is not meeting the standard and quality expected. These issues are often neglected during the design and construction stage of the building (Ali et al., 2013), which may lead to non-conformance such as lack of an access system, unexpected deterioration of materials. One of the critical issues in refurbishment is the lack of understanding of the building design or characteristics among school administrators who can put forward the options in a proper refurbishment strategy for their schools (Abidin et al., 2010). These issues require comprehensive designs and plans, which can provide advantages in operation, adaptability, and maintenance.

According to the report published by Audit NZ (Controller and Auditor-General, 2017), the Ministry of

Education provides schools with maintenance funding, depending on the size of the school property and estimated mainly on the volume of buildings the school uses instead of actual property needs. While the Ministry does not monitor how schools use this funding, the school also does not have an adequate plan for maintenance according to the building standards. As a consequence, the refurbishment strategy of school may not be aligned with the NZ Ministry of Education strategy as expected.

Most of refurbishment projects are commonly delivered as a one-off project, rather than as a program moving towards sustainability based on its strategy and policy (Shah, 2012). Another challenge is understanding how to deliver sustainable refurbishment projects in order to achieve intended targets in the strategy of Ministry of Education. This study fulfills the need to provide a robust strategy for the refurbishment of school building that will not only align with Ministry of Education strategy but also produce environmentally sustainable buildings.

4 Methodology

This review focuses on sustainable refurbishment projects of school buildings in the past 5 years. Based on the objectives of the paper, case studies were sought from available sources such as the journals and online public data. A literature search process with 3 steps was adopted to collect relevant literature. (1) The key words informing the search were “sustainable refurbishment”, “energy retrofitting”, “school building” and “educational building”. The search was conducted in both Scopus and Google Scholar websites, limited to peer-review articles. The initial return to the search were 36 relevant articles. (2) Then, the second selection based on the relevance to the objectives of this study produced 11 projects. (3) The final selection was conducted considering the location of the projects resulting in six more articles being excluded. Therefore, this paper provides a review of five refurbishment projects, namely:

- Project A: EU Project “School of the Future”- refurbishment of school buildings toward zero emission with high-performance indoor environment (2016);
- Project B: Refurbishment in educational buildings-methodological approach for high performance integrated school refurbishment actions (2016);
- Project C: Energy retrofit of educational building: transient energy simulation, model calibration and

mil-objective optimization towards nearly zero-energy performance (2017);

- Project D: Energy performance assessment and retrofit strategies in public school building in Rome (2014);
- Project E: Retrofitting solutions for two different occupancy levels of educational building in tropics (2016);

5 Findings

Table 1 presents projects' information and the objectives (1) and (2) of this paper. In the following, all objectives are discussed.

5.1 Objective 1: Refurbishment Reasons

The main reasons and goals of the refurbishment of school buildings are identified from six projects as follows:

- Building Condition and Performance

All buildings in six projects are at the age of refurbishment. Heating systems, ventilation system, and building envelope are progressively degraded resulting in high operation and maintenance cost. Therefore, all six projects target to reduce energy consumption and improve indoor environment quality except for the only project C which meets the standard of nearly zero-energy performance.

- Educational Outcomes

Projects B and D believed that lack of comfort has negative consequences on pupils' concentration and learning. With the development of new teaching methods, learning environments have changed, requires functional improvements to adapt learning spaces.

- Sustainability Awareness

Projects A and B set the goal of the sustainable refurbishment of a school building to offer a real opportunity for students, teachers, and parents to be aware of saving energy and resources and behave in a more responsible manner. Project A provides training sessions to improve users' behaviour and raises their awareness of energy efficiency and indoor environment. The advantage of this training will effect on other schools, and the residential sector through the students act as communicators to their families and their peers.

5.2 Object 2: Refurbishment Process

- Stakeholders' Involvement:

The successful projects based on thorough and well-led consultation. Projects A and B define clearly the roles and communication between the stakeholders. In the Project A, there is also an advisory group of researchers and practitioners to support schools in planning their project. Each project has the decision-making process

framework.

- Process and Material Used

The building characteristics were identified in all projects as the first step in the refurbishment planning. The surveys of the occupants' comfort were conducted to assess users' comfort of indoor environmental quality. The energy efficiency measures were modeled for the refurbished buildings according to their characteristics and specific functions including building envelope (wall and roof); alteration of windows, natural ventilation, and renewable resources. An air-source heat pump and PV roof systems are considered as the most effective configuration of energy retrofit in school buildings.

In the selected refurbishment projects, simulation software packages such as Energy Plus (Projects D and E) and LIDER (Project B) are used to simulate and estimate energy consumption of each scenario that can assist stakeholders in the decision-making process.

5.3 Object 3: Refurbishment Barriers and Challenges

- Data Acquisition

Project B states the need of data to identify the viability of refurbishment concepts for buildings in public sector, while Project A points out the need of up-to-date building performance data. However, the data acquisition is a challenge in the refurbishment field due to its reliability and validity.

- Other Challenges

Project B addresses limited budgets, the political, institutional framework conditions, and the lack of innovative and holistic concepts are considered as factors to prevent school buildings from comprehensive refurbishment. Furthermore, school building refurbishment focuses mostly on a single measure of maintenance and adaptation of the building structure, while functional changes are rarely considered in the refurbishment plan. The proposed methodology in Project A requires expertise in both building performance simulation software and employed optimization algorithms so users may find difficulties in using the software, designing variables and simulation, optimization parameters. Future research should be focused on developing a simplified and integrated application tool which should be user-friendly and easy to adopt.

Project E points out, in educational buildings, the different function of rooms such as lecture rooms, seminar rooms, labs, offices, and libraries, leads to density fluctuation. Therefore, stakeholders should consider the occupancy of different areas in the refurbishment plan and procedures.

Table 1: Project Summary

Code	Project Reference	Project Information	Objectives
A	EU Project “School of the Future”— Refurbishment of School Buildings Toward Zero Emission with High-Performance Indoor Environment (Erhorn-kluttig & Kempe, 2016)	The project is funded by the European Union’s 7th Framework Program for retrofitting the school buildings in Germany, Italy, Denmark, and Norway. In these countries, four school buildings in different climate zones were selected. The holistic retrofits of the building envelope, their service systems, and the integration of renewables and building management systems were conducted.	Objective (1): Refurbishment reasons - The buildings were in poor conditions and performance, so the refurbishment is considered; - To improve indoor environments quality, building service system and set solutions for zero energy schools with reduction of total energy use and the heating energy consumption by more than 75%; - To demonstrate limited additional costs need for energy efficiency; - To raise public awareness of energy conservation by presenting examples of highly energy-efficient retrofit projects of school buildings; - To provide reliable information, including energy saving potentials and costs to enhance the use of innovative, energy saving retrofit concepts in public building; - To develop national and European benchmarking systems, including those that will estimate the potential of innovative, cost-efficient energy retrofit strategies Objective (2): Refurbishment process - The group of stakeholders meetings was held at each school to develop the Energy-Efficient Retrofit Concepts based on the goals of the project. - Each school is monitored via Stuttgart’s Energy Control System (SEKS), using meters to measure the energy consumption of the whole school and sending the data to the Department of Energy Management daily in a full year. In terms of Indoor Environment, a survey of the occupants' indoor comfort was conducted to assess users' comfort before and after the refurbishment. - Based on the information, the Design Advice and Evaluation Group including researchers and industry professionals, support the stakeholders of school buildings and the local planning team in the detailed design of certain measures and simulations. A building diary includes information of building process in a full year was documented and available on the website of the project. The data of energy performance of selected school buildings before and after retrofit were calculated. - Materials used: Rooftop-mounted photovoltaic systems, LED lighting, brick façade plus addition of insulation and new lightweight façade envelope.
B	Refurbishment in educational	This study summarizes the results of	Objective (1): Reasons to refurbish

	buildings–methodological approach for high performance integrated school refurbishment actions (Orsterreicher & Geissler, 2016)	the research project SchulRen+ [5] in Europe, in a particular building, the Faculty of Architecture in San Sebastian, Vienna, Austria.	- To improve energy efficiency, integration of renewables systems and reduce CO2 emissions of the building; - To change appearance of the building envelope align with innovation in new room concepts, logistic and use; - To adapt classrooms to flexibility of room uses and different learning environments; - To increase awareness and set best practice examples by integrating renewable energy systems in public buildings. Objective (2): Refurbishment process - School buildings stakeholders provided input data (through a monitoring campaign including questionnaire campaign and preferences of users' comfort) to develop optimized school refurbishment concepts, which considered of life cycle cost, energy, and thermal comfort, functionality, and architecture. - Following the requirements of the stakeholders, retrofitting options (level of refurbishment) for winter and summer were subsequently tested using the simulation program LIDER. An integrated approach is considered to select an appropriate scenario of refurbishment from a multi-dimensional perspective such as life-cycle-costs, energy, thermal comfort, functionality, and architecture - Consider using sustainable materials such as resource-oriented construction; use of ecological building materials; green and or landscaped areas and open spaces.
C	Energy retrofit of educational buildings: Transient energy simulations, model calibration and multi-objective optimization towards nearly zero-energy performance (Ascione et al., 2017)	The study is multi-objective optimization of the refurbishment of an educational building of an Italian University. The investigated building has rectangular shapes, with areas of 7000 m2 and 17m height. The building was offices and classrooms of the Department of Law, University of Sannio.	Objective (1): Refurbishment reasons - The building was built in the early '90s and it was in the matter of energy efficiency; - To reduce energy using for heating and cooling up to a value of 12 kWh/m2a, so that the building can be surely considered as nZEB; - To improve indoor environment comfort regarding artificial lighting, thermal and visual; - To reduce operating costs; - To raise the demonstrative role of the public hand in energy efficiency as underlined in Directive 2010/31/EU and 2012/27/EU in EU. Objective (2): Refurbishment process - The building performance was assessed through surveys, interviews with managers and users, in-field measurements. Based on the information, energy performance has been modeled by interactive coupling of MATLAB and Energy

			Plus software. - The decision-making process through a framework which has the two-stage methodology. The first goal is to find optimal packages, which minimize energy demand and thermal discomfort. The second goal is to define cost optimal refurbishment solution. - The whole life-cycle cost of the solution was identified by taking into account various discounting factors leading to lower overall expenditure, and thus the sum of investment and operating costs along the building lifetime. - The refurbishment of building envelope, HVAC systems, and integration of energy supply by renewables was conducted
D	Energy performance assessment and retrofit strategies in public school buildings in Rome (De Santoli et al., 2014)	The study assessed the quality of primary schools in Rome. Different scenarios of refurbishment on both plants and envelopes were defined, taking into account considering of low payback time and environmental benefit achievable in 20 years.	Objective (1): Refurbishment reasons - To investigate current situation of energy consumption and inefficiencies of maintenance and management of these buildings; - To define possible refurbishment strategies to reduce energy consumption in school buildings, considering the cost of retrofit interventions; - To improve levels of users' comfort to influence students' performances; - To develop a good database in terms of analysis on building performance assessment for the government may apply to calculate how many resources to start a process of energy regeneration in other stock. Objective (2): Refurbishment process - With a systemic approach, the data of 1296 school buildings in Rome are provided by the City of Rome's Department of Asset Management including building typology, energy consumption for buildings' envelope and plants. 50% of the buildings used an energy label, 30% were measured energy consumption by metering, and the rest used both data available. - A comparison between data from energy labels and data from energy measurement was drawn and based on the result, a model of analysing current energy consumption and potential actions of intervention is defined. - Data from energy labels was used to produce a strategy for refurbishment. Data from consumption metering was used to identify priority actions to reduce energy consumption. - Standards of envelope refurbishment (calculated through UNI-TS 11300 standards) were defined according to building historical, architectural and characteristics.

			- Plants refurbishment was considered by installation of thermal wall and roof and improvement of windows system. - Any of interventions was taken into account of total cost including lower payback time and investment cost as well as considering environmental benefits in 20 years.
E	Retrofitting solutions for two different occupancy levels of educational buildings in tropics (Yang et al., 2016)	This study presents a detailed retrofitting study of two educational buildings in Singapore. One represents a building with average occupancy variation and containing mainly offices and labs. The other one represents a building with high occupancy variation and containing mainly lecture rooms and studios.	Objective (1): Refurbishment reasons - Two buildings are at the age of 40 years so they are in need of refurbishment; - To improve energy efficiency of these buildings; - To compare different energy saving potentials of different educational buildings types; - To investigate performance of principal components of the buildings, which are influenced stronger by these retrofitting solutions. Objective (2): Refurbishment process - The electric consumption (including the lighting, equipment, and fans) and HVAC load over year 2013 was obtained through the University's facility management office. The energy data for all buildings in the campus are collected at every 30 min interval in 365 days. Outdoor climatic condition data are provided from the Department of Geography, National University of Singapore. - Building characteristic is investigated, and the models of the studied buildings are created. After the models are defined, 34 different retrofitting scenarios for both buildings in saving cooling load and plug load are simulated using Energy Plus. - 10 variables were used in each retrofitting scenario simulation to define a single global indicator. The result highlights highest saving potential, photovoltaic but high investment cost, by comparing all the remaining retrofitting scenarios, shows the correlation matrix of the 10 aspects after applying the 34 retrofitting solutions. - There are different materials and technology used in 34 retrofitting scenarios. The study gave a high priority to ventilation-related retrofitting solutions.

6 Discussion

Ali et al., (2009) point out that refurbishment projects are often completed with high cost and time variances. However, there are effective and efficient ways of designing and implementing successful refurbishment projects. According to the lessons discussed above, recommendations toward sustainable refurbishment of school buildings in New Zealand are defined.

To prepare a sustainable refurbishment strategy for school building, stakeholders should have a clear understanding of their roles and responsibilities to adopt a holistic approach and define a maintenance and refurbishment plan of the school based on their demand. The refurbishment plan needs to embrace sustainability from the early design phase such as a 'Green Star Certification' target. Schools as building owners/operators need to understand their existing situation thoroughly and learn from successful projects to identify a project scope and its constraints. Consultants can support schools to assess the current energy efficiency and building services systems to determine potential refurbishment measures. In terms of users' perspectives, surveys or interviews can be conducted to investigate teachers and students' comfort and demand, to ensure quality of indoor environment and raise their awareness of energy efficiency.

In the decision-making process, school refurbishment projects can include a single-objective or multi-objectives as targets to ensure that they meet their maintenance and refurbishment requirements. These objectives usually involve environmental, economic and social factors to reach projects' targets. Researchers recommend that integrating of the Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) methodologies can generate affordable refurbishment solutions (Kim & Park, 2016). Regarding the environmental aspect, they have the goal of clarifying and objectifying environmental performance levels achieved by buildings. The assessment is based upon scores awarded according to a set of performance criteria such as energy consumption, indoor environmental quality. To evaluate environmental impacts of the refurbishment alternatives, LCA is commonly used (Ghose, McLaren, Dowdell, & Phipps, 2017). From the economic perspectives, sustainable refurbishment offers reduction of energy use, thus the lower of investment and operating costs along the building lifetime leading to lower lifecycle cost. Life-cycle cost analysis (LCC) is used to calculate the initial

investments and the future operation and maintenance costs on retrofit alternatives during a certain period of time.

During the implementation phase, work schedules should be developed from the outset in the right order and make sure that it will meet the completion date. Furthermore, the schools and contractors should consider the school term period and teaching schedules to prevent school activities from any interruption and downtime due to construction activities. If the contractors cannot deliver a maintenance and/or refurbishment project during the school break or before/after school activities, they should ensure that light, water and other services of the existing school will not be disturbed and conduct a site safe workshop and training with school workers and students. At each stage, the progress should be monitored and controlled in terms of time and cost if scope is changed such as the school's budget (Steven & Shephearrd, 2009). Furthermore, building performance should be recorded as school maintenance data in an effective manner because this refurbishment will not be the last project in the service life of schools. Therefore, as-built data including drawings and specifications of the refurbishment project should be kept for the future activities.

According to Martino, Giuda, Villa, and Piantanida (2015), there are key areas to focus on when refurbishment project is implemented: energy efficiency, structural strengthening, collecting information on completed works and quality control and so on. To do this, Building Information Modelling (BIM) is introduced to take an advantage of the information sharing, collaboration and coordination amongst stakeholders and should be adopted from the beginning in the refurbishment process (Martino et al., 2015; Ilter & Ergen, 2015; Alwan, 2016). Recent research in BIM and refurbishment states the following aspects as BIM benefits in this area (Ilter & Ergen, 2015):

- building survey and as-built BIM,
- modeling and managing energy,
- design assessment,
- integration of maintenance information and knowledge, assess to the information
- information exchange and interoperability

However, current problems in regard to necessary data set are explored. For example, the data exchange between different BIM tools and reliable BIM objects library with input data sets should be established for

success of refurbishment projects (Kim & Park, 2016). Furthermore, 3D laser scanning produces point clouds to support BIM adoption to reduce time and effort of producing as-built information and the accuracy and reliability of facility management information. Also, Wireless Sensor Network (WSN) is used for collecting actual energy performance data (Huber et al., 2011) (Woo & Menassa, 2014). Integration of 3D laser scanning and BIM has offered new possibilities for capturing, mapping and analysis of building information (Mahdjoubi, Moobela, & Laing, 2013; Volk, Stengel, & Schultmann, 2014). However, there is still a gap in integrating the 3D laser scan data into the BIM environment at the various stages of building surveying, inspection, and monitoring, which may serve as a starting point for further research.

7 Conclusion

In conclusion, school buildings in NZ are in need of sustainable refurbishment to meet requirements of the National school buildings strategy and sustainable development. Previous studies in the past five years provide practical lessons in methodology, data collection, decision-making framework, planning, and implementing, which can assist stakeholders of schools in developing a sustainable refurbishment plan and strategy of school buildings in NZ. Regarding sustainability, environmental impacts can be assessed by LCA tools, while life-cycle cost of the projects can be calculated by LCC analysis. The social aspects should not be neglected in further research. Besides, 3D laser scanning and BIM in refurbishment can benefit the school buildings refurbishment projects in NZ in ways of building survey and information management for future works.

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Predictors of building development cost trend: A New Zealand multi-level analysis

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ABSTRACT

Building project cost management is of critical importance to the profitability of most building projects, many of which have been experiencing chronic problems such as poor cost management, inferior cost performance, and insufficient cost control. Many researchers and professionals have identified these problems as factors that affect the building development cost, and which have not been fully explored. This study aims to identify, examine, and rank factors perceived to influence the building development cost in the New Zealand construction context with respect to their relative significance. A questionnaire survey was conducted in a statistical sample that draws from construction industry professionals in New Zealand.

KEYWORDS: Cost management, building development cost, cost predictors, New Zealand

1 Introduction

Cost management is widely accepted as a vital part of project management (El-Karim, Nawawy, & Abdel-Alim, 2017). A rigorous measurement of cost performance is likely to enhance the implementation of the cost management methods and improve the confidence of clients about their investment in the building projects. The identification of key influencing factors is a critical first step in developing a proper cost measurement framework (Olawale & Sun, 2010). This study aims to identify the key influencing factors of building development cost in New Zealand for improving project cost performance.

The building development cost for a building project is impacted by many factors and is usually linked to several aspects of the project, for example, organisation, industry, and the economy. Very few studies about the identification and evaluation of the influencing factors regarding building development cost have been conducted in the last decade.

To achieve the margin expected from any building construction project, it is necessary to have control of the influencing factors that significantly affect the cost of a building's development. The objective of this study is to identify and rank the relative importance of those influencing factors as perceived by clients, consultants, and contractors as they impact building development cost in New Zealand.

2 Background and literature review

In this study, building development cost is defined as the total building project cost excluding the cost of land (Havard, 2014). Factors influencing building development cost are defined in this study as those factors influencing the building project cost in the context of building construction projects (Bari et al., 2012).

A study on cost has been undertaken by Elinwa and Buba (1993) stated that the factors, such as shortage of resources, material cost fluctuations, and poor contract management, had significant effects on the total cost of a building project in Nigeria. Besides that, Akintoye (2000) has investigated factors affecting project cost estimating in the UK. The results indicated that market requirements and the macro-economic environment in which the building projects operate are the significant influencing factors.

Research on factors affecting a building project cost in Malaysia carried out by Toh et al. (2012) discovered that the most influential factors affecting a building project's cost are the labour cost, market conditions, and the regulatory system.

After examining a high-rise project in Indonesia, Kaming et al. (1997) concluded that the influencing factors for the project's cost included project complexity, project location, inflation, and local regulations. Moreover, the procurement methods used can significantly influence the building development cost as they possibly transfer the risks from the clients to the contractors who might have no knowledge and experience to manage them effectively (Baloi & Price, 2003) or vice versa. Therefore,

conflicts, poor cost performance, and project failure might occur.

In order to address the factors influencing building development cost, a number of studies and research have been undertaken in different countries. Jha and Iyer (2006) have developed a research model for building project success. Regarding cost objectives, they revealed that clients' support and competency, the experience and knowledge of consultants and contractors, communication and interaction among the project participants, and the level of service of suppliers are the key influencing factors for meeting project cost objectives, and thus the project's success.

According to Belassi and Tukel (1996), the rapid-change business environment in which building projects operate would affect significantly the attributes of the project and the means of managing and operating it. Furthermore, the environment can affect the cost of the building project. Again, in a study conducted by Baloi and Price (2003) it is stated that various factors, namely, natural disasters, taxation, the legal system, and political issues pose more challenges to a building project's cost than do many others, particularly in developing countries. This is because building construction projects operate in an environment, not a vacuum. They are inevitably and constantly influenced by, and interacting with, their outer environment. As Warsame (2006) pointed out, macro-economic factors, such as inflation, interest rates, and building consents, can impose heavy costs on building projects.

As indicated by the discussions above, substantial studies and research have been conducted to address the influencing factors of project cost at an international level. In a New Zealand context, very few systematic studies on this issue have been undertaken.

A list of literature

3 Categorizing the influencing factors

The influencing factors identified in the existing literature encompass from specific aspects to more general analytical foundations. In reality, the various influencing factors indicate different dimensions affecting building development cost. Therefore, it is worthwhile identifying the key influencing factors under a comprehensive framework to obtain an improved understanding of their significance on cost. A total of 45 potential factors have been summarized from a literature review to form the foundation of the identification.

Clear grouping of the influencing factors into clusters can ensure their reliability, validity, and relevance. Both

tangible and intangible factors, as far as they can impact the building development cost, should be considered to generate a comprehensive framework including multi-categories or dimensions. To control the project cost properly will be possible when influencing factors have been identified during the process of cost analysis. In order to achieve this goal, collecting and processing data of the influencing factors is necessary.

Some studies have generally considered that building development cost can be affected by multi-dimensional factors which include different dimensions and a range of influencing factors in respect of each dimension. The building project cost can be influenced by an inner layer or internal environment, an operational environment, and an outer layer or a general environment base on which a study has been conducted by (Baloi & Price, 2003). The general environment can be defined in terms of its physical, technological, economic, social and political aspects (Walker, 1996), while the internal environment relates to the resources and management of the building construction project (Smith et al., 1999). Moreover, a broad classification of the influencing factors could be: construction, technical, legal, economic, natural, financial, commercial and political (Flanagan & Norman, 1993; Thompson & Perry, 1992). Additionally, based on the research performed by Warsame (2006), the influencing factors of the project cost can be grouped into four categories: project specific factors, client-contractor related factors, competition and market conditions, and political and macro-economic factors.

In this study, the dimensions of the influencing factors for the building development cost are underpinned by seven perspectives of the existing studies and research as follows. Project component cost including design cost (PCC1), construction cost (PCC2), and procurement cost (PCC3) (Harding et al, 2000; Jaggar et al, 2002).

The factors in the project characteristics group are procedures methods (PCF1), project complexity (PCF2), project location (PCF3), contract types (PCF4), and technology innovations (PCF5). The project stakeholders' influences category involves several factors, namely, clients (PSI1), contractors (PSI2), consultants (PSI3), material suppliers (PSI4), and building officials (PSI5) (Lowe et al, 2006; Picken & Ilozor, 2003).

The factors of the property market and construction industry (PMCI) category — material market (PMCI1), labour market (PMCI2), level of competition (PMCI3), market structure and size (PMCI4), relationship of demand and supply (PMCI5), and boom and bust cycle (PMCI6), housing investment (PMCI7), and housing rental

index (PMCI8)—account for the vital significance of the category (Warsame, 2006).

The statutory and regulatory category includes the regulations and rules related to the construction industry. It is composed of building code and compliance (SRF1), health and safety regulations (SRF2), political policies (SRF3), financial regulation (SRF4), and the construction contract act (SRF5) (Cha & Shin, 2011). The category of national and global dynamics involves factors such as natural forces (NGD1), global political dynamics (NGD2), global business sentiments (NGD3), and global economic trends (NGD4) (Baloi & Price, 2003).

A total of 15 factors are to be found in the socio-economic category, namely, net population growth (SEF1), gross domestic production (SEF2), producer price (SEF3), construction productivity (SEF4), consumer price index (SEF5), energy prices (SEF6), housing prices (SEF7), employment rate (SEF8), exchange rate (SEF9), building consents (SEF10), monetary policy (SEF11), labour cost (SEF12), capital goods price (SEF13), fiscal policies (SEF14), and investors' confidence (SEF15) (Tsai & Yang, 2009).

In brief, these categories collectively explain how building development cost can be impacted at project level, organisation level, market and industry level, and the operational environment level. The national and global dynamic category represents the factors with a relatively low probability of occurrence, but can impose significant effects on the building project cost. Project component cost and project characteristics factor provide the foundation and primary definition of the building project. By learning and gaining an understanding of the interests of the project stakeholders, proper business strategies can be applied to optimally allocate the building project resources, and then to better respond to the changes in the project operating environment. Moreover, the market and industry factor, regulatory factor, national and global dynamics and socio-economic factor describe the business environment in which the building project is carried out.

A primary list of influencing factors was drawn from the literature review. As the influencing factors were selected from a literature survey, it was decided to take these influencing factors to the New Zealand industry professionals as a pilot survey to obtain their feedback re building development cost. The pilot survey helped to refine the list of influencing factors.

Finally, a list totalling 45 influencing factors was prepared. Although the list could scarcely be called elaborate, it covers most of the factors which influence building

development cost. The groups of the influencing factors are shown in Figure 1.

4 Research Methodology

A research paradigm is a research framework which not only includes those philosophical positions adopted but also the methods of inquiring and exploring (Zorpas, 2010). The interpretivist paradigm is suitable for this study. This paradigm has been widely used in the management research field as it supports that the reality is developed by the people involved. Therefore, exploration of the truth or reality should collect the opinions and perceptions of the participants (Fellows & Liu, 2008).

Following this paradigm, the study first confirmed the existing influencing factors for the building development cost by a literature review. Then a questionnaire survey was developed and distributed to the construction industry to collect the opinions of the key professionals about the significance level of the factors. A series of statistical analyses were conducted to identify the critical factors for building development cost in New Zealand.

4.1 Questionnaire design

The questions on the questionnaire had to be simple, clear and understandable for the participants, and easy to be accurately interpreted. The influencing factors for building development cost were identified through a literature review, and then were re-examined, refined and modified by 12 local experts, a total of 45 factors being identified. The participants were requested to rate the influencing factors based on their own experience on building construction projects. The questionnaire required the participants to rank the influencing factors on a five-point Likert-scale.

A questionnaire survey was designed based on the preliminary list of the influencing factors. The questionnaire contains four sections. The first section includes the cover letter which illustrates the objectives and scope of the survey. The second section is the main body of the questionnaire, which requires the opinions or perceptions of the practitioners on the level of effect of the influencing factors on building development cost.

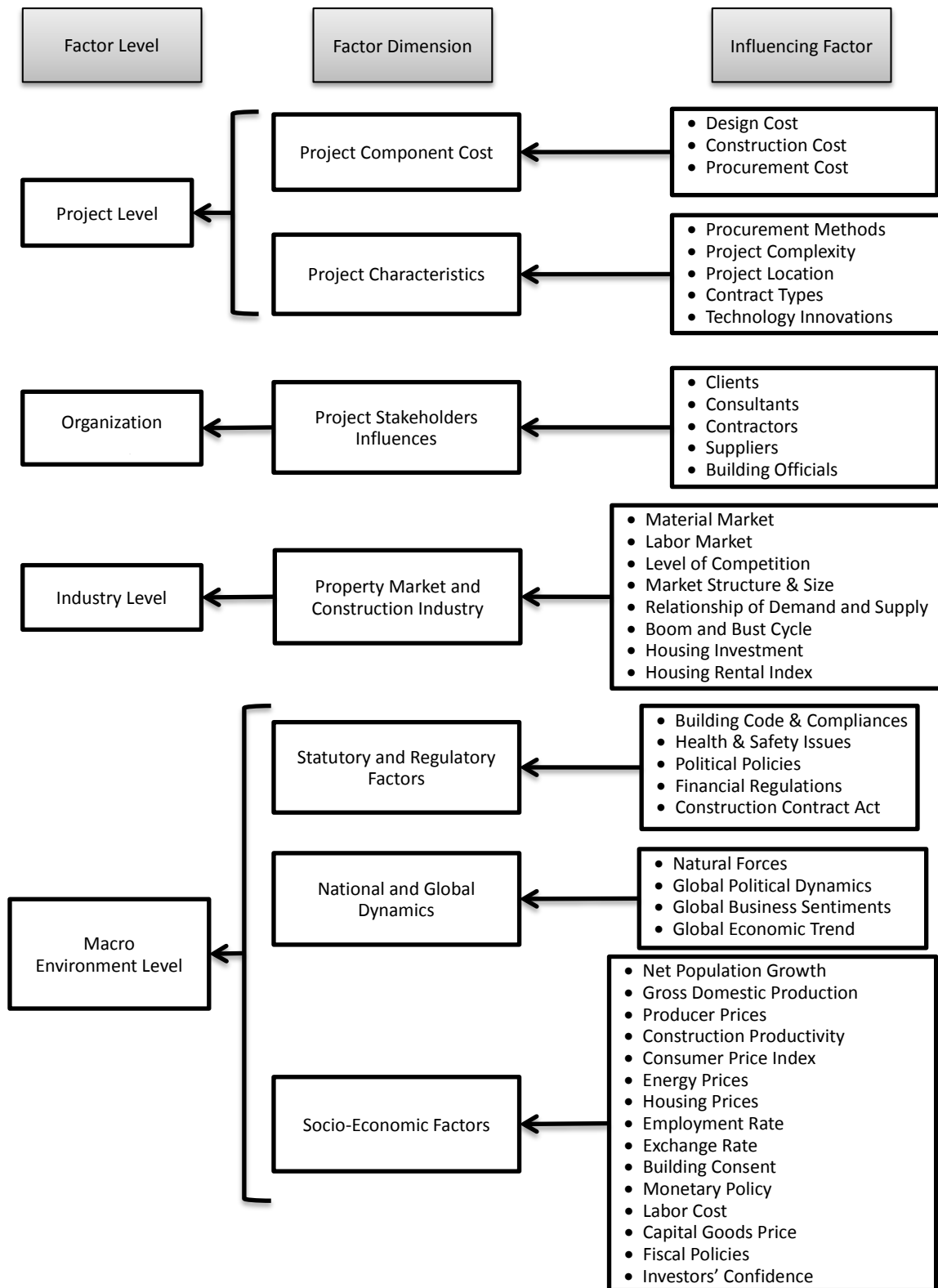


Figure 1 Group the influencing factors

A five-point Likert scale was used to rank the influencing level, namely 1—very weak, 2—weak, 3—medium, 4—strong, 5—very strong. The third section is the demography part regarding the respondents' professional areas, positions, experience, and locations. The final section includes the appreciation and the feedback request.

4.2 Pilot study

A pilot study had been undertaken prior to the questionnaire being distributed. The questionnaire was peer reviewed by two researchers in the same research field. As a result of their feedback, modifications were made. The second stage of the pilot study was tested on ten key professionals from the construction industry who were not among those participating in the questionnaire survey. After that, ambiguities and discrepancies were removed from the questionnaire. The purpose of conducting the pilot study is to validate and enhance the questionnaire in terms of its statements, contents and the format. The questionnaire was improved by including all the suggestions made by the participants.

4.3 Determination and selection of samples

The questionnaire survey collected data from the construction industry professionals including clients, consultants, contractors and project managers. The target population was registered members of institutions and associations.

5 Data analysis

A total of 45 influencing factors in respect of building development cost in New Zealand were determined. The overall factors are categorized into seven major groups as follows: three under the project component cost; five under the project characteristics; five under the project stakeholders' influence; eight under the property market and construction industry; five under the statutory and regulatory factor; four under the national and global dynamics, and 15 under the socio-economic factor. The relative importance index and ranks within the corresponding group, and the overall ranks of the influencing factors, are displayed, discussed and compared with the findings of the previous studies and research.

5.1 Reliability coefficients

Cronbach's alpha can be employed to identify the reliability of the collected questionnaire data. SPSS 23 software package was used to conduct the data analysis, it was found that the Cronbach's alpha for the collected data at 0.907 is greater than the threshold level of 0.7 (Bryman, 2016). Therefore, the collected data gain high internal consistency and reliability at the 5% significance level.

5.2 Factor analysis

In the construction management and economic research field, a factor analysis approach has been widely employed to extract key factors from the correlated variables (Neuman, 2014). Technically, it is an effective technique to reduce the dimension of the variables into a relatively simplified framework that can provide more valuable insights into the influencing factors for the building development cost. The analysis results were displayed in Table 1; the value of KMO is 0.92 which is larger than an acceptable level of 0.5 (Pallant, 2013). Moreover, the Sig value of Bartlett's test is far smaller than 0.05 which indicates that the collected data suit the factor analysis.

Table 1 KMO and Bartlett's test (Source from SPSS)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.92
Bartlett's Test of Sphericity	Chi-Square	6834.738
	df	990
	Sig.	0

The results of the factor analysis were displayed in Table 2. As shown in Table 2, the cumulative variance explained by the key factors is 67.518% which suggests that the vast majority of the variance can be explained by the selected key factors. In the examination and assessment of the attributes and indicators, these key factors are project component cost, project characteristics, project stakeholders' influences, property market and construction industry, statutory and regulatory factor, national and global dynamics and socio-economic factor accordingly.

Table 2 Factor loadings

Group	Factor	Factor loading	Variance explained %	Total variance explained %
PCC	PCC1	0.723	7.812	7.812
	PCC2	0.754		
	PCC3	0.738		
PCF	PCF1	0.785	6.496	14.308
	PCF2	0.808		
	PCF3	0.765		
	PCF4	0.723		
	PCF5	0.699		
PSI	PSI1	0.804	5.968	20.276
	PSI2	0.806		
	PSI3	0.779		
	PSI4	0.762		
	PSI5	0.713		
PMCI	PMCI1	0.819	12.583	32.859
	PMCI2	0.806		
	PMCI3	0.846		
	PMCI4	0.816		
	PMCI5	0.83		
	PMCI6	0.807		
	PMCI7	0.745		
	PMCI8	0.723		
SRF	SRF1	0.743	9.465	42.324
	SRF2	0.749		
	SRF3	0.731		
	SRF4	0.716		
	SRF5	0.743		
NGD	NGD1	0.625	8.511	50.835
	NGD2	0.61		
	NGD3	0.58		
	NGD4	0.638		
SEF	SEF1	0.547	16.683	67.518
	SEF2	0.515		
	SEF3	0.489		
	SEF4	0.52		
	SEF5	0.574		
	SEF6	0.533		
	SEF7	0.571		
	SEF8	0.572		
	SEF9	0.541		
	SEF10	0.513		
	SEF11	0.542		
	SEF12	0.563		
	SEF13	0.544		
	SEF14	0.536		
	SEF15	0.528		

calculate the mean value of the individual indicator. And the formula (2) is used to calculate the relative importance of the influencing factors. Moreover, the formula (3) can be used to calculate the group importance of individual factors.

$$Mean\ value = \sum_{i=1}^5 \frac{n_i}{N} i \quad (1)$$

Where

i is the 5-point Likert-Scale

n_i is the number of respondents that have the same score for the indicator

N is the total number of respondents for the indicator

$$RI = \frac{Mean\ Value}{5} \quad (2)$$

$$GI_t = \frac{\sum_{i=1}^K RI_i^t}{K} \quad (3)$$

Where

t=1, 2, 3 ... 7, number of groups

K is the number of factors in each group

The values of each indicator under the heading of corresponding key factors are shown in Table 3.

5.3 Relative importance of the influencing factors

Furthermore, the formula (1) below was used to

Table 3 Relative importance of the factors

Group	Factor	Mean Value	RI	GI	Group Mean	Important
PCC	Design Cost (PCC1)	3.86	0.772	0.333	0.333	Y
	Construction Cost (PCC2)	3.90	0.780	0.338		Y
	Procurement Cost (PCC3)	3.80	0.760	0.328		N
PCF	Procedures Methods (PCF1)	4.21	0.842	0.209	0.2	Y
	Project Complexity (PCF2)	4.29	0.858	0.213		Y
	Project Location (PCF3)	4.22	0.844	0.210		Y
	Contract Types (PCF4)	3.72	0.744	0.185		N
	Technology Innovations (PCF5)	3.65	0.730	0.182		N
PSI	Clients' Influences (PSI1)	4.12	0.824	0.217	0.2	Y
	Consultants' Influences (PSI2)	4.09	0.818	0.215		Y
	Contractors' Influences (PSI3)	4.08	0.816	0.214		Y
	Suppliers' Influences (PSI4)	3.37	0.674	0.177		N
	Building Officials' Influences (PSI5)	3.36	0.672	0.176		N
PMCI	Material Market (PMCI1)	4.06	0.812	0.130	0.125	Y
	Labour Market (PMCI2)	4.01	0.802	0.129		Y
	Level of Competition (PMCI3)	4.07	0.814	0.131		Y
	Market Structure and Size (PMCI4)	4.04	0.808	0.130		Y
	Relationship of Demand and Supply (PMCI5)	4.06	0.812	0.131		Y
	Boom and Bust Cycle (PMCI6)	4.00	0.800	0.129		Y
	Housing Investment (PMCI7)	3.47	0.694	0.112		N
	Housing Rental Index (PMCI8)	3.41	0.682	0.109		N
SRF	Building Code and Compliance (SRF1)	3.65	0.730	0.203	0.2	Y
	Health and Safety Regulations (SRF2)	3.65	0.730	0.203		Y
	Political Policies (SRF3)	3.56	0.712	0.198		N
	Financial Regulations (SRF4)	3.54	0.708	0.196		N
	Construction Contract Act (SRF5)	3.62	0.724	0.201		Y
NGD	Natural Forces (NGD1)	3.17	0.634	0.253	0.25	Y
	Global Political Dynamics (NGD2)	3.11	0.622	0.248		N
	Global Business Sentiments (NGD3)	3.11	0.622	0.249		N
	Global Economic Trend (NGD4)	3.13	0.626	0.250		Y
SEF	Net Population Growth (SEF1)	3.84	0.768	0.06779	0.06667	Y
	Gross Domestic Production (SEF2)	3.77	0.754	0.06661		N
	Producer Prices (SEF3)	3.79	0.758	0.06691		Y
	Construction Productivity (SEF4)	3.78	0.756	0.06673		Y
	Consumer Price Index (SEF5)	3.75	0.750	0.06620		N
	Energy Prices (SEF6)	3.72	0.744	0.06567		N
	Housing Price (SEF7)	3.77	0.754	0.06661		N
	Employment Rate (SEF8)	3.82	0.764	0.06749		Y
	Exchange Rate (SEF9)	3.74	0.748	0.06603		N
	Building Consent (SEF10)	3.77	0.754	0.06650		N
	Monetary Policy (SEF11)	3.76	0.752	0.06638		N
	Labour Cost (SEF12)	3.78	0.756	0.06673		Y
	Capital Goods Prices (SEF13)	3.81	0.762	0.06732		Y
	Fiscal Policies (SEF14)	3.75	0.750	0.06620		N
	Investor's Confidence (SEF15)	3.79	0.758	0.06685		Y

6 Findings and discussion

The critical factors for the building development cost can be grouped and summarized into seven dimensions: project component cost, project characteristics, project stakeholders' influences, property market and construction industry, statutory and regulatory factors, national and global dynamics, and socio-economic factors. They represent the influencing factors for the building development cost at the level of project, organization, and industry and socio-economics, respectively.

The factor of construction cost (PCC2), with the relative importance index of 0.780, was ranked as the most significant influencing factor for the building development cost in the project component cost category. The second significant factor in this category is design cost (PCC1), with the relative importance level of 0.772. As the construction cost is the main component of the building development cost, it is obvious that the construction cost can significantly influence building development cost in New Zealand. Generally, construction cost accounts for 60-70% of any building development cost (Rodriguez, 2016). Moreover, design fees cannot be ignored, particularly for mega projects (Harding et al, 2000; Jaggar et al, 2002; Lowe et al, 2006). The factor of project complexity (PCF2) in the project characteristics category has been ranked as the most significant influencing factor for building development cost in New Zealand, with the relative importance index of 0.858. This suggests that it has a most significant effect on building development cost in New Zealand. A highly complicated building project adds significant challenges with the impact of its complexity and related factors. According to Bar-Yam (2004), complexity is not just a matter of size, duration or the multiple numbers of parts for a project, but is also the difficulty of deciding on an immediate solution and the difficulty of management in terms of the human, system, and uncertainty aspects. Therefore, project complexity has several possible dimensions that can affect building development cost. These findings agree with the results of the existing findings reported by Shenhar and Dvir (2007) - that complexity is a dynamic state which adds uncertainty to a project and burdens the project with costs. Moreover, a project's location can directly influence building cost through site accessibility, or indirectly impact upon costs through local regulatory requirements. This is consistent with the findings of the research performed by (Lowe et al, 2006). Additionally, procurement methods can affect project cost by transferring potential risks; these, too,

can pose significant challenges for a project's cost, a finding which is supported by Naoum and Mustapha (2000).

The factor of clients' influence has been ranked first in the project stakeholders' influences category, with the relative importance index of 0.824. As addressed by the previous study (Chua, 1999), the satisfaction of the clients is the most vital factor for the stakeholders' management as they can significantly influence the success of the project both directly and indirectly. Moreover, the experiences and knowledge of the consultants and contractors also have significant effects on the project cost, which confirm the results of the study performed by (Cooke-Davies et al, 2011; Flyvbjerg, 2005; Ivory & Alderman, 2005; Remington et al, 2009).

The most significant factor in this category is the level of competition which represents the capacity and limitations of the construction industry and related sectors in New Zealand. As pointed out by the analysis results, this factor provides the boundaries of the construction products. In addition, the boom and bust cycle and the relationship of demand and supply signify the economic cyclic effects on the construction industry. Moreover, the materials market basically refers to the resource market situation, which can influence the supply side of construction products, thus imposing effects – good or bad - on building development cost. The identification of these indicators is consistent with the previous study (Shenhar, 2001; Shenhar & Dvir, 2007).

Specifically, the factors of building code and compliances (SRF1) and health and safety regulations (SRF2) have the relative importance level of 0.73, which suggests that changes in the building code and compliance and health and safety issues can impose significant effects on New Zealand's building development cost (Levin & Ward, 2011). The high rating in respect of the factor of the construction contract act might be due to the fact that intricate business relationships are managed by contract. An understanding of the fundamental rules and practices in contract administration is essential for key industry professionals (Shi et al, 2014).

The factor of natural forces (NGD1) was ranked first in this category, with the relative importance index of 0.634. This finding substantiates the results yield by MBIE (2013), whose study identified that natural forces like the Christchurch earthquake are one of the main drivers for housing development in New Zealand as the sudden shortage of shelter drives up housing demand and prices. The factors of net population growth (SEF1) and

employment rate (SEF8) were ranked first and second in this category. This finding is supported by the previous study (NZIER, 2014) which suggested that the increasing population and incomes would drive up the demand for housing, and that the income surplus can also be invested into the housing market to obtain more interest than from savings in the bank.

7 Conclusion

To improve cost performance and management of building projects, the influencing factors of building development cost should be identified and recognised as important. This study has identified, and then ranked by way of a relative importance index, 45 factors considered to influence building development cost in New Zealand. Furthermore, the study has determined the level of effect of those factors which have been grouped into seven categories: project component cost, project characteristics, project stakeholders' influences, the property market and construction industry factor, the statutory and regulatory factor, national and global dynamics, and the socio-economic factor.

This study surveyed key industry professionals, identified 26 influencing factors out of the 45 potential influencing factors based on the relative importance index, generated in accordance with the views of the industry practitioners.

The findings of this study suggest that the project cost does not merely depend on the three components of capital construction cost, associated capital cost, client-related cost. It also depends on other measures.

The outcomes of this study are in line with previous studies and research. In the light of the findings, it is recommended that these factors should be seriously taken into account when conducting project cost estimating, and project cost management and control.

The outcome of this study can help in improving project cost performance by focusing and acting upon the most significant influencing factors for building development cost in New Zealand. The findings will be of value to enhance project cost performance in the construction industry, and thus improve the whole project performance. Furthermore, researchers can use the results of this study as a foundation for further research in modelling the building development cost by using any advanced techniques, i.e. structural equation modelling. Also, the findings can be used for further research modelling the relationship between the key influencing factors and the building development cost in New Zealand's construction industry.

The research findings can be used by not only local but also international industry professionals who are interested in investing in potential projects, but have little knowledge of the construction industry in New Zealand. Moreover, the findings can widen and deepen the practitioners' opinions and perspectives on the influencing factors for building development cost and guide the professionals towards more efficient cost management.

Although some studies and research have been conducted to explore the influencing factors of building development cost, they seem to tabulate individual influencing factors rather than categorising the influencing factors based on several criteria. Moreover, in regard to the construction industry, studies and research have been undertaken to investigate the influencing factors of building development cost, but few have empirically evaluated the level of effect of the influencing factors. Some studies have provided the significance level of the influencing factors. However, the focus of the studies and research has not evaluated or examined the influencing factors comprehensively.

As the previous analysis suggests, different stakeholders might have different or even conflicting perceptions or opinions on the level of effect of the influencing factors. Evaluation of their different perceptions to balance their interest and enhance their understanding and collaboration should be undertaken in the future.

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Evaluating the Perception of Small-to-Medium-size-Enterprises on Eleven Influential factors of Preparedness Decisions

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ABSTRACT

Small to Medium size Enterprises (SMEs) take up a major share of economic strains after an earthquake disaster. Therefore, SMEs are expected to make critical decisions to be prepared for a potential earthquake. Their preparedness decisions can be greatly affected by their perception about the efficacy of the preparedness actions. This study utilises a quantitative approach to investigate the perception of SMEs in three distinct cities of New Zealand about the importance of eleven particular factors that have been known to affect the preparatory decisions of businesses. The results have revealed a significant reliance on insurance coverage and regulations to take the preparedness actions.

1 Introduction

Earthquakes have posed problems for New Zealand, her inhabitants, economy and dwellings. In order to address qualities such as preparedness in the face of adversity, it has been a point of interest to explore the perceptions of those who are affected about the required actions. According to Hamilton et al. (2011), mitigating actions taken before the occurrence of an earthquake are of two types, pre-disaster actions to minimise damage, and post-disaster actions taken to respond the difficulties that follow the disaster. The pre-disaster actions enable communities to have a lower demand for emergency services following a seismic event (Becker et al. 2012). This, in turn, could liberate valuable resources used for the emergency response in affected areas (Sadiq, 2011).

The process of putting a preparedness measure into practice tends to follow the stages of “intention formation”, “decision-making” and lastly “implementation” (T. K. Egbelakin, 2013). A deep understanding of the decision-making stage takes involving analysis and reasoning of why a particular earthquake preparedness measure may be preferred over another. To find out how the enterprises perceive these actions would open up a discourse on the influential factors and hence the relevant areas of policymaking.

Limited research on how SMEs make decisions to select preparedness actions in earthquake resilience exist. This study directly looks at this decision-making stage in the context of New Zealand and goes about identifying their

perception about the importance of eleven factors that can affect their decisions. The factors investigated include but are not limited to availability of insurance, availability of various resources, compliance with existing regulations, as well as the status of relationships between enterprise stakeholders.

The study is quantitative-based, and data is collected from three prominent cities of New Zealand that include Auckland, Napier and Dunedin. This selection covers varying levels of seismic risk. Hence, the study can shed light on the mechanisms underlying decision-making process of selecting earthquake preparedness actions. A better understanding of this process can ultimately improve national performance in facing earthquake adversity.

2 SMEs and the Preparedness Actions

An SME is defined as an enterprise employing the services of fewer than 50 employees (MBIENZ, 2016). In New Zealand’s 97% of enterprises are categorised as SMEs that employ 30% of the Nation’s workforce. They contribute to 28% of the national GDP (Institute of Directors, 2016). Therefore, in the event of a catastrophic seismic event, the way in which SMEs respond can have significant consequences on the national economy. Carlson et al. (2012) assert that the resilience of a smaller unit (in this case an SME) is a good representation of the all-encompassing community’s resolve. A summary of the existing literature on the potential preparedness actions

of businesses is summarised in Table 1. The table gives a range of 21 preparedness actions which are compiled by amalgamating existing research conducted by Michael K. Lindell (1994), Mileti and Darlington (1997), J. Mulilis and Lippa (1990), Russell, Goltz, and Bourque (1995), and Turner, Nigg, and Paz (1986). The actions are divided into four broad categories.

3 Factors that affect decisions about businesses preparedness actions

It has been found that several factors can affect the decisions made by businesses in the context of earthquake preparedness (Bostrom, Turaga, & Ponomariov, 2006; Michael K. Lindell et al., 1997). They include but are not limited to the business characteristics such as its size, age, location, ownership, type and the industry sector. For example, a large business with a high number of full-time employees is likely to be more financially secure in comparison to a smaller one and consequently would have a more comfortable buffer in the event of a significant disaster (Chang & Falit-Baiamonte, 2002; Rose et al., 2007). Similarly, more mature businesses will likely have substantial contingency plans than younger ones (Drabek, 1991). The location of a business is also a major factor, which greatly affects a business' exposure to risk. In New Zealand, a majority of SMEs are leaseholders that are found settling in earthquake-prone buildings. These types of buildings typically adhere to less than 34% of the new building regulations, and so are prone to earthquake risk (Murphy, 2017). Businesses in insurance sector typically demonstrate a higher level of earthquake preparedness (J. M. Dahlhamer & D'Souza, 1997; Kroll, Landis, Shen, & Stryker, 1991; Tierney, Lindell, & Perry, 2001).

In addition to the factors above, the decisions made by the businesses can be attributed to the personal background of the decision-makers. Their outlook on risk and previous exposure to a disaster can likely influence their actions (Han & Nigg, 2011; Pennings & Grossman, 2008; Rossetto,

Joffe, & Solberg, 2011; Slovic, 1987; Tierney et al., 2001). The level of efficacy perceived for each preparedness action can also affect their adoption (T. K. Egbelakin, 2013; Michael K. Lindell, Arlikatti, & Prater, 2009; J. P. Mulilis & Duval, 1995). This perception is found to be correlated with knowledge, skills and financial status of the decision-makers (Arma & Avram, 2008; Bandura, 2010; Johnston et al., 2005; M. K. Lindell & Perry, 2004; Paton, 2003).

It has also been found that the benefits perceived to be gained from adopting a preparedness action can be another influential factor in the decisions made by SMEs (Michael K. Lindell et al., 2009; Tien, 2000). These benefits include safety-related advantages such as an increased likelihood in the preservation of life post-disaster, or financial-related advantages such as an increase in the valuation of the property (Anthony, Wood, & Holmes, 2007; Rose et al., 2007).

Building codes and regulations are other factors known to be influential on the preparedness decisions of SMEs (May, 2001). The main focus of such regulations is on minimising casualties, infrastructure damage and general upheaval caused by a disaster. The Public Act No 70 (2015) is an example of the regulations that promote a higher level of preparedness.

Besides the regulatory mechanisms, insurers are known as a pivotal player of adopting preparedness actions (Michael K. Lindell et al., 1997; Petak, 2002). They have a legal obligation to safeguard the property and running the business after an earthquake (T. K. Egbelakin, 2013). Numerous insurance packages are offered to businesses that include life, contents, property and worker compensation (Athavale & Avila, 2011; R. Palm, Hodgson, Blanchard, & Lyons, 1990). However, the money owed by a business in return for these services results in a spike in the expenses needed to run it (De Mel, McKenzie, & Woodruff, 2012). Thus, the perception of a business unit about the insurers and their insurance policy can affect the decisions about undertaking a certain preparedness action.

Table 1: Four broad groups of earthquake preparedness measures and their corresponding actions

Group 1. Enriching Preparedness and Awareness about the Earthquake Risk		Group 2. Insurance and Business Continuity Plans		Group 3. Business Survival Actions		Group 4. Structural and Non-Structural Retrofit Measures	
No	Measures	No	Measures	No	Measures	No	Measures
1	Received written information on earthquake preparedness	6	Purchased business contents insurance	11	Obtained a first aid kit, extra medical supplies	16	Ensured a backup of computer and electronic data
2	Discussed with employees about earthquakes	7	Purchased business interruption insurance	12	Stored water and canned food	17	An engineer conducted a seismic assessment of the building
3	Attended a first aid course	8	Purchased earthquake insurance to cover damage to building	13	Stored extra fuel or batteries	18	Braced shelves, cabinets or objects
4	Conducted earthquake drills or exercises for the employees	9	Developed a business disaster recovery plan	14	Arranged a business relocation plan in case of an Earthquake	19	Heavy objects are stored on the floor
5	Supported earthquake preparedness or training programs for employees	10	Developed a business emergency plan for event of earthquake	15	Obtained an emergency generator for power failure	20	Business records and supplies are secured
						21	The building is retrofitted to a higher seismic performance

4 Research Method

This study used a quantitative method to analyse the perspectives of SMEs about the importance of different factors that may affect adoption of the preparedness actions. More specifically, a survey was employed rather than an experimental design. Experimental designs are largely associated with lab experiments (Dillman, Smyth, & Christian, 2014). On account of the complexity in modelling a human decision-making process, especially with regard to earthquake preparedness, the survey method was the preferred route. Surveys have been the most utilised method for studies with a similar scope.

The survey aimed to collect information about the perception of the members of SMEs. Samples for the survey were collected from three cities of New Zealand with differing levels of seismic risk. Auckland and Dunedin have been identified as areas carrying a low seismic risk factor (an index of how likely and how severe a seismic event may occur). Contrastingly, Napier is allocated a high seismic risk factor.

Data collection was done through an online questionnaire.

This is a particularly cost-efficient method used to collect data in the case of large sample sizes spread over multiple locations. Questionnaires have the added advantage of eliminating interviewer bias in the data collection process and give survey participants adequate time to answer the questions (Kothari, 2004). The questions involved the demographics of the participants along with their opinion about the importance of the eleven factors listed in **Table 2**. As discussed, in the first part of the questionnaire the survey recorded the socio-demographic profiles of the participants. This explored characteristics such as the number of full-time employees enlisted by businesses. The main question was formulated to be close-ended so that the results could be meaningful and easy for pattern analysis. Accordingly, the answers were made quantifiable for ease of analysis. A five-point Likert score was used for the survey participants to indicate their answers (including a neutral answer). The terminologies used in the questionnaire were standardised so that it was ensured all participants could clearly understand all phrasings. Moreover, the drafted survey was pre-tested to

ascertain the appropriateness of the questionnaire wordings.

The questions were also designed to follow a logical order so that participants could answer appropriately (McGuirk & O'Neill, 2005). Each section of the questionnaire carried headings and descriptors for further clarity, while an uncomplicated level of language was maintained throughout.

Table 2 presents a list of eleven factors that was presented to the respondents.

Table 2: List of the survey questions

No.	The corresponding item in the survey questionnaire
1	Availability of information about disaster preparedness initiatives
2	Access to staff with technical skills for disasters
3	Time required for implementation
4	Cost of implementation
5	Materials and equipment required
6	Potential losses adequately covered by insurance
7	Potential loss of lives
8	Potential to increase property value after seismic retrofitting of the building
9	Compliance with business, safety, and health regulations
10	Difficulty with insurance
11	Potential losses adequately covered by disaster relief grant

5 Results: Analysis and Discussion

A majority of the participants from each city were part of small enterprises, with 75%, 85% and 82% of survey participants being part of enterprises with ten or fewer employees in Auckland, Dunedin and Napier respectively. Only a fraction of participants (6% from Auckland and 5% from Napier) stated they employed more than 50 employees and hence, by definition, could not be categorised as SMEs. The data associated with these participants were excluded from the study's analysis. Most businesses with an operational age between six and ten years were found in Auckland, while younger ones (under six years) were located in both Dunedin and Auckland.

Table 3 details a ranking of the influential factors of preparedness decisions as seen by the survey participants. As stated, each factor was allocated a score from 1 to 5 (with increasing importance) in the survey. A final weighted score for each factor was found by averaging all the responses from each respective city.

Table 3: Weighted scores and ranking of the factors in the investigated cities

Items	Auckland		Dunedin		Napier	
	Rank	Score	Rank	Score	Rank	Score
Potential losses adequately covered by insurance	1	4.13	1	4.46	1	4.52
Compliance with health and safety, business, and building regulations	2	3.91	2	4.26	2	4.21
Cost of implementation	3	3.87	3	4.06	8	3.82
Time required for implementation	4	3.87	5	3.73	7	3.83
Difficulty with insurance	5	3.86	4	3.86	3	4.12
Availability of information about disaster preparedness initiatives	6	3.83	6	3.71	6	3.93
Potential losses adequately covered by disaster relief grant	7	3.71	8	3.55	4	4.04
Potential to increase property value after seismic retrofitting of the building	8	3.67	11	3.21	5	4
Potential loss of Lives	9	3.58	9	3.44	9	3.8
Materials and equipment required	10	3.43	7	3.68	10	3.67
Access to staff with technical skills for disasters	11	3.09	10	3.38	11	3.52

Among the three datasets recorded, Napier demonstrated the highest median and mean weighted scores (Table 4). It reflects a higher concern by SMEs about being prepared for a potential earthquake in this city. It can be associated with the past experience of the respondents and the geographical location of Napier that exposes the city to a

higher seismic risk.

Table 4: Descriptive statistics of the weighted scores of the decision-making factors

Statistics	Auckland	Dunedin	Napier
Median	3.83	3.71	3.93
Mean	3.72	3.76	3.95
Standard Error	0.084	0.114	0.082
Standard Deviation	0.280	0.380	0.274
Sample Variance	0.078	0.144	0.075
Kurtosis	1.74	-0.32	0.79
Skewness	-1.10	0.53	0.58
Range	1.04	1.25	1
Minimum	3.09	3.21	3.52
Maximum	4.13	4.46	4.52
Confidence Level (95.0%)	0.19	0.25	0.18

An ANOVA test was conducted, which approved the homogeneity of the three datasets collected. Therefore, the datasets were not significantly different to each other and could be combined into one.

Table 5 details the overall weighted scores of the eleven factors based on the combined datasets.

Table 5: Overall weighted scores and ranking of the items

Items	Overall Rank	Weighted average score
Potential losses adequately covered by insurance	1	4.40
Compliance with health and safety, business and building regulations	2	4.16
Cost of implementation	3	3.95
Difficulty with insurance	4	3.93
Availability of information about disaster preparedness initiatives	5	3.80
Time required for implementation	6	3.79
Potential losses adequately covered by disaster relief grant	7	3.72
Materials and equipment required	8	3.62
Potential loss of lives	9	3.58
Potential to increase property value after seismic retrofitting of the building	10	3.54
Access to staff with technical skills for disasters	11	3.34

The factor that singled out as the most influential on adopting the preparedness actions was related to *insurance and its coverage*. Nearly 92% of survey participants seemed to regard the insurance coverage as a very important factor in their preparatory decisions. It was the same across all three cities investigated. It is not an unexpected outcome, as the research conducted by Kunreuther et al. (1978), F. D. Davis (1989), Garcia (1989), R. Palm et al. (1990), R. Palm and Hodgson (1992), R. I. Palm (1995), Michael K. Lindell et al. (2009) and others have shown the same tendency among businesses. Insured units can recover from a significant disaster and

resume normal proceedings swiftly (M. S. Davis, 1989; R. Palm et al., 1990; Wang, Lin, & Walker, 2009) and hence insurance stands to directly help an SME's economic, property and personal plights brought on by an earthquake (Brown, Seville, & Vargo, 2013; Ding & Hu, 2014).

The second highest rated factor of the preparatory decisions of SMEs in the three cities investigated was the *compliance with building, health, and safety regulations*. It received an overall weighted score of 4.16 (Table 5). Almost 84% of the participants in the integrated datasets rated this item as an important to very important factor influencing their decisions. This high importance perceived by SMEs can be related to the influence of state mandate that in turn demonstrates a high potential for an active participation from the community in policy development and adoption (Burby, Salvesen, & Creed, 2006; Comerio, 2004; May, 2001; Prater & Lindell, 2000). The *cost of implementation* was rated as the third important factor that may affect the decisions on adopting preparedness actions. Around 78% of the respondents identified this item as an important to very important factor. The weighted average score for this factor was 3.95 (Table 5). Previous studies have discussed a positive correlation between the size of an enterprise and its financial capability (Bradley, Dhakal, Cubrinovski, & MacRae, 2008; Chang & Falit-Baiamonte, 2002; Rose et al., 2007). Accordingly, by definition SMEs are expected to be associated with tighter financial constraints. This may account for the relatively high importance given to the implementation costs. The age of the business can be another contributor to the rank scored by this factor. Approximately, 30% of the businesses investigated had an operational age of fewer than six years. Inexperienced businesses tend to have inadequate financial security in developing preparedness actions (J. Dahlhamer & Tierney, 1998).

The *difficulty with insurance* scored the next rank on the list of importance (Table 5). Close to 73% of the participants recognised this item as either an important or a very important item. It can be related to a local situation in which the businesses sometimes face insurers that assess their building as uninsurable or associate it with a high uneconomical price (T. K. Egbelakin, 2013).

The *availability of information* about disaster preparedness actions was the next that was ranked as an important item with a weighted score of 3.8 (Table 5). It suggests that SMEs are ready to have proper access and exposure to reliable and effective earthquake preparedness information. Less technical, inexpensive,

sources of information that are convenient to use, such as do-it-yourself workbooks, can be useful supplies in this regard (T. Egbelakin, Rabel, Wilkinson, Ingham, & Rasheed, 2016).

From the remaining six factors, three were related to supply and their repercussions on the preparatory decision-making (Table 5). The *time, materials and equipment* required along with the *access to staff with technical skills* scored ranks between neutral and important. Having fewer full-time staff members, SMEs may have fewer agents to delegate towards affairs of preparedness actions (Chang & Falit-Baiamonte, 2002; J. M. Dahlhamer & D'Souza, 1997; T. Egbelakin et al., 2016). Other factors that were perceived as of lesser importance included *disaster relief grants provided by the government*, *the potential to increase property value after seismic retrofitting of the building*, and the *potential loss of lives*. It indicates a little reliance on government funding in making preparatory decisions. With a majority of the survey respondents being tenants of their places of operation, it is not of a surprise that less importance was given to the increase of the property value. Webb, Tierney, and Dahlhamer (2000) had also observed the same attitude among businesses in the US. The percentage of respondents who ranked *the potential for loss of life* as a very important factor in their preparatory decisions was around 16% that was the minimum among all factors investigated.

6 A tendency to transfer the responsibility to authorities outside the enterprises

A review of the results indicates that the people who were running the businesses in SMEs demonstrated a tendency towards transferring the risk mitigation responsibility to other stakeholders. The former studies conducted by Fowler, Kling, and Larson (2007), Tierney et al. (2001) had reported the business decision makers as typically ignorant about the importance of their contribution to disaster resilience, which affects their intention and decisions in adopting preparedness measures. The respondents of this study also selected two items that were transferring the risk to the insurance company and the regulatory system as their top choices, which can re-confirm the findings of preparedness in US context.

7 Conclusion

The adoption of earthquake preparedness actions can be related to three successive stages: intention formation; analysis and decision-making; and implementation. The focus of this study was on the second stage. It included the appraisal the perception of SMEs about eleven key factors found to be influential on the preparatory decisions in

previous studies. A quantitative approach was utilised that carried out a survey. The survey provided quantifiable results that enabled the statistical characterisation of the responses. The respondents showed the highest concern about the insurance coverage of the potential losses, compliance with health and safety, business, and building regulations, and the cost of implementation. The two factors with the highest rank can indicate a propensity among the SMEs to transfer the responsibility of seismic risk mitigation solutions to the authorities outside their enterprises. At the same time, it can be translated to a higher trust in insurance companies rather the governmental supports. The monetary concern was likewise found to have an imperative part in the choices made by the SMEs. Resource-wise they gave the highest priority to the cost of implementation that is a financial-related item. From a benefit perception point of view, they prioritised safety over financial benefits.

The research, however, has some limitations that may serve as a basis for future research. First, the study included a restricted geographical scope. It could bias the study results. Further research should secure larger samples in a wider scope before generalising the research results. Second, most of the respondents were from units with less than ten employees. A higher balance between the respondents from small businesses and those from medium business sizes should be established in the future research. Third, the study focused on only eleven items conveying the perception of SMEs about the risk mitigation measures. Further research can involve additional factors, particularly the potential role of monetary policies and incentives.

Acknowledgements

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Prefab timber panels - A study to investigate the potential of export trade

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ABSTRACT

New Zealand's timber availability is projected to increase to 35m³ by early 2020s. This will require marketing additional 7m³ of timber logs. According to New Zealand Forest Owners Association, it is observed that more than 53% of country's timber logs are exported to different countries. Export of prefab timber panels in place of timber logs, can increase the domestic wood processing business and at the same time there will be an increase in export of value-added products. This study aims at reviewing the export potential of prefabricated panels used to create packaged houses to promote business and economic activities.

1 Introduction

New Zealand is one of the largest timber exporter of the world, however most of the timber is exported in form of raw timber logs. At the same time, New Zealand construction industry has not yet fully realised the potential benefits of prefabrication technology. The focus of this study is to explore the potential of exporting the prefabricated timber panels instead of raw timber logs to the global market. The study aims at investigating the business and economic activity generated for New Zealand if the country's timber industry finds a space for prefabricated panels in the global market.

The term prefabrication is often abbreviated as 'Prefab'. There are varied definitions for the single term Prefab, and few misunderstand prefab as some flimsy and non-sturdy means of construction. Prefabrication suffers from historical misperceptions such as low-quality, poor and one-size-fits-all construction (Hart, 2003). These misperceptions have been a major historical impediment to consumer's acceptance and subsequent commercial success (Craig, Laing, & Edge, 2000).

A simple understanding of prefabrication is, anything that is manufactured away from the project site and is later transported to site for assembly/erection. Prefabrication is a system or process, not a product. This distinction is where much of the confusion and misperception about prefabrication lies (Bell, 2009). Prefabrication can be viewed as a system to bundle products and services and pre-package them for delivery to clients. It can be interpreted as both a literal construction process and as a systems-based approach for delivering housing (Bell,

2009). Prefabricated construction can be classified into five broad categories: (1) components; are pre-cut, pre-sized, pre-shaped elements of a structure that are manufactured in factories and assembled on site, (2) panels; are manufactured elements of a structure that form the building envelop, (3) modules; are manufactured 3D structural components in shape of a box, (4) hybrid prefab; is a combination of panelised prefab and modular prefab and (5) whole building prefab; is a complete building manufactured in a factory that is later transported on project site for its erection on foundations (Shahzad, 2016).

Prefabrication can potentially offer more benefits for less resources, that is prefabrication can offer better quality construction for less time on site, more known and definite project outcomes and less uncertain outcomes, and potentially more energy efficiency for less resource utilisation (Bell, 2009).

Improvement in quality of output product is regarded as the principal advantage of prefabricated construction (Cook, 2005). Improved co-ordination between project team, material, automation, use of machines and factory controlled conditions contribute to the better-quality product.

Key findings of the McGraw-Hill construction smart market report 'Prefabrication and Modularisation' (2011) showed the following productivity improvements from the architecture, engineering and construction professionals surveyed:

- 66% decrease in time (35% by 4 weeks or more)
- 65% decrease in cost (41% by 6% or more)
- 77% decrease in site waste (44% by 5% or more)

- 98% expect to be using some prefabrication on some projects in next two years

The growing demand for packaged products and service delivery is blurring the traditional boundaries between manufacturing, design, construction and service sectors (Gann, 1996).

The aim of this paper is to review the export potential of prefabricated timber panels used to create kit set homes/package houses.

1.1 Research Objectives

Specific objectives of this research include:

1. Review the potential of exporting prefabricated timber panels to outside of New Zealand instead of current export of raw timber logs.
2. Explore the demand of New Zealand made Prefabricated Timber Panels outside the country.
3. To identify factors responsible for constraining the export of Prefabricated Timber Panels.

1.2 Research Method

This paper is based on the review of existing literature relevant to the timber's export potential and prefabrication technology. Review of books, academic journals, industry and government reports was carried out. Most of the information for this research has been acquired from reports published by New Zealand Forest Owners Association (NZFOA), Ministry of Agriculture and Forestry (MAF), New Zealand construction industry and PrefabNZ. These publications have guided the understanding of export potential of timber panels and how New Zealand timber panels can reach the global market, overcoming the current constraints.

2 Literature Review

2.1 Prefabricated houses as an industrialized consumption good

"Standardization and pre-assembly within construction industry has been proven to be successful in some projects including Hong Kong airport and much modern hotel construction" (Craig et al., 2000).

Laing et. al. (2001) claims that standardizing the construction process can create value for the consumers, which is one of the essential goals of marketers.

Aladdin Ready-Cut Houses, founded in 1906, was the first

company to offer a true "Kit" house composed of pre-cut, numbered pieces. But the first and most notable company to offer houses by mail was Sears, Roebuck & Co., which sold houses through its catalogue and sales offices to nearly 100,000 clients between 1908 and 1940. Priced from \$650 to \$2500, each house was delivered by mail, the kit included lumber, nails, shingles, windows, doors, hardware, and house paint (and instructions to assemble). The affordable cost and ease of construction made home ownership a real possibility for blue collar workers. It was Sears' goal to make acquiring a house as easy as buying a stove or chair. Their concept of packaging and shipping high-quality pre-cut materials and precise instructions directly to the buyer was sound. The volume of homes sold allowed sears to maintain flexibility and offer its clientele a wide variety of designs. Its skilful marketing strategy convinced thousands of Americans that a Sears house would offer them the comfort and security of their dreams (Arieff & Burkhart, 2002). Decision making process of purchasing prefabricated houses involve a lot of time, effort, and participation (Koklič & Vida, 2009). As price is used as an indicator of quality by consumers, prefabricated houses being less costly than traditional houses are often perceived as of being a less quality product (Cooke & Friedman, 2001).

Quality is one of the prime factors that is disturbing the buyers when considering purchasing a prefabricated house. Unfortunately, prefabricated houses are thought to have less quality when compared to that of traditional on-site houses.

Many marketing studies have been made by various organizations with the purpose of determining what style and design of house the industry should produce. In summary, apart from geographical differences in architecture, they point to the free standing, three bedroom house, with amenities that promise to keep it a marketable security for at least as many years as are required to pay off the mortgage on it (Wittausch, 1948). The processes of traditional and industrialized construction are quite different.

2.2 Potential benefits of prefabrication to be realized by New Zealand

In the United States, a third of all single-family residences are manufactured houses, and the other two-thirds are built on-site mainly from industrial components made in factories. Prefabrication, whether total or partial, "is central to the modern housing industry" (Rybczynski, 2009).

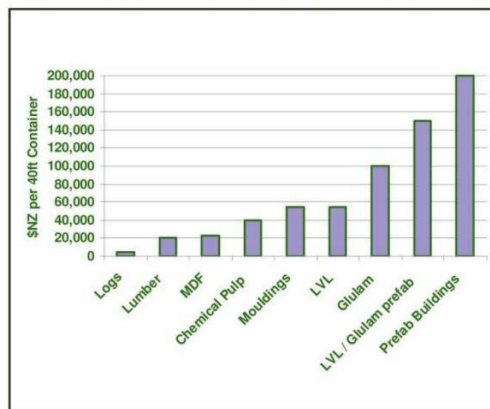
Secondary processed wood products - builder's

carpentry and joinery, mouldings and millwork, wooden furniture, and prefabricated buildings - have grown significantly in importance in the global trade of wood products (Turner, Buongiorno, Zhu, & Maplesden, 2008). By industrialising the production of houses, it implies that New Zealand with more availability of timber, can industrialise the prefabrication production and potentially trade with different countries.

In a Ted Talk by Pamela Bell, the CEO of the PrefabNZ addressed one of the potential benefits of Prefabrication. The potential to capture jobs in export dollars is missed by exporting timber logs as “just logs”.

Prefabrication of the raw timber logs can not only turn it into a value-added product but can also provide more jobs and skills required which in turn can develop the economy of this country. The raw logs are processed into panels for prefabricated homes, more value is added for their export. There are various export opportunities for value added wood products (see Figure 1).

Export opportunities in Value-Added Wood Products:



Source: Pine Manufacturers Association

Figure 1: EXPORT OPPURTUNITIES IN VALUE-ADDED WOOD PRODUCTS (PrefabNZ, 2012)

“Lately timber producing countries are severely curtailing log exports to stimulate wood processing at home. This force wood-based enterprises in Japan and other log importing countries to identify, evaluate and implement several adjustment strategies for their survival. It also implies significant industry realignment and new competitive relationships for the timber companies in Indonesia, Malaysia and Philippines”(Laarman, 1984).

2.3 History of prefabrication and industrialized pre-cut buildings in New Zealand

New Zealand’s most familiar colonial house, the treaty house, was bought by James Busby from Sydney to Waitangi in 1833 as a pre-cut frame with fittings and most

materials. Other notable early prefabs include the Auckland Governor’s house, Chief Justice Martin’s house at Judges Bay and a number of ready-made houses that were shipped from England and France to Canterbury (Bell & Southcombe, 2012).

In the early 1900s, the New Zealand Railways Department was the first and largest producer of prefabricated housing. They used standard planning, together with a kitset of pre-cut and numbered timber components. A factory was established in the early 1920s at Frankton, the largest rail junction in the country. This factory could produce components for a house in a day and a half, which were then transported by rail around the North Island for assembly at site by just two people in two weeks’ time (Bell & Southcombe, 2012).

In the late 1960s Industrialized Building Systems (IBS) began under the leadership of entrepreneurial Palmerston North property developer Keith Clark. The IBS team ambitiously planned for three separate associations in New Zealand and six in Australia with each factory forecast to produce 1200 homes per annum, or 25 homes per week (Bell & Southcombe, 2012).

There are very few examples of historical prefab housing systems still in production and prefab housing companies that remain in business today, despite many heroic attempts. There are three main reasons for this; macroeconomic factors such as the 1978 recession, design and manufacture shortcomings that didn’t allow for enough customization to meet the changing client demands, and sociocultural issues around communication and marketing.

An overall lack of financing, marketing and customer awareness has caused the demise of many prefab business and the loss of many innovative systems to the construction industry (Bell & Southcombe, 2012).

2.4 Timber trade, employment and exports of New Zealand

The current growth in forest harvests has been brought about by the steady rate of planting that took place from 1980 to mid-1990. These new plantings have started to reach maturity, which has given rise to increased wood availability. Based on national yield tables, it is estimated that between 2007 and 2012, the volume of standing timber in age classes 26 years and older increased by approximately 7.1 million cubic metres. This has contributed to the rise in harvests from 20.3 million cubic metres in 2007 to 27.5 million cubic metres in 2012 (MAF, 2013). This increase was predicted since at least as early as 2000 (MAF, 2000), but there has been limited interest

in processing this resource domestically. Faced with limited domestic demand, forest growers took advantage of opportunities offshore (A. Katz, 2013).

The growth in New Zealand log export has been steadily increasing from 2007-2012 (see Figure 2 and 3).

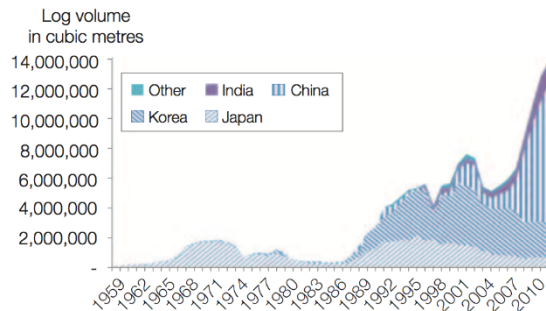


Figure 2: Volume of log exports from New Zealand – 1959 to 2012
Source: www.stats.govt.nz

Source: (Evison, 2013)

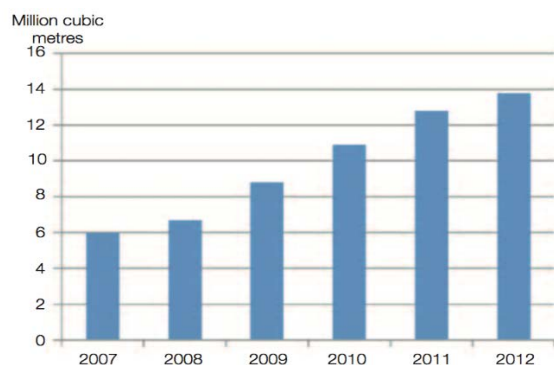


Figure 3: GROWTH IN NEW ZEALAND LOG EXPORT, Source:(A. Katz, 2013)

Currently New Zealand exports half of its forest harvest as timber logs (MAF, 2012).

According to Ministry of Primary Industries New Zealand (MPI) and Forest Owners Association (FOA) New Zealand the log flow in the New Zealand Forest Industry has been depicted (see Figure 4).

The industry employment and top export destinations of forestry and logs are shown in Figure 5, 6(a) and 6(b).

Currently New Zealand exports half of its forest harvest as raw timber logs (MAF, 2012). The Woodscape research indicates there are profitable processing opportunities, and increasing the scale increases profitability in almost

all cases. These findings highlight the importance of markets – increasing your scale only works if you can sell the entire output – and of investment in processing to fulfil the potential of the forestry sector. (Evison, 2013).

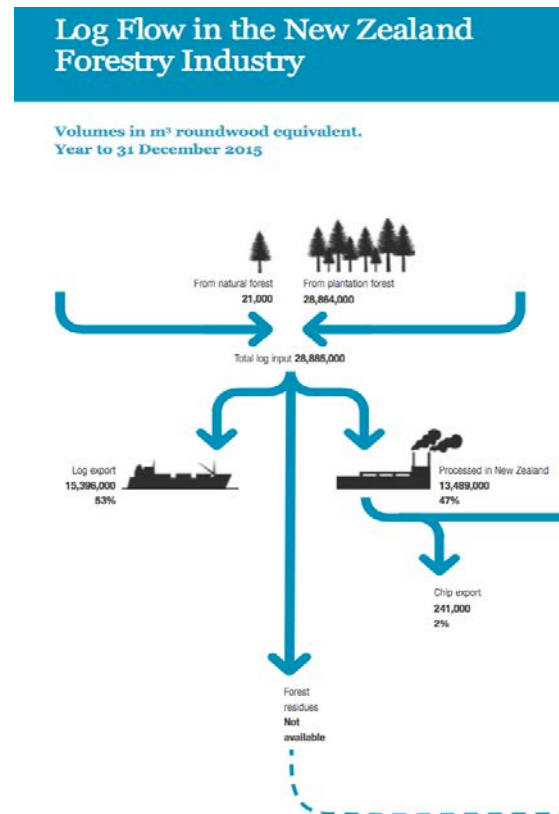


Figure 4: Source: (New Zealand Forest Owners Association. (2016). New Zealand plantation forest industry facts and figures. NZFO Association (Ed.), 2015-16)

It is clearly understood that New Zealand has a trend to export more unprocessed logs rather than adding value to the product within New Zealand. However, in other countries the scenario is different. For example, Indonesia has been utilising export restriction on unprocessed roundwood to encourage domestic producing. But, how far the restriction of raw wood logs be an appropriate policy to increase the level of in-house processing is still a question mark.

Industry Employment

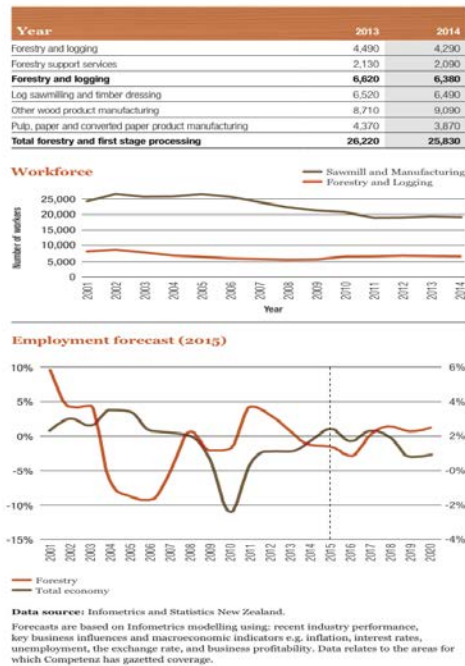


Figure5: Source: (New Zealand Forest Owners Association. (2016). New Zealand plantation forest industry facts and figures. NZFO Association (Ed.), 2015-16)

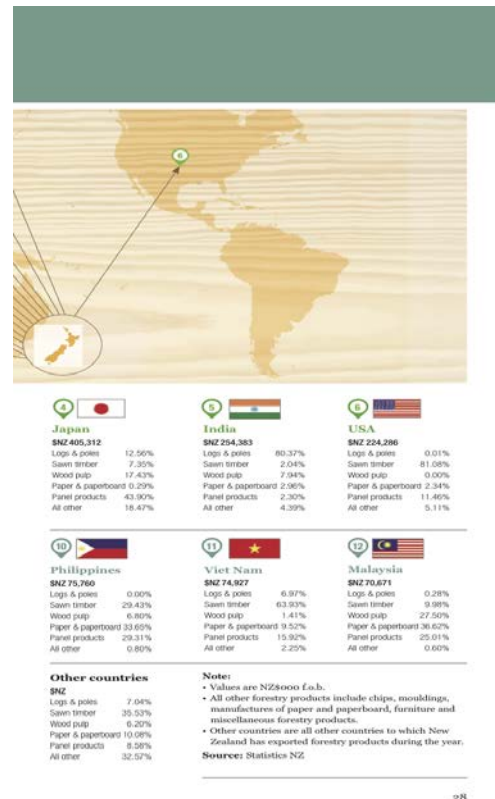


Figure 6 (b): Source: (New Zealand Forest Owners Association. (2016). New Zealand plantation forest industry facts and figures. NZFO Association (Ed.), 2015-16)

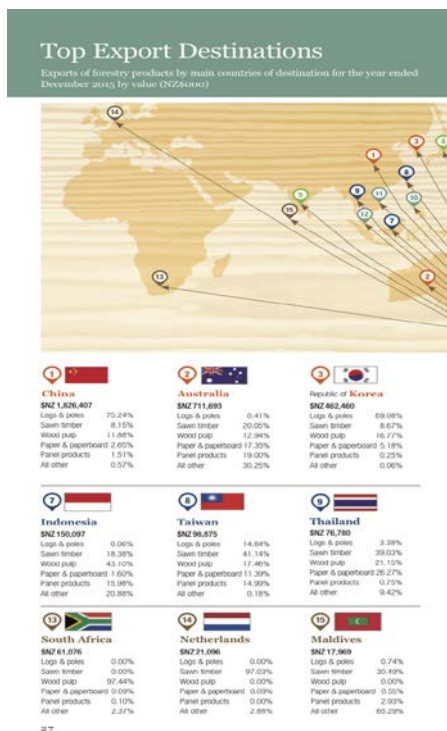


Figure 6 (a): Source: (New Zealand Forest Owners Association. (2016). New Zealand plantation forest industry facts and figures. NZFO Association (Ed.), 2015-16)

2.5 Export potential assessment

New Zealand timber availability is projected to increase to 35 million cubic metres by the early 2020s (MAF, 2010; Woodco, 2012). This will require marketing an additional seven million cubic metres of logs without compromising the returns and expectations of investors and stakeholders. It is well known that an increase in supply without a commensurate increase in market demand leads to weaker price for product (A. Katz, 2013).

By 2022, the forest industry in New Zealand will be harvesting an additional 10 million cubic metres of logs, with a potential annual harvest of 36 million cubic metres. If all this harvest increase is exported as logs, the industry would generate an additional \$1.29 billion in export revenue by year 2022. By processing more of the harvest and manufacturing a range of higher-value products, the industry could increase export revenue by \$6.2 billion to generate annual export earnings of \$12.3 billion by year 2022. This is more than double the \$4.9 billion in export earnings in year 2011. (Kantz, 2012).

Prefabricated exports are supported by an extensive supply chain. This includes sawmills, timber merchants, joinery manufacturers, which supply wooden doors, windows, and other components; and suppliers of other

building products such as metal roofing, windows and insulation materials. Prefabricated house manufacturers export to developers and builders who sell to home buyers, institutions and property investors (Andres Katz, 2008) See Figure 7.

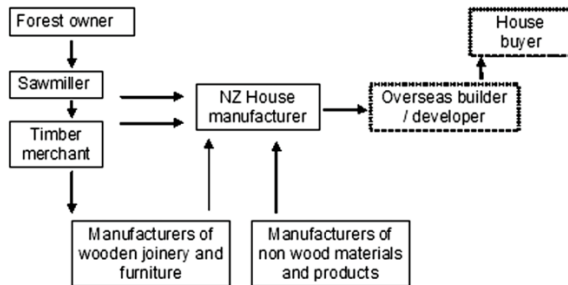


Figure 7: Key stakeholders in exports of prefabricated houses

The conclusion of the study for the “potential export revenues from forest and wood products by 2022” by Andres Katz on 2012 stated that, “The analysis showed export revenues increasing from \$4.8 billion to \$12.3 billion, by marketing a larger quantity of wood and increasing the quantity and value of wood processing. This will require the industry to expand into new product areas and participate in more sophisticated, higher-valued building applications where currently engineered steel and concrete based products are used. In addition, it was assumed that the industry would capitalise on the potential demand for ‘green’ wood chemicals and create additional value from what is an under-utilised part of the resource”(Kantz, 2012).

Diversifying the economy and broadening the export base towards high growth sectors is critical for future development and poverty alleviation in many developing countries (Kabir, August 2016). International Trade Centre (ITC), which is a joint trade agency of World Trade Organization (WTO) and United Nations (UN) has developed an export potential assessment flow chart. The flowchart is shown in figure (Figure 8).

Basically, the export potential assessment methodology is to help countries assess their export opportunities and increase their share in the world trade by;

1. Export Potential Index: Identification of priority Products
2. Market Attractive Index: Selection of target markets

The simple way of depicting export of a product can be presented in a flowchart (see Figure 9).

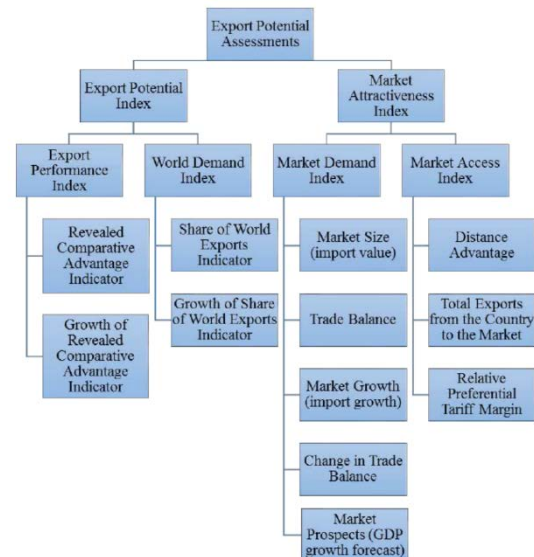


Figure 8: EXPORT POTENTIAL ASSESSMENT FLOW CHART, Source:(Kabir, August 2016)



Figure9: PRODUCT EXPORT, Source: https://www.academia.edu/27918426/Export_Potential_Assessments

The exporter in this study is New Zealand and the product that is viable to export is ‘prefabricated timber panels’ for prefabricated houses and the destination market is the country which imports the timber panels used for prefabricated houses.

There is a series of steps and formulas that is used to find out the export potential of a product, but since this is beyond the scope of this study, a recommendation will be made to the future researchers to investigate the analytics of export potential.

2.6 Non-tariff barriers and export markets

One of the few product categories where wood is exported in finished form is prefabricated houses. These houses contain high added-value components and showcase New Zealand wood products in areas less well represented in other exports. They can also act as a conduit for the exports of other products such as aluminium joinery, roofing and insulation materials. (Andres Katz, 2008). Hence there may be widening of opportunities for varied export products if prefabricated houses were exported.

The non-tariff barriers are trade barriers such as regulations or government policies. These non-tariff barriers are the rules that makes it difficult or costly to

export a product to a market.

World Trade Organisation (WTO) negotiations aim to reduce trade barriers that distort and inhibit international trade. While there has been significant success in lowering tariff barriers, a simultaneous rise in non-tariff barriers have also been reported (APEC, 1999; Andres Katz, 2008). Hence the aim of trade policy is clearly understood, it is to abolish the rules that does not have realistic reason to obstruct the imported product.

2.7 Sweden's industrialized housing

LINDBACKS is a company that was founded in 1924 and its legacy spreads over four generations. It developed from a small sawmill to production and supply of industrialized housing. They build multi-story buildings up to 8 floors on design-build contracts and build. They offer efficient construction and sound living for a sustainable future.

In LINDBACK, automation is not done for its own sake as they believe that watching machines work is mind numbing. Floor and ceiling are least automated aspect of production with extremely complicated details and variations. All the required services are concealed with outlets.

2.8 Summary of literature review

Review of books, academic journals, industry and government reports was carried out on prefabricated construction as a consumer good and the potential of export for prefabricated panels that can be assembled at site to volumetric units was the importance of the study. From the review of literatures, it is understood that New Zealand has the potential ability to export value added processed timber than just exporting the raw timber logs. It was also noted that by marketing a larger quantity of timber and increasing the quantity and value of timber wood processing a significant increase in export revenues can be achieved. Thus, New Zealand industry must expand its significance and concentrate in research and development of producing higher-value added timber products which can partially replace steel and concrete based products. One such product is the timber panels for floors and walls which together can make volumetric prefabricated modules. Case study of Sweden based construction manufacturing company LINDBACKS provides a better understanding of the workability of prefabrication and timber together. It was once said by Tony Robbins "If you want to be successful, find someone who has achieved the results you want and copy what they do and you'll achieve the same results", what we are trying here is almost the same context on production but

we want to be one more step further by importing factory manufactured panels.

It is also observed that there is no effort made in finding out the potential value of export of prefabricated panels. This study will mainly focus to bridge the gap between the export of prefabricated panels rather than timber logs and what are the factors that are hindering New Zealand to pursue this idea despite knowing the profit is expected to be higher if it happens.

3 Conclusion

It is evident that Europe, North America and Japan are already producing industrialized housing successfully. It is also evident that not many countries have thought about taking prefabricated/industrialized buildings to the next level of mass producing it and exporting it to different countries depending upon the market needs. New Zealand has the potential to utilize its timber to generate more business and more access to international market by transforming raw timber into prefabricated panels and exporting it to the global market.

Manufacturing a range of higher-value products, could increase the New Zealand export revenue by \$6.2 billion to generate annual export earnings of \$12.3 billion by year 2022 i.e. more than double the \$4.9 billion in export earnings in year 2011.

Export of timer panels is restricted by the finances, marketing and stakeholder's awareness of extent of benefits. New Zealand timber industry needs to be supported by a trade policy that can encourage the export of timber panels in place of raw timber logs.

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A critical review of the organisational waste in the construction industry

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ABSTRACT

The purpose of this review paper is to unravel the various types of wastes in construction Industry and its influencing factors. The construction industry worldwide has been working on waste reduction, which primarily focuses on material wastes. Construction is a \$30 billion industry in New Zealand and literatures estimate a 23% waste in the construction Industry. However, the estimate excludes certain factors such as the wastage due to design factors, environmental factors, and goal conflicts between architects, structural designers, and contractors. The literature focuses on the types of wastage of the construction process, which would aid to improve productivity, reduce cost, and optimise resources.

1 Review Question:

What are the types of waste generated in the construction industry?

1.1 Review significance and rationale

The construction industry wastes a considerable quantum of its materials and labour in a project. A BRANZ report suggests that in New Zealand, 23% of the material, labour and time are wasted during a residential build (Burgess, Buckett & Page, 2013). However, the report does not include wastes other than the material, labour and time. For example, at every stage of the construction, the human factors influence the process to generate wastes. The effective tackling, of the factors, would aid in the timely completion of the project. Identifying those other wastes would aid in the reduction of wastes and optimal use of resources.

The waste reduction would improve profitability, paving the way for optimal resource consumption, and in turn, reduce environmental damages. If the study on wastes could bring 5% savings, that would add \$1.5 billion to the bottom line of the industry (MBIE, 2017).

Practical implications are multifold:

The tracking of wastes could be used to compare estimated and actual resources at every stage of the process. It aids to reduce wastage stress on people, and environmental impacts while improving productivity and profit. Once a reasonable set of data is available, it can be used for budgeting and costing to gain a competitive advantage.

2 Construction Phases.

The construction industry works on six phases (Cooper et al., 1998; Styhre, Josephson, & Knauseder, 2004):

Planning and Development: In this stage, the identification of the project, its location, and concept design are worked

out.



Figure 1 Construction Phases

Construction Planning: The next stage is working on the feasibility study and design of the building.

Pre-construction: This stage includes preparation of material list, obtaining quotes, preparing contracts, obtaining building approval, and completing insurance formalities.

Procurement: At this stage, the contracts, material supply orders, and labour sourcing are completed.

Construction: This stage is from site preparation until the physical build is completed.

Post-Construction: The last stage is preparing the building for occupancy, checking the construction specification, auditing for defects, completing handing over formalities and physical handing over is done.

3 Waste

The construction industry focuses on waste reduction and managing the flow of the construction process (Ballard & Howell, 1997). Waste is the disproportionate consumption of resources and materials: the resources means the human effort, energy, air, water, land, and biodiversity (Cobra et al., 2015). The material or substance waste managers focus on reduce, reuse, recycle, rethink and recover (Li, Chen, Yong, & Kong, 2005). The resource waste managers at the organisational level focus on reduction and elimination (Womack & Jones, 2010). This study draws

on research conducted in an organisational resource waste management context.

Lean construction is a step in this direction, which use supply chain management to link material and the construction processes to maximise value addition and minimise waste (Feng & Price, 2005). Organisations adopted the Lean methodology that focuses on eliminating various types of wastes to improve their efficiency (Ohno, 1988).

Corvellec (2016) argues that waste happens in all stages of design, extraction, construction, distribution, consumption, and waste management. Likewise, Osmani, Glass, and Price (2008) study point out that every stage of the construction contributes to waste, with the prime origin being design and modification. This fact was affirmed by Faniran and Caban (1998) two decades earlier. Similarly, Majerus, Morgan, and Sobek (2016) ascertained design error as waste.

Likewise, Alor-Hernández (2016), Duffy and Wong (2016) and LeMahieu, Nordstrum, and Greco (2017) suggested underutilised skill, knowledge, experience, talent or innovation as waste. In addition, individual, project team and organizational factors, influence work and productivity of a construction project (Thevendran & Mawdesley, 2004). Substantiating, Mokhtar, Mahmood, Che Hassan, Masudi, and Sulaiman (2011) stated that construction method, storage method, human error and a technical problem can affect the amount of waste generated at the construction sites. Likewise, Durdyev and Mbachu (2011) study on on-site labour productivity of New Zealand construction Industry affirmed wastes due to statutory compliance, unforeseen events, reworks, the method of construction, supervision, and coordination (Durdyev & Mbachu, 2011). Further, Sajedeh, Fleming, Talebi, and Underwood (2016) related decision-making deficiencies wastes. Organisational waste includes the excessive use or underutilisation of anything to the optimum requirement of resources like men; machine; method; measurement and material for adding value to the product (Prasad, Khanduja, & Sharma, 2016).

Organisations engage people to perform activities that enhance, create, or add value. Do organizations' define and measure the errors or wastes that happen due to activity? Literature capture the waste generated by the construction process and its resultant discharge that to harm the environment. However, the wastes generated by information technology function, the individual's activities, limitations of department boundaries and hierarchical system are not well-defined. It is noteworthy to relate all these segments to the appropriate categories, ascertain

the wastes in an organisation for elimination.

3.1 Lean waste

The wastes generated by the process of construction, which affects the organisation, is referred as lean waste.

As the preliminary step, Ohno (1988) classified seven kinds of waste to aid Lean processes: Overproduction; Waiting; Transportation; Over Processing; Inventory; Movement; and Defective products. More wastes were added to this list by various authors. Of them, Health and Space waste are critical to the Lean process.

Health waste

In its strategic thinking, the New Zealand waste strategy emphasises health by reducing harm to the people (MFE, 2010). Former Secretary-General of United Nations, Kofi A. Annan affirmed, future depends on occupational safety and health (Leka, Griffiths, and Cox, 2005). The United Nations Conference on the Environment and Development (UNCED) affirmed that people have the right to lead a healthy and productive life in harmony with nature (Leka, Griffiths, and Cox, 2005).

Worldwide health is attaining greater awareness and importance. However, the construction industry accounts for one-third of work fatalities, injuries, and ill health (Haslam et al., 2005). Substantiating, Curtis, Meischke, Simcox, Laslett, and Seixas (2016) published on the risk of exposure to toxic chemicals, heavy equipment, electrocution that affects health in construction in the United States of America. Concerns of health exist in New Zealand construction industry due to onsite slips, trips and falls (Bentley et al., 2006). Additionally, Crandall, Zagdsuren, Schafer, and Lyons (2016) stated prolonged workplace sitting causes health risks such as musculoskeletal issues, cardiovascular diseases, and increased mortality. Substantiating, Org et al. (2016) account absence due to health as loss of productivity, which made organisations to invest in workforce health and care. Concluding, waste generated due to process, which harms the health of employees and affects the organization is referred as health waste.

Space waste

Space is limited for on-site operations and excess space hard to find (Sriprasert & Dawood, 2003). In addition, the storage space for unwanted material, scrap and excess inventory increases handling and storage cost, and reduces performance levels (Shah & Khanzode, 2017). Concluding, space waste includes more than optimal space occupied by materials, machines, men, and motion.

Summarising, the process related wastes, which affect customers, employees, and organisation, are listed below:

- Waiting;

- Over-production;
- Over-processing;
- Defects;
- Space;
- Motion or Movement;
- Inventory;
- Transport; and
- Health.

3.2 Environmental waste:

The construction Industry views waste as an unavoidable by-product, however reduction of wastes is important for environment and organisation (Teo & Loosemore, 2001). Supporting the environmental concerns, environmental waste defined as the unnecessary or excess use of resources or its material constituent disposed to the air, water, or land that could harm human health or the environment (Cobra et al., 2015).

Conversely, Alotaibi and Alotaibi (2016); King and Lenox (2001) claim that organisations' exercise of reducing waste lessen the environmental concerns. Though recycling is being adopted (Garlapati, 2016; Yoshida et al., 2016), containment at source and resource conservation need to be done through waste prevention or recovery (Murphy & Pincetl, 2013). Hence, it is of fundamental importance to measure, keep track and solve spills and wastes (Bianciardi, Credi, Levi, Rosa, & Zecca, 2017).

Various governments are focusing on environmental concerns. For example, the New Zealand waste strategy focused on managing and minimising waste and set targets to move New Zealand towards zero waste (MFE, 2010). Substantiating, the New Zealand government in a strategic direction recognised technological feasibility and economic viability on collecting and transporting materials for recycling, reuse, and recovery (MFE, 2010). These strategies are focused to reduce the harmful effects of waste and to improve the efficiency of resource use, which augments the necessity of organisations categorise and focus on environmental waste.

3.3 Information technology waste (IT waste):

As the digital era had its impact on industries, information technology (IT) has attained more significance. It is a critical and indispensable tool to the construction industry (Cherian & Kumaran, 2016). Further, information technology connects the construction process internally through 'building information modelling' systems (Sacks, Koskela, Dave, & Owen, 2010). Any deficiencies in this system tend to create waste.

IT function also has defects such as security threats (Ur Rahman & Williams, 2016; Zhang, Song, & Yan, 2015), hardware defects, software bugs (Bhattacharya & Fiondella,

2016) and connectivity issues (McFarlane, Troutman, Noble, & Allen, US9329922 B1/2016), which causes wastes. Summarising, IT waste is triggered by the information technology function, such as defects due to delay, programming, hardware, connectivity, training, documentation, and storage. Organisations need to focus on this waste to improve productivity and customer service.

3.4 Decision-making individual waste:

Growing connectivity through information technology prompts stakeholders' demand for quick decisions. Decision-making is an important aspect in every phase of the construction project (Ning, Lam, & Lam, 2011). Obviously, the project success depends on leader's decision-making ability (Chan, Scott, & Chan, 2004).

Sanayei, Mousavi, and Yazdankhah (2010) claimed that while making decisions, the individual is influenced by doubt, problems, ambiguous situations, and facts. Likewise, Saaty (2012) argues that factors like perception, intuition, feelings, mindsets, and experience cause decision-making errors. Similarly, Guy, Karny, and Wolpert (2015) stated that imperfection and selfishness in decision-making are associated to cost and though not stated explicitly, implies wastes. Notably, self, situation, and the probable solution influence decision-making to generate waste.

Self-factors that influence decision-making includes intuition, feeling, experience, procrastination, bias, fear, carefulness, motivation and ignorance (Mann, Burnett, Radford, & Ford, 1997; Saaty, 2012; Tonetti et al., 2016). Situation factors are the gravity of the problem, doubt on fact, the uncertainty of the situation, goal clarity, supervisor support, autonomy and team support (Lingens, Winterhalter, Krieg, & Gassmann, 2016; Sanayei et al., 2010). The solution factor includes focus on the outcome, buck-passing, being adamant, personal judgement, emotion, and confusion on others' perspective (Bernal, 2017; Kaufmann, Wagner, & Carter, 2016). Particularly, decision-making individual waste is the waste generated by the individuals' delay, lack of decision and wrong decision-making.

3.5 Department or Function Waste

The decision-making process is also constrained by well-established departmental hierarchy and boundaries. These boundaries are established to achieve fast and positive results (Samli, 2016). Substantiating, Amadei (2016) claims that the departmental policies and procedures help to identify gaps, provide improvement opportunities and logically implant the right controls. Conversely, Floyd (2017) argues that the departmental

boundaries frequently fail in practice, as it is only followed by bottom level staff, while others ignore it. Likewise, Kamal, Yusof, and Iranmanesh (2016) stated that organisations adopt hierarchy, bureaucracy and inflexible procedures affect innovation in the construction industry. Further, the hierarchy focuses on the accountability in a department (Ghoshal & Westney, 2016). They block communication, delay and initiate defects in the construction industry (Pheng Low & Faizathy Omar, 1997; Wilensky, 2015). Obviously, the waste generated by adopting boundaries, procedures, policies, and hierarchies needs to be monitored for quick and effective functioning.

3.6 Decision-making cross-functional team waste

The departmental boundaries are crossed when complex situations arise or to deliver innovative solutions in the construction industry (Bossink, 2004; Shulzhenko, 2016). The coordination between members of the cross-functional team is essential to success. Littlepage, Hein, Moffett, Craig, and Georgiou (2016) findings' affirm cross-functional coordination training as an investment for organisations. In spite of the training, the cross-functional teams show negative results due to lack of trust and leadership (Simsarian Webber, 2002). Besides, the cross-functional teams lack uniqueness, accept workable arguments, which creates negative results (Saaty, 1990). Unpretentiously, decision-making cross-functional team waste is generated by the teams' delay, lack of decision, or wrong decision.

3.7 Human Resources waste

Naturally, people are an important factor in the decision-making process. The Human resources department that is responsible for the human factor, play an important role in the organisational progress (Sela, Jacobs, Michel, Klai, & Steinicke, 2016). Nevertheless, there are instances of underutilisation of the people where their skills, talents, and intellectual abilities are not captivated (Womack, Jones, Roos, & Carpenter, 2007). This is a waste to the organisation (Womack, Jones, Roos, & Carpenter, 2007). Furthermore, Biazzo, Panizzolo, and de Crescenzo (2016) pointed out that people with limited ability, authority and responsibility produce defects. To overcome the deficiencies organisations enhance ability by educating and training (Ong & Jambulingam, 2016). There is a considerable cost incurred in training. Therefore, when talent underutilised or wrong training being imparted is a form of waste. Besides absenteeism is a factor which, indicate workplace productivity (Magee, Caputi, & Lee, 2016).

Human resources waste is imparting non-rewarding training, underutilisation of talents, absenteeism, and

overstaffing.

3.8 Enterprise engagement waste

Human resource team suffice with internal people and the organisation as such bond with external people and agencies. Notably, organisations face issues as architects and contractor do not resolve their issues on time, which impacts the construction project (Kumaar, Deventhiran, Kumar, Kumar, & Suresh, 2016). Similarly, enterprises or organisations face conflict due to the engagement of consultants (Brandon-Jones, Lewis, Verma, & Walsman, 2016), audit firms (Ayres, Neal, Reid, & Shipman, 2016), and external certifiers (Dranove & Jin, 2010). The organisations tend to look at external agencies' success factor and ignore the delay or failure caused (Dranove & Jin, 2010). To summarise, deficiencies by external experts, consultants, and auditors is enterprise engagement waste.

3.9 Stress Wastes

The organisation's top management deals with the stress from external agencies but internal stressors remain a challenge. The internal stressors attain significance as the working methods continue to change (Jahanian, Tabatabaei, & Behdad, 2012). Importantly, Hobfoll and Shirom (2001) observe that the consequences of work-related stress are emotional exhaustion, dwindled enthusiasm, demotivation and lower productivity. Work stress is a challenge worldwide as it affects people health and competitiveness of the organisations (REPRESENTATIVES, 2003). Similarly, stress generated by the pressure from superiors and peers impact employees' decision-making ability and inappropriate behaviours (Samat, Ishak, & Nasurdin, 2016)

While themes for after work stress management are available for employees (Holton, Barry, & Chaney, 2016), the wastes caused by stress are to be eliminated by addressing its root cause.

3.10 Methods waste (Design, Overhead and Eagerness & error) Waste:

Waste generated due to the method of performing an activity is referred as methods waste. For example, Tauriainen, Marttinen, Dave, and Koskela (2016) affirm that design methods generate wastes. Likewise, Chipeta, Bradley, Chimwaza-Manda, and McAuliffe (2016) indicate that overheads in an organisation generate wastes. Similarly, Nezam, Ataffar, Isfahani, and Shahin (2016) point out that eagerness to conduct experiment trigger significant wastes. The wastes created by the methods of design, overhead, and eagerness are discussed in this session.

Design Waste

Bolviken and Koskela (2016) affirm that design is a factor

for waste reduction in construction that aids cost reduction and on-time project completion. Likewise, Shaar, Assaf, Bambang, Babsail, and Fattah (2017) concluded that the key problem in the large construction projects is deficient synchronisation between various specialities of the design team, lack of proficiency in designers', and faulty drawing /specification. Maki (2015); and Whang, Flanagan, Kim, and Kim (2016) point out that construction design-related issues delay project completion. In addition, Dhillon (2013) stated design problems create defectives. Similarly, the design factor of safety calculation differs between an organisation, method, and countries (McGuire et al., 2016; Zhou, Esaki, Mitani, Xie, & Mori, 2003). This generates wastes and adds cost. Substantiating, Llatas and Osmani (2016) stated that the design in construction as the pivotal process to achieve waste reduction at source. To express, design function as a process creates design wastes.

Overhead Wastes

Waste generated overheads in an organisation are referred as overheads waste. Organisations aim to eliminate wastes adding supervisors, management staff, and indirect labour. They also employ employee staff for finance functions. The Defects produced by such functions are to be addressed to reduce wastes (Drory & Meisler, 2016).

Eagerness and Error Wastes

Organisations often do not limit eager experiments and their subsequent errors. The eagerness to know how things work, or carrying out changes in the work process to find the solution, or to give faster results, involves risks, uncertainty and error (Nezam et al., 2016). However, risk-taking may be positive in attitude, but generates wastes. The wastes generated due to eagerness and its subsequent errors need to be tracked and regulated.

4. Conclusion.

From the literature review, a correlation between the wastes and the construction phases is tabulated in table 1. The table shows that wastes occur in every stage of the process. However, the wastes in each stage are yet to be

quantified. Wastes in any form consume time, resource, and effort and in turn influence cost, delivery, and value. Continuous efforts are needed to reduce or eliminate waste to attain optimum efficiency; the process induces a considerable stress in the system, which tends to affect the people associated with the organisation.

In order to attain focus on the waste, the wastes in organisations have been categorised in this review paper for further study. The effect of wastes, influencing factors such as men, material, machine, methods, and measurement and its impact on productivity (P), Delay (D), Accidents (A), Recourse Utilisation(R), and Cost(C) are correlated in figure 2. The purpose of the literature review is to point out that the various organisational wastes that are yet to be quantified and a study would be beneficial to the construction industry. If the study could bring a 5% savings, it would yield a \$1.5 billion to the bottom line of New Zealand's construction industry.

Table 1 Waste categories in construction

Construction Phases	Lean waste	Decision-making individual waste	Department or Function Waste	IT waste	Enterprise engagement waste	Decision-making cross-functional team waste	Human resources waste	Environment waste.	Stress waste	Methods waste
Planning and Development		✓	✓		✓	✓	✓		✓	✓
Construction Planning		✓	✓	✓	✓	✓	✓		✓	✓
Pre-construction		✓	✓	✓	✓	✓	✓		✓	✓
Procurement		✓	✓	✓	✓	✓	✓		✓	✓
Construction	✓	✓	✓		✓	✓	✓	✓	✓	✓
Post-construction	✓	✓	✓		✓	✓	✓	✓	✓	✓

Men	PDARC	PDARC	PDARC	PDRC	PDARC	PDARC	PDARC	RC	PDARC	PARC
Material	PDARC	PDARC	PDARC	DRC	RC	RC	RC	RC	R	DAC
Machine	PDARC	PDARC	PDARC	PDARC	PDARC	PDARC	PDARC	RC	PA	PDARC
Method	PDARC	PDARC	PDARC	PDARC	PDARC	PDARC	PDARC	RC	PDARC	PDARC
Measurement	DC	D C	D C	DC	DC	DC	D	R	D	DC
	Lean waste	Decision-making individual waste	Department or Function Waste	IT waste	Enterprise engagement waste	Decision-making cross-functional team waste	Human resources waste	Environment waste.	Stress waste	Methods waste

Figure 2 Correlation of wastes, influencing factors and affected results

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Maximizing the productivity of the precast concrete plants by implementing the lean management system

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ABSTRACT: There is a growing market demand for precast concrete elements in the New Zealand construction market. However, within so many improvements in the management, production technology, transportation, and quality assurance systems, the precast construction system remains one of the least developed systems with the minimum productivity and profit margins. This study aims to investigate how the lean management system could be implemented in the concrete precast plants to increase the productivity and organisation's profit margin. To achieve successful application of the system, the study conducts a comparative analysis of existing lean approaches in literature, followed by face-to-face interviews. Then, a lean management system framework concludes to be implemented in the precast concrete plant to improve the plant productivity while increasing the profit.

1 Introduction

Off-site production (OSP) is an increasingly popular approach in construction that relocates some on-site operations to a more controlled factory environment. It is a unique hybrid of manufacturing and construction, which describe as a series of operations on a progressive assembly line (Arashpour, Wakefield, Blismas, & Maqsood, 2015). It offers several advantages over traditional site-built construction, such as superior quality (Boyd, Khalfan, & Maqsood, 2012), swift delivery (Moya & Pons, 2014), improved health and safety (Blismas, Pasquire, & Gibb, 2006) and customization capability (Pan, Gibb, & Dainty, 2008). The competitive advantage of off-site manufacturers over their on-site counterparts has its roots in different factors such as broad adoption of information technology, modern equipment, and innovative production layouts (Arashpour et al., 2015). Also, countries with a massive public housing program such as USA, Malaysia, Canada and Australia have increasingly turned to the use of precast building/structural elements and site automation to increase site or construction productivity.

Productivity in the construction industry generally can be explained: "As a measure of how well resources are leveraged to achieve a set of objectives or desired output" (Durdyev & Ismail, 2012). Productivity can also be explained as a measured rate of successful delivery of the main project objectives with a high level of

cost-effectiveness (Mbachu, 2008). Productivity in off-site construction relates to the rate of achieving the targeted schedule, the rate of the project cost-effectiveness, and the level of achieved quality (Bock, 2017). The off-site production of precast concrete contributes significantly to various construction types, including commercial, residential and infrastructure to reduce environmental uncertainty during the building process and satisfy the requirements of process industrialisation (Bock, 2017; Eastman, Sacks, & Lee, 2003).

The precast concrete market is a major supplier of offsite-prefabricated components to the construction industry. The construction of a building can be regarded as an assembly of hundreds of different designs and delivery dates of precast concrete units. This demand creates the difficulty in the precast production (Benjaoran & Dawood, 2006). Inside the plant, components must be produced according to schedule; over-early or over-late production will result in storage problems and delays in the construction site (Yin, Tserng, Wang, & Tsai, 2009). If the inventory elements in stock cannot meet site demand on a given day, delivery is delayed until production meets the demand, thereby incurring contractual penalty costs associated with a missed delivery (W. Chan & Hu, 2002). Often the unplanned jobs require to be done in the production queue or vice versa; the production was delayed due to project delays. On these occasions, handling the

production and spaces at the precast concrete plant becomes extremely critical.

The precast construction method is gradually becoming an automated market and can be divided into four cycles: design, production, storage and transportation, and erection (Chen, Yan, Tai, & Chang, 2017). The process begins with the design process, where the client's requirements are issued. The project design can be developed and passed to the precast plant for fabrication. The precast plant must transport the components to the site for erection based on the project's erection requirements and schedule (Badir, Kadir, & Hashim, 2002; Elliott & Jolly, 2013; Polat, 2008; Wong, Hao, & Ho, 2003; Yee & Eng, 2001). Although, precast concrete plants usually serve limited geographic regions and restricted by the distance over which pieces can be economically transported (Scheer, Santos, Quevedo, & Mikaldo Jr, 2005), the New Zealand precast concrete demand is increasing. Despite many improvements in the management, production technology, transportation, several and quality assurance systems, the precast construction system remains one of the least developed systems. According to Pheng (2001), 32 precast construction sites in Singapore were studied, and over 95 percent of project managers believed that 20% of the projects would have the late completion date. These managers believed that the underlying cause of the project time delays relates poor quality, incorrect quantity, production delays and structural damage in the precast pieces (Pheng & Chuan, 2001). In the other hand, Henderson and Venkatraman (1993) pointed that one of the difficulties for the companies in getting profits with the implantation of IT relies on the lack of ability to coordinate and to line up the business strategies with the IT strategies. In addition to above, Laudon (2003) conclude that the most difficult part of an information system project is to understand the actual problem that should be considered effective.

Lean manufacturing is one of the initiatives that many major businesses in the United States have been trying to adapt to remain competitive in an increasingly global market (Abdulmalek & Rajgopal, 2007). Additionally, that is a systematic approach to process improvement, and it is based on finding and reducing waste coupled with continuous improvement (Abdulmalek & Rajgopal, 2007; Ray, Ripley, & Neal, 2006). Lean will reduce the lead time from customer order to delivery by eliminating sources of waste in the production flow (Liker, 2004). Lean was

first developed by Toyota (the Japanese car manufacturer) but has now been applied to many diverse industries and businesses. Theoretically, lean production has two fundamental goals, namely waste reduction and respect for people. From a lean production point of view, a problem that IT could contribute is to reduce all waiting, transporting, inspecting and controlling activities that interfere with the material/information flow.

This study aims to fill in the knowledge gap and improves the productivity of the precast company by investigating and implementing the related lean management to the system. That will help the concrete precast companies to optimise their production while increasing the reputation in the market.

A precast concrete plant in Auckland, New Zealand is used as a case study for investigating the applicability of the lean management to precast concrete production. The study will examine how the lean management system could be used to improve supply chain management and increase their productivity by achieving improving logistics processes, waste reduction and avoiding time delays.

2 Literature Review

In precast construction method, the main building components such as beams, columns, and walls are often standardised components through precise design, planning, and manufacturing. These components are then transported to site for assembly. The precast construction system is often considered as the industrialisation of the construction industry (Badir et al., 2002; Elliott & Jolly, 2013; Wong et al., 2003).

Research trends in concrete structures since the last few decades have improved within a good pattern of innovation, optimisation and implementation. In precast concrete, a Beam-to-column mechanical connection has attracted interest in 1965 which they had been focusing on strength. In the 1990s the rotational stiffness and 2010s the frame stability studied. The Prestressed concrete hollowcore floor units have been researched in waves, for example, shear capacity (the 1970s), lateral load spread (1980s), floor diaphragm action (1990s), flexible supports (2000s) and fire resistance (2000 to date). Prefabricated concrete technology has also peaked the alkali-aggregate and silica reaction in the 1970s, self-compacting concrete (SCC) in 1990s and blended cement and high-strength concrete (HSC) in 2000s (Elliott & Hamid, 2017).

The term of supply chain management is to define the stages through which precast concrete plant resources (material, equipment, personnel) entirely proceed from supply points to the construction sites. The supply chain in construction is more concerned with the planning of materials where the object is assembled from incoming materials (O'Brien, Formoso, Ruben, & London, 2008). The construction supply chain management in the precast production aims to solve problems such as production scheduling, handling space and adjusting of production resources. A closer look at the precast industry shows that a considerable amount of waste produced is rooted in the poor management of the material supply chain (e.g. delivery services, inventory, communications) (O'Brien et al., 2008).

The computer simulations and the sharing of the construction information and their influences on the construction inventory were studied to explore the impact of preliminary operations on subsequent operations (Tommelein, 1998). Then it is demonstrated that the variances in the preliminary preparations and information sharing influenced subsequent operations (Chen et al., 2017). Therefore, reducing variance in preliminary preparations and improving communications can reduce uncertainty in follow-up operations and high supply chain inventories (Chen et al., 2017). A study by (O'Brien & Fischer, 2000) also found that production constraints affected supplier production output; the significant variances in site progress mean that suppliers must constantly adjust their production by moving production and construction resources between different projects. Scholars have kept searching for better ways to optimise the fabrication and management of precast components (Yin et al., 2009).

Precast production and handling: In past literature on precast production, Warszawski and Dawood researched on production planning for precast concrete plants. They also split the production in the precast plant into Long-Line Production for standard products and Short Line Production for special project specifications (Warszawski, 1984). It has been researched on the overall production system model regarding how precast concrete plants with limited resources approached the assignment of project production management personnel, production schedule, and production plan (W.-T. Chan & Hu, 2001; Ko & Wang, 2010; Leu & Hwang, 2002; Patterson, 1984). In regards to storage and transportation, (Nashwan Dawood & Marasini, 1999)

began studying the layout of handling yards for precast building products. A model was constructed, and simulations carried out to find high-efficiency storage, loading and unloading, and allocation. This would enable the precast production plan and give the yard administrator more detailed, complete, and timely information (Nashwan Dawood & Marasini, 1999; Dean, Denzler, & Watkins, 1992; Marasini & Dawood, 2002).

How lean management can potentially improve the precast concrete industry productivity: In particular, tools have been developed to help producers stay focused on finding and reducing waste. Lean manufacturing methods have been applied across entire firms, including engineering, administration, and project management departments, as well as manufacturing and construction. Its end purpose is to find waste and reduce costs to transform a company into an efficient, smoothly running, competitive, and profitable organisation that continues to learn and improve (Ray et al., 2006). (Peng & Pheng, 2011) While identifying the contribution of the lean concepts to achieve sustainability in precast concrete factories, reported that by using appropriate lean principles, the precast concrete industry can move closer towards achieving sustainability.

The lean management system has been applied in manufacturing in the United States and other industrialised countries for more than a decade (Abdulmalek & Rajgopal, 2007). Despite its wide use in other industries, lean manufacturing has only recently been applied to the precast concrete industry. According to Ray's research in 2006, in one hand, it was estimated that about 5% of precast concrete industry members had undertaken a serious initiative in applying lean manufacturing and about 6% of the precast concrete companies had active lean manufacturing programs in the United States. On the other hand, they found that these companies are attaining a 20% or more improvement in labour productivity per year, up to a 50% increase in production (without major capital spending), and up to a 50% reduction in defects and rework (Ray et al., 2006).

Minimizing the non-value added activities: The focus of the lean manufacturing is on cost reduction by eliminating non-value added activities (Abdulmalek & Rajgopal, 2007). Value added is defined as any activity that transforms the product toward what the customer wants. Everything else is defined as "waste." Waste is any processing step that consumes resources without adding value (Abdulmalek & Rajgopal, 2007; Ray et al., 2006). In 2006, the day-to-day activities of 120 companies tracked

and the results indicated that, on average, only 5% of activities were value added while the remaining 95% is a waste (Ray et al., 2006). The lean manufacturing discipline has identified seven main categories of waste (Table1) (Chahal & Narwal, 2017; Henderson & Venkatraman, 1993).

Learning to identify waste is an important part of the lean manufacturing process, because, often businesses have become so accustomed to waste that it is not recognised. The value stream mapping method is the basic, analytical starting point in the lean manufacturing process to break down the work process into detailed steps. The process steps are then classified as either value added or waste (Chahal & Narwal, 2017). Table3 shows how to break down the work process into detailed steps.

Table 1: Sources of wastage (Chahal & Narwal, 2017; Henderson & Venkatraman, 1993)

Waste	Reasons / Explanation
Overproduction	From “getting ahead” concerning production schedules. Here the required number of products is disregarded in favour of efficient utilisation of the production capacity
Inventory	Final products, semi-finished products, or parts kept in storage do not add any value. Even worse, they normally add cost to the production system by occupying space and financial resources and, also, by requiring additional equipment, facilities and workforce
Repair or reject	May end up discarded or damaging other equipment or generating extra paperwork when dealing with customer complaints
Motion	Any motion not related to adding value is unproductive
Transport	To be an essential part of production, but moving unnecessarily will not increase the value at all
Over-Processing	Use of inadequate technology or poor

	design results in inefficient processing activities.
Waiting	Hands of a worker are idle such as when there are imbalances in schedule, lack of parts, machine downtime or when the worker is simply monitoring a machine performing a value-adding job

Lean manufacturing techniques: There are many techniques available to analyse and improve production systems using the flow model as the conceptual base. They allow the analyst to understand actual behaviour, sequence, proportion and variability of inspecting, waiting, processing and transporting activities. Many of them were invented in the early days of scientific management, such as time-lapse video recording, work sampling and flow charts (Scheer et al., 2005). Additionally, lean manufacturing provides tools and methods that effectively reduce waste once it is recognised in the workflow. Here is a summary of some of the tools that producers have used successfully (Chahal & Narwal, 2017; Ray et al., 2006):

Rapid improvement events (Kaizen) tool, which involves setting up a cross-functional waste reduction team to focus on a specific problem area. The standardized task is the next method that is usually one way to perform a task most efficiently. In the Balanced flow (Takt time) method, once standard tasks are established, process cycle time and standard staffing can be developed. Balancing staffing and material flows to minimise walking, waiting, and repetitive material handling is frequently a source of significant improvement in precast concrete plants. Workplace organisation (5-S) is another tool that many producers are familiar with this workplace organisation and housekeeping system and have tried it. Next tool is Visual controls which can be as simple as painting lines on the floor to guide the placement and flow of materials. In the plant layout method, most producers find many opportunities to streamline material flow, minimize crane time, and reduce walking. This tool includes an analysis of flow and how it relates to inventory. In the precast concrete plant, the carpenter shop and the steel shop are often a good place to start. The mistake-proofing method will be designed so that it is harder to do them wrong than to do the right. In

Inventory reduction method, the inventory is a waste for the following reasons: It has to be handled and stored. It is often subject to damage or obsolescence. Someone must keep track of inventory and find it when needed. It ties up capital that should be earning a return on investment. To be specific, work-in-process inventory beyond the needs of the immediate casting is a waste. Moreover, there are some more methods and tools such as; Correction at the source, Bed setup reduction, Total preventative maintenance, and Team problem solving, which help reduce the waste.

3 Research Method

A case study approach is adopted in this research, with the objective of knowing and understanding the actual process and operations flow. The case study carried through direct observations within the precast plant, as well as semi-structured interviews and discussions with the precast concrete representatives who are team leaders involved with estimating, planning, design, production, quality, and delivery of precast concrete elements. The first stage of empirical data gathering involves the use of pilot interviews conducted with the experts in the company. A selective and purposive sampling method (Bernard, 2011) is used to select a convenience sample of interviewees from the sampling frame who are willing to grant approximately one hour for an in-depth discussion. An interview protocol was used to the data collection tool. Based on the principles of the lean production, the interviewees provided detailed discussions comments on the transformation processes of producing units of precast concrete, from raw materials to finished products. The meetings adopted the "brainstorming" as a tool to activate the participants to put their views on the problems and solutions related to information flows that support production. Those discussions aimed to explore the key factors constraining productivity performance in concrete precast projects in New Zealand.

A total of ten interviews were conducted within a precast concrete organisation. A summary of the participants is provided in Table 2. It is expected that the feedback from those who make strategic decisions about the optimising the precast concrete production by implementing the lean systematic management, hence improving the reliability of the study findings and conclusions.

Table 2: Interviewees from precast concrete company

#	Role	Years of Experience
1	Estimating manager	30
1	Project manager	10
1	Senior draughter	15
1	Branch manager	15
1	Operational manager	20
1	Production Supervisor	20
1	Quality control manager	10
1	Quality control supervisor	6
1	Despatch manager	10
1	Consultant	30
10		166 Yrs

4 Results and discussions

Production

Any precast company is divided into different departments which need to have enough communication. Interviewee 5 believed lack of communication between those departments is causing the duplicating and extra cost to the company. He also added: *"The jobs undertaken by precast production companies can be roughly divided into structural design, production planning, component manufacturing, and handling operations. The time from production planning to the completion of storage and transportation may run for weeks or even months"*.

Interviewees 1, 2 & 3 added some points; *"The mould production space is significant to the plant's overall production allocation. Proper mould production planning will greatly affect total plant production and mould costs. Mould production planning starts by verifying the component specifications based on the project's structural design. Precast components with similar specifications should be assigned to the same mould group for production. This prevents excessively complex mould setup during production that increases mould production time and takes up production space"*.

Planners balance the different objectives of meeting due dates, improving mould utilisation rates, reducing mould

changeovers, and maintaining inventory levels (W. Chan & Hu, 2002). Interviewee 5: *“Plant operators should make full use of their moulds and minimise the number of changeovers. Long runs of a particular element type on a single mould are preferable if this does not compromise due dates and exceed desired inventory levels”*. Interviewee 2: *“Planning in response to due dates alone may result in many changeovers and may drive up mould adaptation costs, which can be considerable if the cost of lost production time is included”*.

Quality

According to the interviewee 7 and 8; *“The planning and production should be linked to avoid any overproduction of the precast concrete components. The overproduction will cause so many quality concerns such as; (a) Long staying of the casted products on site which cause deformation and some more chemical and physical changes, (b) Late concreting of the product which causes the low strength and waiting time to demould them during the next day. (c) Late concreting will cause over time working with the workers who cost the company. (d) Require more moving of the products if the storage space is limited, which cause product defects”*.

Managing and Planning

Having no proper planning will cause extra cost to the company and reduce the company's reputation in the competitive market. Interviewee 2: *“Due to the large variances in project size and difficulty, the decision-maker at the precast plant must assign appropriate planning personnel based on the project characteristics”*.

A flexible/interactive planning including weekly team meeting required for all *“in progress”* jobs to reduce the unnecessary expenses. Interviewee 2: *“Current scheduling practices in precast plants are basic and depend greatly on experience. This may lead to inefficient resource utilisation, over-inventory, and missing delivery dates. Computer-assisted scheduling may, therefore, be useful in producing better production schedules”*. He also added: *“the precast plant must be relatively flexible in terms of production scheduling and storage space due to (1) build-to-order makes economies of scale difficult to achieve; (2) multiple projects may be running concurrently; (3) erection requirements and design changes at project sites are always variables; and (4) production, storage, transportation, and erection must be dynamically balanced”*. Moreover, *“during the*

construction process at precast concrete plants, the distribution of production resources, design, and progress management are all dependent on communication and coordination between experienced engineers with strong project skills. One person always does not know all of the technical capabilities and productivity of these project personnel or all of the plant resources of different projects. This would, however, be necessary for optimal planning”.

To reach the required deadlines the planning team should consider all the current resources, such as the precast concrete plant's production area, mould production capability, concrete production, and storage area. Interviewee 10: *“when considering the different workloads and deadlines of each project as well as the different combinations of projects under contract, along with the erection requirements and production and supply characteristics for each project site, project planners must then take into account all of the subsequent production schedules, moulds, and handling plans”*.

The precast production aims to solve problems such as production scheduling, handling space, adjusting of production resources in response to requirements that minimise the project completion time. To satisfy the various constraints, the emphasis is on compressing the schedule with limited resources, using a production line approach, or a full-crew review of the optimisation strategy. However, only a little research has been conducted on precast production planning and optimal decision-making for storage and transportation, increase the company's profits are the important topics for decision makers (Chen et al., 2017). Interviewee 2; *“In practice, we often find that the internal resources are not used most efficiently and logically. Sometimes, we even find that poor decision during the project production and handling”*.

To improve the overall productivity and performance of precast concrete plants, this study looks at real-world projects and constraints such as their production costs, delivery deadlines, storage yard area, machinery and mould resources, and construction workforce. Interviewee 2; *“By using computers and applying the mathematical programming theory, to reach the research objectives, we propose to develop an optimal model for precast production, storage, and transportation that will satisfy project sites' variable requirements, supply and production resources, and storage space resources with the explicit goal of minimizing the cost of production to the company and*

maximizing profits”.

Recent developments in computational methods have also led to novel ways of constructing better production schedules, and it is timely to see what benefits these methods hold for precast scheduling (W. Chan & Hu, 2002). The 1960s and 1970s saw a steady advance in research on efficient planning and scheduling in precast plants. Ziverts in 1976 highlighted the problems faced by the precast concrete industry then in relation to production planning and scheduling, and they described a computer program for estimating labour, scheduling orders, and controlling the flow of raw materials (Ziverts & Bajars, 1976). Afterward, the main features of a proposed information system for planning, cost, and quality control in precast production identified (Warszawski, 1984; Ziverts & Bajars, 1976). In less than ten years after that, a computer-based capacity-planning model for precast concrete building products to help production managers make better planning decisions and explore options developed by (NN Dawood & Neale, 1993). The model used backward planning and simulation techniques in process planning to compare the effects of planning choices.

Interviewee 4: *“Requiring an integrated database for the storage and retrieval of information related to the planning, design and manufacturing for the whole precast concrete components”.*

Design

As the production schedule needs to be adjusted weekly based on the actual production and erection changes at the site (Chen et al., 2017), communication and having a proper planning will help the draughter to finish their work in due date. Interviewee 3: *“preparations needed during project production planning include: confirmation of the engineering drawings, component classification, production resources, and site requirements. Generally speaking, production planning consists of short work cycles and the decision-maker must complete the production schedule for the project as quickly as possible”.*

Yard Management

The precast concrete components in the plant usually involve only typical shapes or configurations, and theoretically, the moulds are repeatedly used for production (Chen et al., 2017). Interviewee 9 also added this point that *“The precast concrete plant delivers the*

components to the site for erection based on the progress of each project”.

Interviewee 4 mentioned that *“The inventory of completed precast components is an important constraint for precast concrete plants. Some precast components are quite large, so the inventory takes up storage space and represents a cost to the company. Faced with limited production space and pressure from project clients on delivery and acceptance, precast concrete plants usually plan their production to build up inventory in advance. This inevitably leads to a shortage of storage space at precast concrete plants as well as difficulties in the component handling”.*

Interviewee 9: *“each project site usually needs several different types of elements. There may be several pieces of elements needed for each type at different due dates. Plant production schedules are obviously tied to site progress and site delivery schedules. Most construction sites do not have much space to stockpile large and bulky elements, so plant operators cannot deliver more elements than specified in the delivery schedule. If elements are produced before their delivery date, they must be stockpiled at the plant itself and will incur inventory cost. Inventory space in the plants is also severely limited. If the inventory elements in stock cannot meet site demand on a given day, delivery is delayed until production meets the demand, thereby incurring contractual penalty costs associated with a missed delivery”.* In the other way, interviewees 2, 6 and 9 added that; *“Sufficient inventory stock levels to be maintained to meet variations in site progress or as a possibility due to delays in the production process”.*

Findings from the interviews revealed 19 constraint factors which cause extra cost to the company. Those categorised under five themes as table 3.

Table 3: Factors constraining extra cost

Department	Factors
Production team	Lack of materials, Daily planning issues, lack of communication, lack of mould utilization and unnecessary mould changeovers.
Draughty and design	Changes in design and Lack of communication with production
Quality Assurance	Late concreting, overproduction and long-time standing of products in yard
Planning and scheduling team	Having no proper planning, Pushing the schedule from clients, Delay on loading the products, Liquid damages and claims due to missing delivery date,

	quality issues and poor decision during production and handling.
Yard Management team	Storage management issues, Unknown site progress and delay in production.

In addition to above interviews and discussions with the experts, the value stream mapping method used to break down the work process of “Super Tees” product into detailed steps. The process steps are then classified as either value added or waste. Table 4 shows how to break down the work process into detailed steps.

To brief illustration, Interviewee 5 noted that *“the workers who are working on a long line casting bed walked lots of km per day”*. Time studies have shown that precast concrete plant personnel typically are paid one to two hours a day for just walking. Walking is not value added and does not transform the product toward what the customer wants. Thus, unnecessary walking is a waste.

Here is another illustration. Interviewee 8 observed that *“one forklift was operating 1 hour each day to lift and shuffle the special steel material from the other side of the site to prepare the next super tee to be poured”*. In reality, the customer is only interested in having the super tee on-time that adds value to the product. The other operations do not add anything to the value of the products in the yard; the customer is not willing to pay for any of those valueless operations. Therefore, those operations according to Ray (2006) are all defined as waste. Table 4 shows some waste which is analysed in that particular product.

Table 4: Value-added and type of waste – Super Tees

Activity	Value Added	Time/ Mins	Type of waste	Time /mins
Mould cleaning	Yes	180	--	--
Reo Tiding	Yes	700	--	--
Welding the beams to place internal formwork	No	--	Processing	120
Transporting cutlers	No	--	Transport	60
Placing cutlers	Yes	180	--	--
Placing the cages	Yes	180	--	--
Placing the strands	Yes	180	--	--
Stressing	Yes	60	--	--
Stressing	No	--	Waiting	240
Waiting for trucks	No	--	Waiting	180
Pouring concrete	Yes	300	--	--
Curing	Yes	60	--	--

Lifting and moving	No	--	Transport	360
Remedial	No	--	Repair	240
Walking	No	--	Motion	180
Smoking	No	--	Motion	120
Total of all activities	55%	1840	45%	1500

The key insight from the information in Table 4 is: 45% of the effort that is expended in this “Super tee” example does not add value to the product, at least from the customer’s viewpoint.

5 Conclusion

Improving the productivity requires the precast concrete plant to change the way it does business, which is not easy. Producers who have successfully implemented a lean manufacturing program are lowering costs, improving productivity, and improving quality. Ultimately, producers following lean manufacturing principals will grow, inspiring new producers to adopt this discipline; indeed, based on the authors’ observations, this is already happening.

This paper shows the lean manufacturing strategies impact on lean waste which is very important to make a better solution for the industry to select a good strategy for related waste as shown in table 4. It will help to save the implemented cost and time also for an industry which results in a high efficiency as shown in Table 3. As it has been shown in Table 5, implementing the lean strategies will reduce those waste times and transform the company into an efficient, smoothly running, competitive, and profitable organisation that continues to learn and improve. Also, the material and information process flow should always receive top priority in improvement activities within production systems. For example, and conventionally, most people simply think that improving transport efficiency refers to the adoption of forklifts or installing conveyors. However, within the process/operation model, improving transport can also mean reducing or even eliminating the transport. In the entire process, improvements should be devoted to the actual operation of transport.

Table 5: The possible lean tools to reduce the possible waste in Super Tee production of the case study plant

Waste activities	Possible lean strategy to improve them
Welding the	• Rapid improvement events (Kaizen)

beams to place internal formwork	- Balanced flow (Takt time) - Standardized task - Visual controls which can be as simple as painting lines on the floor to guide the placement and flow of materials
Transporting cutlers	- plant layout method - Correction at the source, Bed setup reduction, Total preventative maintenance, and Team problem solving,
Stressing	- Workplace organization (5-S) - Balanced flow (Takt time) method, once standard tasks are established, process cycle time and standard staffing can be developed.
Waiting for trucks	time-lapse video recording
Lifting and moving	- time-lapse video recording - plant layout method - work sampling and flow charts - Inventory reduction
Remedial	- mistake-proofing method - Standardized task - Rapid improvement events (Kaizen) - Visual controls which can be as simple as painting lines on the floor to guide the placement and flow of materials
Walking	- time-lapse video recording - plant layout method
Smoking	Visual controls which can be as simple as painting lines on the floor to guide the placement and flow of materials

In table 5, the lean management system concludes the possibility of transforming the case study into a more efficient, smoothly running, competitive, and profitable organisation that continues to learn and improve.

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Capturing construction client values

ABSTRACT: To improve the delivery of construction services, it is important to understand client values. The research aims to capture construction client values. To help achieve this, a systematic literature review was used. The research identifies a knowledge gap in current construction literature and provides a research direction to address the identified gap. As a theoretical contribution to the existing body of knowledge in the construction management domain, this paper focuses on a concept that can help in managing the relationships and the service transactions between clients and service providers. This theoretical work provides an essential basis for satisfying client values.

1 Introduction

In the construction literature, the term construction “refers to a process of delivering value to the client through a temporary production system” and the term client “is a representative for a number of – often conflicting – values, interests and time perspectives” (Bertelsen and Emmitt, 2005).

The provision of satisfactory delivery of construction services with respect to time, cost, and quality has been accepted as clients’ expectations within contractual relationships. However, clients dissatisfaction can be occurred even though explicit time, cost and quality criteria have been achieved (Torbica and Stroh, 2001). This is because clients hold numerous values, with varying degrees of importance.

Continuous improvement of construction services requires a concerted effort to deliver on client values (Egan, 1998; Ahmed and Kangari, 1995). Thus, client values should be the key point of reference for key project participants throughout the project life cycle (British Standard Institute, 2014).

2 Research method

A comprehensive review of relevant literature on client values was conducted to review cutting-edge scholarly contributions in the literature during the last 20 years. Using systematic reviews, 171 (out of 898) research studies were critically analysed to explore the client values. Further details, including the sample-selection procedure, can be found in Aliakbarlou et al., (2017b).

3 Finding

The significance of understanding construction client values has been widely highlighted by a research team at The University of Auckland (Aliakbarlou et al., 2017a; Aliakbarlou et al., 2017b; Aliakbarlou et al., 2017c;

Aliakbarlou et al., 2017d, Aliakbarlou et al., 2017e, Aliakbarlou et al., 2017f, Aliakbarlou et al., 2017g, Aliakbarlou et al., 2017h, Aliakbarlou et al., 2017i). In addition, through a lens of client values, client needs and requirements, reported in the literature, have been identified by Aliakbarlou et al. (2017b). Their findings addressed the client values by which a service provider can manage the relationships and the service transaction in order to develop a system for managing construction delivery practice. Considering the definitions and constituent attributes in the ambit of construction, they argue that there is no broad-brush adherence to the value theory or other related theories by construction scholars.

4 Future Research Direction

Having acknowledged the presence of various subjective and objective preferences on and around the concept of “value” in construction scholarship, future research can aim to build definitions and construct theories around client values. In addition, developing project management strategies to satisfy client values within construction services is an important future research area.

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Fostering Productivity across New Zealand Construction Industry using Innovation

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ABSTRACT

The New Zealand government has set a target to lift the productivity of construction sector by 20% from the year 2010 to 2020; as such, it seems that the traditional building approaches request an urgent revision. This paper is a literature review of previous respective works with the aim of emphasizing on productivity improvement using innovative practices within the process of construction phase; further, the main enablers of innovation across the construction industry are acknowledged. The evidence indicates that innovation could increase productivity as a whole, whereas cooperation among government, industry and academia would constitute the main pillars for boosting productivity during the construction phase by providing conducive arena for construction firms in order to conduct them toward compliance with innovative proceedings.

1 Introduction

Generally, the construction industry is considered as an inefficient industry with poor performance (Aouad, Ozorhon, & Abbott, 2010; Cox & Ireland, 2002) and also perceived as a 'laggard' industry (Suprun, Sahin, Stewart, & Panuwatwanich, 2016), thus it could not attain its objectives include time, cost, quality, health and safety, which are major scales of productivity. To refine this setback, traditional approaches to the process of building should be converted into innovative strategies.

Despite productivity is a well-defined term within the construction industry, innovation is poorly characterized and broadly understood solely in abstract terms, whereas productivity could be promoted through superseding inefficient strategies with novel ones. Since construction industry is a multiparty sector, therefore, its goals could be achieved through close cooperation between respective participants; however, there is a gap in this regard, which impedes holistic implementation of prospective practices.

This paper aims to figure out potential domains for more interaction among main enablers of construction

sector in terms of promoting productivity by utilizing innovation during construction phase.

2 Methodology

This paper is constituted upon previous relevant works associated with productivity and innovation terms through the body of construction industry; first, the importance of productivity in construction industry for economy as well as construction sector itself has been illustrated. Further, the main beneficiaries of construction industry has been represented, and then their potential capacity for instituting mutual collaboration to raise innovation across building phase has been conceptualized. Ultimately, a brief of discussed themes has been drawn.

3 Importance of Productive Construction Industry for Economy

The construction industry comprises one-tenth of "Gross Domestic Product" (GDP) across the world (DCBEA, 2004; Gallaher, O'Connor, Dettbarn, Jr, & Gilday, 2004; Murie, 2007), so as one of the largest contributors of any economy and its subsequent influence on country's GDP, its low profitability (low return on assets or investment) brings concern to economists (Akintoye, Goulding, & Zawdie, 2012; Manley, Blayse, & McFallan).

Evolution in economy, international competitiveness and drawing a bright perspective of economic growth all are extremely depend on rate of productivity. “Productivity isn’t everything, but in the long run it is almost everything. A country’s ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker” (Chan & Kumaraswamy, 1995).

As the construction industry is one of the vital industries that has a significant influence on the world’s economy, immense distribution of infrastructure is perceived as a global development Indicator, so efficient investment on this industry is crucial for any country.

4 Importance of Productivity for Construction Industry

Productivity works as a scale to realize how well resources are deploying to obtain predetermined objectives and desired outputs. Undoubtedly, without creativity and innovation, the business could not grow because only by achieving more outputs with fewer resource inputs (the basic definition of productivity), the opportunity to accelerate the business will be in place otherwise it remains steady and other more efficient competitors would be replaced. However, Low productivity in the construction industry is seen as a great concern and several studies have been focused on the identification of the productivity’s factors.

Generally, growth of productivity reveals amount of change in technical efficiency, technological improvements and evolutions in the external environment and these could be achieved by means of complying best practice frontiers or moving toward higher levels of development by technological change (Chancellor, Abbott, & Carson, 2015). Accordingly, the construction industry needs to improve its outputs not just in terms of enhancing amount of quantity, but the level of quality of its outputs is significantly contribute to productivity improvement.

Inadequate growth in productivity entails increases in construction costs, accompanied by adverse social effects and decreasing work for the industry (Ganesan, 1984). On the contrary, Durdyev and Mbachu (2011) asserted that productivity makes an organization to be competitive, achieve set purposes, meet stakeholder value propositions and maintain strategic and financial health; Moreover from industry perspective, productivity enables the sector to retain satisfied clientele, attract capital, remain viable and contribute to the economic growth and well-being of the nation.

In addition, productivity brings a blend of multi-dimensional evolution include:

- Aspiration of competitiveness across different levels of organization
- Agility in construction
- Boosting quality of finished products
- Enhancing social aspirations as well as the challenges of changing climate, demographic growth, financial constraints and aging infrastructure
- Motivating more cooperation among stakeholders
- Adding value in public procurement
- Completion of the projects held by the company on time and within budget
- Fostering the firms' efficiency and effectiveness
- Identifying the needs for generating the new ideas in order to enhance overall organizational performance and Cost-effectiveness justification of construction investments

5 Innovation in Construction Industry

Nevertheless, a considerable number of research has revealed that productivity in construction can greatly benefit form new technologies, construction industry mostly tends to be stagnant in terms of technology adoption and is generally risk and change averse. It could

be globally assumed that the construction industry is a low-technology sector with low rate of investment on proceeding in terms of innovation (Seaden, Guolla, Doutriaux, & Nash, 2003).

Nowadays, population growth and the complexity of new challenges along with increasing competition between construction firms lead to the highest essentials of innovation deployment. In this regard, there is a diversity of actors' choices and motivations and the processes involved in taking up and using new technologies. Inevitably, diffusion, adoption and transformation of novel ideas are vital to fill the needs and expectations of stakeholders and their aspirations as a whole.

From a global angle, the utilization of innovative technologies and techniques to increase human resource productivity will decrease the issue of more demands for labor and cause a more dynamic business climate, which leads to enhancements of national wealth.

6 Enablers of Innovation in Construction Industry

The construction Industry roots in national social structure so that extensively affected by governmental and other institutional actors. Innovation distribution across a country demands coordination and interaction among a series of activities consist of: industrial, publicly, and user-driven research; knowledge transfer; supply of venture capital; training and education of scientists and engineers; institutions regulating intellectual property and standards; governing innovation policies by government departments; and global collaboration between scientific and technological institutes (Turville, 2007).

Furthermore, incremental innovation requires long-term investment, highly collaborative unions and robust employer associations, effective professional training systems and persistent tight cooperation with research institutes and universities (Matraves, 1997).

Previous literature reviews mostly mention three national pillars as enablers of innovation, namely government, industry and academia that undertake the main responsibility for diffusion and implementation of innovative technologies through interaction and close cooperation.

6.1 Government

As the highest managerial and regulatory entity across the country, government can play an influential role over the process of accurate implementation of innovation in construction industry. The development and regular reviews of national innovation strategies, meanwhile the industry is developing, are significantly effective for more conformation and expanding the domestic capacity.

In keeping with Suprun et al. (2016), government can foster the process of innovation by making a bridge between industry and research institutions through its financial support and systematic incentives. To this core, the government can inspire particular strategies to enable construction firms in terms of developing their internal capabilities and boosting the dynamics of their firms.

As a client, government can motivate and affect other actors by requiring utilization of innovation and science in their routine activities (Andersson, 2003; Edquist, 2010). The motivation toward innovation can be considered preparation of arena to harvest competitive benefits (Porter, 1985). Moreover, governments can create conditions under which respective countries exploit new technologies using an international cooperation (Na Lim, 2014).

Suprun et al. (2016) affirmed the advantages of collaborative partnerships between academia, industry and government, in particular governmental support of innovative pilot projects introduced by research institutes as well as hurdling impediments to construction firms in order for innovative activities.

Na Lim (2014) pointed out the significant effect of public subsidization in construction R&D to improve enterprises' innovation performance.

As a result, Government could exploit forces and opportunities for innovation and consequently stimulate construction firms and their sub-sectors toward adoption of higher level of innovation.

6.2 Industry

The construction industry is recognized with private and public firms, which comprise consultant companies in the field of design and architecture; relevant and supportive industries; material and equipment vendors; and service industry (e.g., building and civil infrastructure contractors and consultants) (Suprun et al., 2016). Adoption and successful implementation of innovation, in a large extent, depend on the existing conducive context provided within industry sectors.

Construction industry is persuading by many factors toward using innovative mechanism to enhance productivity. Industrial specifications such as cooperative structure, project-based approach, wide communication requirements, site complexity, competitiveness, and complex project requirements stimulate moving toward innovation and technology transfer (Tatum, 1986). Additionally, contractual project constraints, such as time and cost, customer expectations, for instance quality and service, performance-based benchmark, governmental regulations/standards, technical specifications, organizational culture and innovation strategies are indicators of pressure on construction companies to innovate (Demirdöğen & Işık, 2016).

6.3 Academia

According to Suprun et al. (2016), academia is recognized: "technical colleges, higher education institutions, and research institutions responsible for providing platforms of knowledge creation and diffusion using fundamental and applied research and training the next generation of industry professionals, and acting as

guardians of the inherited body of knowledge" (Suprun et al., 2016).

Academia, moreover, enhances national innovation efficiency (Manseau & Seaden, 2003; Na, Ofori, & Park, 2006; Winch, 1998) as well as improves construction firm's capability to transform knowledge from research laboratories into applied environment, and further commercializing innovative products, processes and services (Dulaimi, Nepal, & Park, 2005; Na et al., 2006; Seaden & Manseau, 2001; Slaughter, 2000).

Nevertheless, solely providing R&D investment for national institutions is insufficient to stimulate contractors toward innovation (Lim & Ofori, 2007), and in this respect Na Lim and Peltner (2011) recommended that in line with support of developing advanced technological landscape, considering internal capabilities and reinforcing the dynamic aspects of firms by government lead to international competitiveness. In line with the process of dynamic mechanism of applying technology innovation within mega infrastructure projects, identifying the various stakeholders, perfect system and process control are necessary to achieve a bright view of technology innovation (Zhang & Xue, 2014).

The research and development collaboration between industrial and academic research partners leads to competitive advantage in larger enterprises (Schumpeter, 1942) as well as developing applied research for engendering more tangibility of research results across the quality of construction projects and eventually more client's satisfaction of the final product cost (Suprun et al., 2016).

Private and public firms considered as mediators to distribute novel technologies and knowledge of R&D institutions (Winch, 1998). As such, encouraging initiatives might stimulate academia and industry to foster more collaboration and interaction in terms of the process of innovation performance improvement (Gann, 2001).

Developed countries, such as Germany, Japan, South Korea, and the USA, have boosted practical innovation by making a strong connection between industry and research and high education institutions (Hampson, Kraatz, & Sanchez, 2014).

The governments not only can facilitate the process of industrial research but also, with regard to limitation of available resource, might strategically prioritize the investment on and application of research within the industry. Furthermore, architectural, engineering and construction firms can join together to fulfil research activities coherently and share the risks of R&D efforts.

7 New Zealand Construction Industry

The construction industry in New Zealand is significantly laggard in terms of innovation whereas innovative initiatives could improve productivity remarkably (Davis, 2007). Over recent years, enormous passion has been declared with regard to boosting the level of productivity and efficiency across the New Zealand construction industry.

The proportion of construction industry in New Zealand's Gross Domestic Product (GDP) is around \$6 billion per annum (or 4-5%) (*A report to the Construction Strategy Group*, 2011) whereas there are many dependent industries positively affected by the construction brightness. Therefore, the promotion of construction industry leads to business fosterage and economy expansion.

Understanding that New Zealand companies are mostly small to medium size enterprises, this requires their own way of functioning. A significant portion of those get involved in the building sector, but neither can increase housing affordability nor have the reliable financial capacity to invest on innovative productive mechanisms in order to reduce final product cost. Inevitably, if this trend raises more inefficiencies, not only the business would be suffered from it but also the foreign firms would be preceded by domestic ones which means that a huge amount of national capital should be

invested continuously whereas many people would miss their jobs, thereby economic disadvantage and growth of unemployment rate would appear.

Productivity improvement is dramatically tied to economic development and extension of welfare. This fact also extensively affects the condition of entire industries especially in respect of New Zealand construction industry, where affordability of housing is a critical issue that could be alleviated via productivity growth. However, reports ascertain construction in New Zealand has witnessed weak productivity improvement over recent years and this may have wide adverse effects on the nation's "quality of life".

The growth of productivity is associated with close cooperation between different engaged sectors with construction projects. With regard to decreasing trajectory of productivity in the New Zealand construction industry since 2004, government (through the Department of Building and Housing) established "the Building and Construction Sector Productivity Partnership" in November 2010 with the aim of lifting the construction sector productivity by 20% from the year 2010 to 2020 (Fuemana, Puolitaival, & Davies, 2013).

It is noticeable to say that, over the period of 1991 by 2004, the New Zealand construction industry experienced incremental rate of productivity; its most important enablers were population growth, education of people in the industry, research and development, and apprenticeships (Davis, 2007). With the exception of population growth, other experienced factors potentially seem to be achievable in a short period.

8 Conclusion

To conclude, growth of efficiency and productivity within construction industry has a direct effect on economy, so this demands more attention to exploiting most effective alternatives concerned with motivating firms to substitute their traditional mechanisms with modern productive approaches. To this core, a multi

collaboration among engaged partners within construction sector, particularly government, industry and academia, seems to be essential in order for hurdling the obstacles to deficit of efficiency as well as benefiting entire economy.

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Benefits and Issues in Uptake of Smartphone Apps in New Zealand Construction Industry: What Micro and Small Business Perceive

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ABSTRACT: Productivity of New Zealand construction sector is low. Prior research has suggested that smartphone could help construction workers improve efficiency and productivity. This paper reports findings of an exploratory study with the objective of examining the perceived benefits and issues regarding uptake of smartphone apps in small-scale New Zealand construction sector. Results showed that they have a positive attitude towards the benefits smartphone apps could bring. “Internet connectivity” and “Flexibility of apps” are two top issues. These findings provide a starting point for further research aimed at improving the uptake smartphone apps to improve the productivity in construction industry.

1 Introduction and Background

The construction sector in New Zealand employs more than 194,000 people and is a key driver of economic growth with annual revenues of \$30 billion plus (Ministry of Business, Innovation & Employment, 2015). Productivity within construction industry is low compared with other major economic sectors and its productivity has shown practically no growth in the last 20 years (Page & Norman, 2014). The New Zealand government and construction industry has identified productivity growth as a priority (Ministry of Business, Innovation & Employment, 2015). New Zealand Ministry of Business Innovation and Employment encourage better use of digital technologies by small businesses to improve productivity across the economy (Ministry of Business Innovation & Employment, 2017a)

The mobile technology has pervaded both our daily lives and our professional lives. More than 70% of all adult New Zealanders own smartphones while 91% of smartphone users reporting that they use their smartphone every day (Research New Zealand, 2015). Smartphones are portable communication and computing devices. The construction professionals’ workspace is not always confined to a specific office

location. They need to communicate across contractors, suppliers, customers, transporters and regulatory organizations. Hence, smartphone could offer construction professionals a convenient platform to help them communicate relevant on-site information to other stakeholders situated in different locations. Therefore, smartphones can help reduce the time spent on many support functions to increase productivity (Pilat and Lee, 2001).

5 million apps are on leading app stores as of March 2017 (statista, 2017). It can be estimated in that there may be nearly 13,000 construction related development and design apps presently in the market (Yovino, 2013). Construction industry related smartphone apps currently available on the market offer a range of functionalities ranging from simple calculations to project management (Ekow and Kofi, 2016). The smartphone can provide more opportunities for faster data collection and exchange, and improve workflow efficiency (Bowden et al., 2005). Despite the amount of apps designed for the construction industry and the claimed benefits, little information is available on the perceptions of the small-scale construction industry on the value and issues of the smartphone apps (Ministry of Business Innovation & Employment, 2013).

This study reports on an investigation on the perceived of benefits and issues in uptake of construction related apps in New Zealand small-scale construction sector. The next sections discuss relevant literature, including an overview of the New Zealand construction sector, smartphone and smartphone apps. Subsequent discussions are focus on the research methods adopted, including the target population for sourcing the empirical data. The findings in relation to the research objectives are discussed next. Finally the limitations and study contributions are stated.

2 Literature Review

While one of the largest business sector in the New Zealand economy, construction industry productivity is low compared with other major economic sectors like agriculture, forestry manufacturing and service industry (Page and Norman, 2014). The construction industry is one of few industries which has dragged down New Zealand's aggregate productivity growth performance (Conway & Meehan, 2013). New Zealand Ministry of Business defines small businesses as type of enterprise or firm with fewer than 20 employees. In New Zealand, 97% of business have fewer than 20 employees; further 98.5% of construction companies are small businesses (Ministry of Business Innovation & Employment, 2017b, Ministry of Economic Development, 2011). A small business can be further segmented into sub-sectors based on firm size where 'micro' represents businesses with 1 to 5 employees; 'small' represents businesses with 6 to 19 employees. A typical smartphone has (1) computing power, (2) a touch screen display, (3) mobile broadband Internet connectivity or high-speed data transfer, (4) memory or storage, (5) camera (still and video), (6) GPS navigation (7) build-in application or ability to installed application, and many other features (Apple, Google). Portability is one of the important features of smartphone. It is small compared to a laptop for example, iPhone 7 measures 138.30 x 67.10 x 7.10 mm (height x width x thickness) while Google Pixel measures 143.80 x 69.50 x 8.60 mm. It is light-weight (iPhone 7 weighs 138.00 grams while Google Pixel weighs 143.00 grams) (Gadgets360). Smartphones also have long battery life (for example iPhone 7 lasting about 12 hours between charges, while the Galaxy S7 "lasted twice as long" and the HTC 10 lasted about 31 hours) (Crothers, 2016). Moreover they also offer

camera function, which is not normally available in other desktop devices (e.g. PC).

A smartphone app is an application or computer program designed to run on a smartphones since it is built on an operating systems similar to those used in computers. An app is an acronym or abbreviation word to say applications or software programs developed to run on smartphones. 2.8 million Android's apps and 2.2 million Apple's apps are on leading app stores in March 2017 (statista, 2017).

The available construction industry related smartphone apps range from calculator, safety, cost and accounting, project management, computer aided design (CAD), estimating, and building information modelling (BIM), etc. (Apps, 2013, Top Apps, 2013). Liu et al. (2016) Searched "best construction apps" on Google search engine which listed 9 recommender websites (Capterra, Software Advice, SmartBidNet, The Daily Reporter, The balance and tSheets). Among the total 479 apps listed, only four apps (SmartBidNet, PlanGrid, Procore and JobFLEX) have been found to be recommended by more than two websites. Liu et al. (2016) conducted interviews with 14 Master builder reporting the smart phones apps they commonly use. Only 4 of the 27 apps (namely, My Inspection, iauditor, Bimx, LocknLoadHub, BuilderTrend, Basecamp, Workflow max, etc.) mentioned by the New Zealand interviewees were listed in the global search results.

Many apps have software bugs and limited functionality (Sattineni and Schmidt, 2015). Unless tailor made in-house software, apps could have flexibility issues, which limits customization of functionality to required needs.

Data or files need to remain identical in more than one location. But Network or server problem could cause data synchronization issues, data or files do not remain identical in more than one location (Sattineni and Schmidt, 2015).

To transfer files, smartphone needs Internet access. Mobile data needs to be transferred through the data plan if it is out of Wi-Fi range. This can make app usage costly. For example, Spark charges about \$70 for 6GB per month (Spark, 2017). Wi-Fi or data coverage unavailability is issue found form USA construction survey (Sattineni and Schmidt, 2015).

Workers might be distracted by mobile phones which cause productivity loss and safety issues (Sattineni and Schmidt, 2015).

The New Zealand construction sector is unique in many respects, such as tradition, scale and regulations.

Overseas findings relating to the topic may not be fully applicable in the New Zealand context given its unique characteristics.

Knowing the perspectives on value and issues of smartphone apps uptake in small construction companies would be useful to help small businesses to better use digital technologies for improving productivity. This study is a step in that direction.

3 Research Questions and Method

The research questions are:

- What are the popular apps used in New Zealand construction industry?
- What are the perceived benefits of the use of smartphone apps in small construction companies in New Zealand?
- What are the issues to uptake of mobile technologies in small construction companies in New Zealand?
- Are there any different views between 'micro' and 'small' construction companies towards the benefits the smartphone apps might provide?
- Are there any different views between 'micro' and 'small' construction companies towards the issues of uptake the smartphone apps?

Answers to the above research questions are not known, especially in the current New Zealand context. To provide answers to the research questions, two stages of survey methods were applied.

In the first stage an exploratory survey method was applied to explore the key constructs expressed in the research questions. The choice of this research method was justified on two grounds. Firstly, exploratory surveys are suitable for research where the aim is to generate constructs or theories which will be validated in future quantitative research (Zikmund et al., 2013). Secondly, the method is suitable for empirical data that are qualitative in nature and for which scale of measurement is ordinal (Bryman and Bell, 2015). Therefore the qualitative components of the empirical data for the research were obtained through in-depth interviews conducted with 14 members of the New Zealand Registered Master Builders (RMB). While the sample size used was small, it was in line with the exploratory nature of the study – i.e. to explore social phenomenon as against quantitative experimentation. Through the first stage in-depth interviews conducted with 14 members of RMB and insights gained from previous related

research studies, we identified the eight benefits of using mobile phone apps as follows: (1) more efficient management of checklists, documentation and sign-offs, (2) greatly improve efficiency and accuracy of site inspections and reporting, (3) better client relationship management and satisfaction, (4) more efficient employee or subcontractor timesheet management, greater visibility into workforce productivity, performance monitoring and evaluation, (5) greatly reduce liability and risks through accurate and prompt compliance reporting, (6) ability to more accurately and efficiently price and track change orders, (7) more accurate customer invoicing and real time tracking for prompt payments, and (8) overall improvement in productivity and profit margin on the job;

The nine issues of using mobile phone apps are as follows: (1)Internet connectivity issues, (2)Flexibility issues or inability to customise functionality to specific needs, (3)Steep learning curve required to get up to speed with the use, (4)Software bugs and limited functionality issues, (5)Cyber security concerns about classified information, (6)Data synchronization issues, (7)Device too fragile for rugged construction environment, (8)Worker distractions causing productivity loss and safety issues, and (9)Associated mobile data costs

In the second stage of data gathering, questionnaire was designed based on feedback from the in depth interviews and insights gained from previous related research studies (Ikediashi et al., 2016, Azhar and Cox, 2015). Before the questionnaire distributing to the study sampling frames, the questionnaire was pretested by industry professionals to identify any problems or unclear of questions. These were reworded for clarity and relevance with a view to improving the capability to generate good responses. The survey started with a brief description of the aims and objectives of the research, expecting time to complete, the benefits for participating in the research and participants' rights. Participants were assured that their survey responses would be confidential and anonymous. The first part was used to collect data about the respondents' perceptions of the benefits, barriers and issues of using smartphone in the New Zealand construction industry. Those survey questions were ranked degree of agreement to disagreement using a 5 point Likert scale. The second section of the questionnaire looked at demographics information including the respondents' company size. The questionnaire was hosted online and links were

provided in emails requests to the members of the New Zealand Registered Master Builders (RMB), Licensed Building Practitioners (LBP), New Zealand Institute of Building (NZIOB) and New Zealand Institute of Architects (NZIA). All the members of those construction affiliations were given the chance to reply.

The analysis comprises two steps. First the means of benefits, barriers and issues using apps from 'micro' and 'small' construction companies are calculated. Then 2-sample t-test is used to determine whether the means of the view of benefits, barriers and issues between 'micro' and 'small' construction companies differ.

4 Results and Discussions

This section presents the results of the questionnaire survey. 39 responses from micro company and 44 responses from small company were received. Among the 83 responses, 80 answered all the questions. The exploratory nature of the study meant, we wanted to first obtain the demographic profile of interviewees. 70.45% of the interviewees were in the top management having roles such as CEO or director in their company, while 16% were in the middle management having roles such as project/construction or site manager, rest are sole-trader, architect, engineer, quantity surveyor and consultant.

Popular Apps

Among the 38 listed apps shown in table 1, only four apps were selected by more than 10 construction professionals as shown in figure 1. The four apps are:

- Dropbox: Offers cloud storage, file synchronization and client software.
- Xero: Accounting software for small and medium-sized businesses.
- MetService: Weather Forecasts, including Radar Maps and NZ Weather Maps.
- HazardCo: Review and manage health and safety in workplace

Table 1: List of Apps

Dropbox	Xero	MetService
MYOB	Workflow max	Aconex
SafetyMate	Co-construct	SmartBidnet
PlanGrid	CONQA	Corecon
Adobe Photoshop	NZTA Zero Harm	Basecamp
T-Sheets	Box	60 Panorama
NZTA Zero Harm	AutoCAD 360	Converter Plus
BuilderTREND	LocknLoadHub	BIMx
HazardCo	iAuditor	BuildIT
Harvest	Procore	IFixit
Builders Buddy	Handyman Calculator	
Timelines - Time Tracking		JobFLEX Fieldwire
Responder (Site Safety Manager)		MyScript Calculator
My Inspection (Auckland Council's builders' app)		

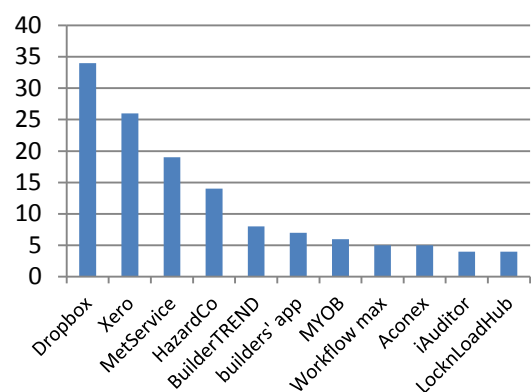


Figure 1: Popular Apps Used in New Zealand Construction Industry

The top three selected apps are general use apps which are not designed for construction specifically.

Among the most recommended construction apps (SmartBidNet, PlanGrid, Procore and JobFLEX), only one interviewee selected PlanGrid. None of interviewees selected SmartBidNet, PlanGrid, and JobFLEX. This could be due to the fact that these apps are more linked to a specific country's environmental and construction business context.

Perceived benefits of app use

The participants were provided with a list of potential benefits offered by smartphone apps and asked to rank their disagreement or agreement over a 5 point

Likert scale which ranged from 1-strongly disagree, 2-disagree, 3-neither agree nor disagree, 4-agree to 5-strongly agree. As shown in table 2 and figure 1, the means of all eight benefits are above 3. This means that respondents have average positive views of benefits that the smart phone apps can bring. The top three agreeable benefits of using apps are "More efficient management of checklists, documentation and sign-offs", "Greatly improve efficiency and accuracy of site inspections and reporting" and "Better client relationship management and satisfaction".

Table 2: Perceived benefits of the use of smartphone apps

Benefits	Mean
More efficient management of checklists, documentation and sign-offs	3.6905
Greatly improve efficiency and accuracy of site inspections and reporting	3.6829
Better client relationship management and satisfaction	3.675
Ability to more accurately and efficiently price and track change orders	3.622
More efficient employee or subcontractor timesheet management, greater visibility into workforce productivity, performance monitoring and evaluation	3.6145
Greatly reduce liability and risks through accurate and prompt compliance reporting	3.5679
More accurate customer invoicing and real time tracking for prompt payments	3.5
Overall improvement in productivity and profit margin on the job	3.3902

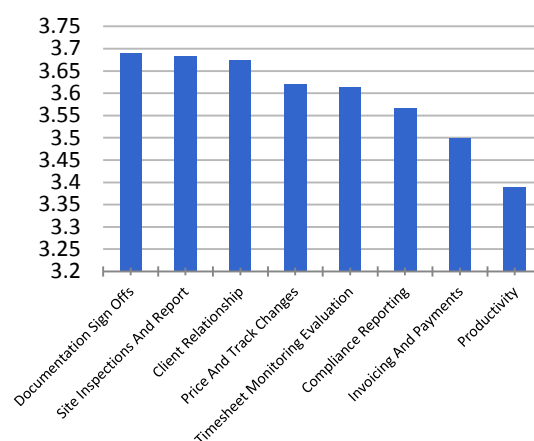


Figure 2: Perceived benefits of the use of smartphone apps

Then the means of responses for the benefits of smartphone apps between micro businesses and small businesses are compared. The results are shown in table 3. The p value is > 0.05 except for B4. There are no significant difference in views between the micro businesses and small businesses towards the benefits the smartphone apps might provide except, one (i.e. "more efficient employee or subcontractor timesheet management, greater visibility into workforce productivity, performance monitoring and evaluation").

Small businesses consider smartphone apps could help construction industry with "more efficient employee or subcontractor timesheet management, greater visibility into workforce productivity, performance monitoring and evaluation" as compared with micro businesses value it.

Table 3: Two-Sample T-Test results of perceived benefits of the use of smartphone apps

Benefits of the use of mobile technology	Mean Micro	Mean Small	p
More efficient management of checklists, documentation and sign-offs	3.537	3.837	0.122
Greatly improve efficiency and accuracy of site inspections and reporting	3.525	3.833	0.082
Better client relationship management and satisfaction	3.538	3.805	0.147

More efficient employee or subcontractor timesheet management, greater visibility into workforce productivity, performance monitoring and evaluation	3.350	3.860	0.007
Greatly reduce liability and risks through accurate and prompt compliance reporting	3.550	3.585	0.841
B6:Ability to more accurately and efficiently price and track change orders	3.550	3.690	0.459
More accurate customer invoicing and real time tracking for prompt payments	3.375	3.619	0.204
Overall improvement in productivity and profit margin on the job	3.250	3.524	0.142

To find if there are different views of overall benefits, all the rated values of benefits were added together, the Two-sample test was applied. The result shows that the P value is greater than 0.05, which means there is no significant different views between the micro business and small businesses towards the aggregated benefits the smartphone apps might provide (as shown in table 4).

Table 4: Two-Sample T-Test Results of total perceived benefits of the use of smartphone apps

Benefits of the use of smartphone apps	Mean (Micro)	Mean (Small)	P
Total Benefits	27.00	26.60	0.795

Perceived issues of app use

The participants were provided with a list of identified issues of using smartphone apps and asked to rank their disagreement or agreement over a 5 point Likert scale which ranged from 1-strongly disagree, 2-disagree, 3-neither agree nor disagree, 4-agree to 5-strongly agree. As shown in table 5 and figure 3, the means of all nine issues are above 3. This means that the average responses agree with the issues of using

the smartphone apps. The top two agreeable issues are “Internet connectivity” and “Flexibility issues or inability to customise functionality to specific needs”.

Table 5: Perceived issues of the use of smartphone apps

Issues	Mean
Internet connectivity issues	3.639
Flexibility issues or inability to customise functionality to specific needs	3.5301
Steep learning curve required to get up to speed with the use	3.482
Software bugs and limited functionality issues	3.4268
Cyber security concerns about classified information	3.337
Data synchronization issues	3.321
Device too fragile for rugged construction environment	3.289
Worker distractions causing productivity loss and safety issues	3.253
Associated mobile data costs	3.193

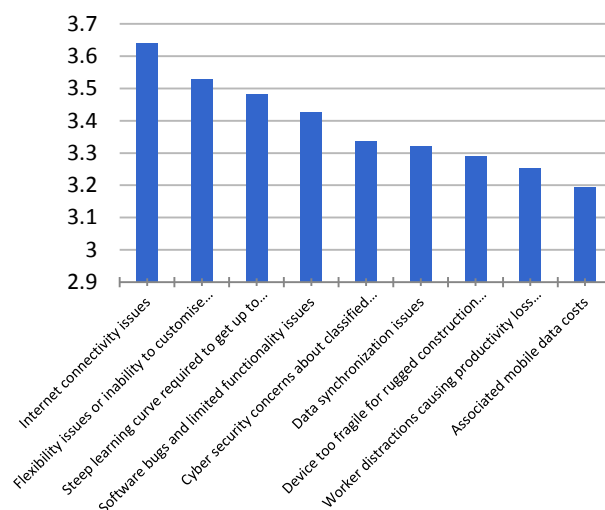


Figure 3: Perceived issues of the use of smartphone apps

The means of aggregated responses for the issues of smartphone apps between micro businesses and small businesses are compared. The results are shown in table 6. All the p value is > 0.05. There are no significant difference views between the micro businesses and small businesses towards the perceived issues of the uptake of smartphone apps.

Table 6: Two-Sample T-Test results of perceived issues of the use of smartphone apps

Issues of the use of mobile technology	Mean Micro	Mean Small	P
Worker distractions causing productivity loss and safety issues	3.36	3.16	0.411
Cyber security concerns about classified information	3.513	3.18	0.121
Internet connectivity issues	3.718	3.568	0.474
Data synchronization issues	3.324	3.32	0.978
Steep learning curve required to get up to speed with the use	3.538	3.432	0.613
Software bugs and limited functionality issues	3.368	3.477	0.555
Associated mobile data costs	3.308	3.09	0.308
Device too fragile for rugged construction environment	3.462	3.14	0.140
Flexibility issues or inability to customise functionality to specific needs	3.590	3.477	0.547

To find if there are different views of aggregated issues, all the rated values of issues were added together, the Two-sample test was applied. The result shows that the P value is greater than 0.05, which means there is no significant different views between the micro business and small business towards the aggregated issues of uptake the smartphone apps as shown in table 7.

Table 7: Two-Sample T-Test Results of aggregated issues of the use of smartphone apps

Issues of the use of smartphone apps	Mean (Micro)	Mean (Small)	P
Total Issues	29.75	27.94	0.318

5 Conclusions

This research has investigated perceived benefits and issues of uptake smartphone apps by the micro business and small business in New Zealand construction industry. Both micro business and small business have a positive attitude towards the benefits smartphone apps could bring. Small businesses think that smartphone apps could help construction industry with “more efficient employee or subcontractor timesheet management, greater visibility into workforce productivity, performance monitoring and evaluation” than micro businesses view of it.

There is no significant difference view between the micro business and small business towards the issues of the uptake of smartphone apps. “Internet connectivity” and “Flexibility of apps” are two top issues of use smartphone apps in small New Zealand construction business.

This study is not without limitations. The views expressed represent only 88 construction professionals which is a small percentage of construction professionals workforce. Hence the view cannot be generalized beyond the study’s scope. However, it provides a snapshot of the micro and small business views and challenge uptake of smartphone apps in the New Zealand construction sector.

These findings provide a starting point for further research aimed at improving the uptake and leveraging of smartphone apps to improve productivity in the construction industry.

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Estimate the ventilation rate in two New Zealand primary classrooms

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ABSTRACT

The ventilation rate in two classrooms from a New Zealand primary school was investigated. Real time carbon dioxide (CO₂) concentration was measured during winter (from June to September) in 2013. The ventilation rate was estimated using the mass balance analysis on an hourly basis. The air stuffiness of classrooms was estimated. Results showed CO₂ concentration was between 1400ppm and 5000ppm for around 70% of school hours in Room23. Ventilation rate in the classrooms was always lower than the recommendation from New Zealand Standard 4303:1990. The air was qualified from high to very high stuffiness level for both classrooms during school hours. This study result showed a need for increasing ventilation in New Zealand primary schools during winter.

1 Introduction

New Zealand has 1961 primary schools, which consists of 1078 full primary, 766 contributing and 117 intermediate school (Ministry of Education, 2014). Ninety percent of the classrooms within these primary schools are naturally ventilated through open windows (McIntosh, 2011). New Zealand Building Code has recommended an occupant's density of 0.5 users per m² in classrooms (Department of Building and Housing, 2011). Due to the combination of a reliance on natural ventilation and a high density of occupants, it is challenging to provide an adequate ventilation rate and consequently acceptable indoor air quality (IAQ) during the winter months (Jurelionis & Seduikyte, 2008).

An adequate ventilation rate will expel moisture, bacteria and chemical compounds from the indoor environment, and should significantly benefit occupants' health (Canha, Almeida, Freitas, Täubel, & Hänninen, 2013; Kim et al., 2007; Smedje & Norbäck, 2000). Natural ventilation (driven by wind or buoyancy through open windows, doors and vents) and mechanical ventilation (using a powered fan) are the two ventilation methods. The total ventilation rate is equal to the sum of natural ventilation, mechanical ventilation and infiltration/exfiltration. Infiltration/exfiltration refers to air moving through leakages of a building envelope (CEN, 2006), which is related to the wind direction, building orientation, ventilation strategy, internal to external temperature gradient, occupants' behavior and building envelope airtightness. The total ventilation rate is equivalent to the

air change rate, which is reported as the number of air changes per hour (ACH or ac/h), meaning the number of room volume per hour that are being displaced with outside air. Some studies found the inadequate ventilation rate was strongly associated with the prevalence of health symptoms (Daisey, Angell, & Apte, 2003; Sun, Zhang, Bao, Fan, & Sundell, 2011).

In New Zealand, four studies have investigated the ventilation rate in primary schools (Bassett & Gibson, 1999; Cutler-Welsh, 2006; McIntosh, 2011; Wang et al., 2014, 2016). Among these four studies, Bassett and Gibson (1999) estimated the ventilation rate using CO₂ levels and measured the classroom infiltration rate. Cutler-Welsh (2006) and Wang et al. (2016) reported CO₂ levels and the percentage of school hours had CO₂ measurements below 1000 ppm.

In this study, the ventilation rate in two naturally ventilated Palmerston North (New Zealand) primary classrooms was investigated using build-up mass balance analysis method. The CO₂ level in classrooms and the percentage of school days had different CO₂ measurements were reported. The air stuffiness level in classrooms was also estimated using air stuffiness index and compared with European levels.

2 Ventilation rate estimation

Carbon dioxide (CO₂) concentration can be used to estimate the ventilation rate. Table 1 shows the guidelines for CO₂ levels and their corresponding ventilation rates from American Standard ASHRAE-62,

European Standard EN-13779 and British Standard Building Bulletin 101 (BB101).

As shown in Table 1, the recommended indoor CO₂ levels and ventilation rates are different in different standards. EN-13779 divides the indoor air into four categories of IAQ based on the indoor CO₂ levels; low IAQ, moderate IAQ, medium IAQ and high IAQ. BB101 defines the daily mean CO₂ level, the minimum ventilation rate in the naturally ventilated classroom and the minimum daily average ventilation rate. Based on ASHRAE-62, the New Zealand Standard "Ventilation for Acceptable Indoor Air Quality" states 8 litres of fresh air per second (l/s) per person in a classroom should be provided with an assumed maximum occupant's density of 0.5 users/m², and it should result in a CO₂ level below 1000 ppm (NZS, 1990).

Table 1: Guidelines for CO₂ and ventilation rate in schools.

Documents and reference		Indoor CO ₂ (ppm)	Ventilation rate (l/s/person)
ASHRAE 62 (ASHRAE, 2007)		1000	8
EN-13779 (CEN, 2007)	Low IAQ ^a	> 1400	< 6
	Moderate IAQ	1000 – 1400	6 – 10
	Medium IAQ	800 – 1000	10 – 15
	High IAQ	< 800	> 15
Building Bulletin 101 (BB101, 2005)		1500 ^b	3 ^d
		5000 ^c	5 ^e
			8 ^f

^a IAQ, indoor air quality; ^b daily mean level; ^c maximum daily level; ^d minimum ventilation rate in naturally ventilated classrooms; ^e minimum daily average ventilation rate; ^f classroom should be of the capability of achieving it.

Build-up CO₂ mass balance and steady-state CO₂ mass balance are widely used to estimate ventilation rate. Both estimations are conducted under assumptions that air is well-mixed in the single zone place; ventilation rate and the net rate of CO₂ generation are constant (Boulic, 2012). Chen (2009) reported that this assumption is acceptable for small rooms, i.e. small office, hotel rooms, bedrooms. But for large rooms, like theaters, hotel lobbies and gymnasias, the well-mixed assumption might not be acceptable. Classrooms could also be considered as a well-mixed zone taking into account its average size

and the high density of occupants (Basset, personal contact).

2.1 CO₂ mass balance

In classroom environment, CO₂ build-up mass balance equation (Eq. (1)) can be described as the CO₂ generated in classrooms plus the CO₂ coming into classrooms from outside minus the CO₂ exhausted from classrooms is equal to the net change of CO₂ in classrooms (ASTM, 1998; Bearg, 1993).

$$V dC(t)/dt = S + FVC_{out} - FVC(t) \quad \text{Eq. (1)}$$

Where,

V = classroom volume (m³)

$dC(t)/dt$ = net change in CO₂ concentration at time t (mg*m⁻³*h⁻¹)

S = CO₂ generated in classrooms at time t (mg*h⁻¹)

F = number of air change per hour (h⁻¹);

C_{out} = CO₂ concentration coming from outside (mg*m⁻³);

$C(t)$ = CO₂ concentration in classrooms at time t (mg*m⁻³);

The CO₂ generation rate from occupants metabolic depends on occupant's activity, age, weight, height and respiratory (ASHRAE, 2013; ASTM, 2012). ASTM (2012) reports CO₂ generation rate of 0.0052 l*s⁻¹ for an average-sized adult and of 0.0029 l*s⁻¹ for an average-sized child at the office work (writing and desk, similar to classroom work). This generation rate was adopted as students' CO₂ generation rate in the classroom when they are engaged in the school work. Sun et al. (2011) used CO₂ build-up mass balance method to estimate ventilation rate in classrooms. The calculation of CO₂ change rate at different time interval was undertaken. The ventilation rate was estimated with the least squared method, finding out the most fitted theoretical exponential curve.

When the CO₂ generated from occupants plus the CO₂ coming into classrooms from outside is equal to the exhausted CO₂ from classrooms, the net change in CO₂ concentration is equal to zero. This specific circumstance is called steady-state CO₂ mass balance. The steady-state would be achieved with sufficient time and constant ventilation rate and the net rate of CO₂ generation. The equation of steady-state CO₂ mass balance is as Eq. (2).

$$FVC_{(ss)} = S + FVC_{out} \quad \text{Eq. (2)}$$

Where,

F = number of air change per hour (h⁻¹);

V = classroom volume (m³)

$C_{(ss)}$ = the steady-state CO₂ concentration (mg*m⁻³);
 S = CO₂ generated in classrooms at time t (mg*h⁻¹)
 C_{out} = CO₂ concentration coming from outside (mg*m⁻³);

Shaughnessy, Haverinen-Shaughnessy, Nevalainen, and Moschandreas (2006) used steady-state CO₂ mass balance to estimate ventilation rate of a room. In this study, mean CO₂ concentration during the monitoring period was regarded as the steady state CO₂ concentration (Shaughnessy et al., 2006). The results found using daily mean CO₂ concentration as the steady-state CO₂ concentration to estimate ventilation rate resulted in an overestimate of the actual ventilation when the ventilation were extremely lower. It also resulted in an underestimate of the actual ventilation rate when the room was not fully occupied in some conditions, i.e. lunch breaks, playground breaks. Haverinen-Shaughnessy, Moschandreas, and Shaughnessy (2011) compared the estimated ventilation rate in classroom calculated using build-up CO₂ mass balance analysis and steady-state CO₂ mass balance analysis. The peak CO₂ concentration measured during the school hours was used at the steady-state CO₂ value. It found the estimated ventilation rate using build-up mass balance analysis and steady-state mass balance analysis was significantly correlated (Pearson correlation 0.886). But under the lower ventilation rate, the steady-state approach (using the peak value) might under predict the ventilation rate.

2.2 Index of Air Stuffiness in Schools (IASS)

Index of air stuffiness in schools (IASS) was developed by French Indoor Air Quality Observatory based on both the intensity and the frequency of CO₂ level between 1000ppm and 1700ppm (Riberon, Derbez, Lethrosne, & Kirchner, 2011). The CO₂ level of 1700ppm was chosen because in France the difference between indoor and outdoor CO₂ concentration of 1300 ppm in non-smoking and non-residential public buildings is required (RSDT, 1978). Given the ambient CO₂ level of 400ppm, the indoor CO₂ level should be lower than 1700ppm. The IASS is a tool to inform occupants of the ventilation management. It is mandatory to monitor IASS in public building in France (Canha et al., 2016).

Table 2 shows the IASS, adapted from (Ramalho, Mandin, Riberon, & Wyart, 2013). It ranges from 0 (sufficient ventilation, no air stuffiness) to 5 (extreme air stuffiness). A score of 0 means CO₂ level is always below 1000ppm; a score of 5 means CO₂ level is always above 1700ppm. Scores from 1 to 4 correspond to a ratio of CO₂ level

exceeding either 1000ppm or 1700ppm.

Table 2: Index of air stuffiness in schools (IASS), adapted from (Ramalho et al., 2013)

IASS score	Frequency of CO ₂ values (ppm)			Air stuffiness
	> 1000	1000 ~ 1700	< 1700	
0	100%			Fresh air (no air stuffiness)
1	2/3	1/3		Low air stuffiness
2	1/3	2/3		Average air stuffiness
3		2/3	1/3	High air stuffiness
4		1/3	2/3	Very high air stuffiness
5			100%	Extreme air stuffiness

The calculation of IASS using CO₂ measurement is given in Eq. (3), adapted from (Riberon et al., 2011).

$$IASS = [2.5 / \log_{10}(2)] \log_{10}(1 + f_1 + 3f_2) \quad \text{Eq. (3)}$$

Where,

f_1 = the proportion of CO₂ values between 1000 ppm and 1700 ppm;

f_2 = the proportion of CO₂ values above 1700 ppm;

The CO₂ measurement during school hours in the normal occupancy (more than half students attended) was used to calculate the IASS in French classrooms (Canha et al., 2016). The final IASS for a given classroom was the score rounded to the nearest integer and corresponding to one of the six categories of air stuffiness (0 to 5).

Ramalho et al. (2013) investigated the air stuffiness and air change rate in 896 classrooms or child playrooms from 310 schools and day-care centers based on CO₂ measurements. The IASS of the investigated classrooms was the average of two weekly scores. This study found 65% of elementary schools were with IASS score 3 and 4. 5% of schools with the IASS score 2. 50% of day-care centers and nursery schools were with IASS score 1 and 2. Canha et al. (2016) investigated the IASS in 42 French schools. This study found the similar result to Ramalho et al. (2013). Around 60% of classrooms were with the IASS scores of 3 and 4. The IASS scores in elementary schools were higher than in day-care center and nursery schools.

2.3 Study objectives

In New Zealand, there were researches investigating CO₂ concentration in primary schools, but no research estimates ventilation rate with the build-up CO₂ mass balance, neither the IASS in primary schools. This study is

a case study to estimate the ventilation rate using build-up mass balance and air stuffiness in two naturally ventilated classrooms. The fieldwork was conducted in Palmerston North, New Zealand, during winter (from June to September).

3 Methodology

3.1 Research design

This research was carried out in Palmerston North (New Zealand, southern hemisphere) during winter (from June to September). Two classrooms from one school were selected. These two classrooms were located side-by-side, with very similar heating, building characteristics and population characteristics. Figure 1 shows a planview of the two selected classrooms, the location of environment monitoring equipment, the heater, the desk, windows and doors.

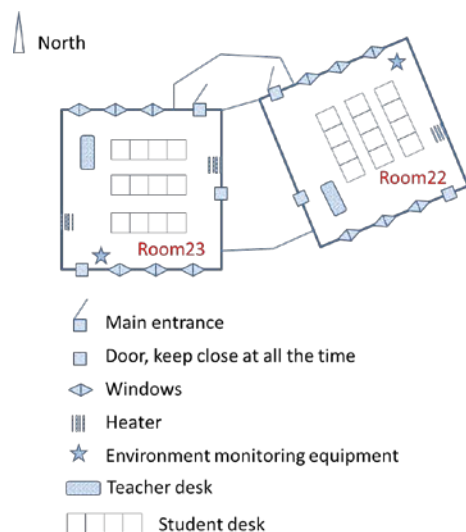


Figure 1: Simple planview of the two selected classrooms and the location of environment monitoring equipment, the heater, the desk, windows and doors.

The two classrooms had the same volumes of 175.8m³. The building azimuth angle of Room22 and Room23 was -18.5° and 0° respectively, meaning Room23 is facing due north. There were no mechanical ventilation systems in both classrooms. The same wall mounted electric heater (SKOPE, 981Q) was used in the two classrooms. There was one heater installed in Room22 while two heaters were in Room23. There is a store room between the two classrooms. The door connecting classrooms and store room was kept closed at all the time. Outside the entrance door, there is a cloakroom. There were 29 and

31 pupils in Room22 and Room23 respectively.

Real-time classroom CO₂ concentration had been measured by a Gas Probe IAQ monitor (BW Technologies Ltd, Calgary, Canada) at 2-mins interval during occupied (weekday school hours) and unoccupied (night, weekends, school holidays) periods. The devices were checked and calibrated before the commencement of the fieldwork and rechecked following the fieldwork.

3.2 Data analysis

In this study, the ambient CO₂ concentration of 400ppm was assumed to be the baseline. This outside CO₂ level is accepted in European Standard (CEN, 2007). The CO₂ generation rate is 0.0052 l*s⁻¹ per teacher and 0.0029 l*s⁻¹ per student (Persily & de Jonge, 2017). The CO₂ molecular weight of 44.01 g*mol⁻¹ and CO₂ standard molecular volume of 22.4 l*mol⁻¹ were used to calculate the CO₂ generation for the unit of mg*h⁻¹ in classrooms. The hourly air change rate in classrooms was estimated using build-up mass balance analysis. Air stuffiness in schools was estimated using the index scores. Data were analyzed using computer program R version 3.3.3 (www.r-project.org).

4 Result and Discussion

4.1 The ambient air temperature during the fieldwork

The ambient temperature data were retrieved from New Zealand National Climate Database (NIWA), with the closest monitoring station located at the Palmerston North airport. The distance between the climate monitoring station and this participated school was less than 2km. Table 3 shows the monthly mean temperature (24-hour/school hours) in Palmerston North during the fieldwork.

Table 3: The monthly mean temperature (24-hour / school hours) in Palmerston North in 2013 from June to September.

Month	24 hours temperature, °C (mean, ±95% CI)	School hours (9am to 3pm) temperature, °C (mean, ±95% CI)
June	9.62 (9.35, 9.89)	11.62 (11.14, 12.1)
July	9.61 (9.39, 9.83)	11.50 (11.14, 11.86)
August	10.95 (10.75, 11.15)	13.16 (12.82, 13.46)
September	11.45 (11.2, 11.7)	13.72 (13.36, 14.08)

Table 3 shows in 2013, June and July had similar daily mean temperature (9.6 °C). The daily mean temperature in August and September was around 11 °C and 11.5 °C respectively. The school hours (9am to 3pm) daily temperature ranged from 11.50°C to 13.72°C. This level was 2 °C higher than the monthly daily averaged

temperature. However they were lower than World Health Organization and New Zealand recommended minimum temperature (18°C) in classrooms. This implies natural ventilation would cause a large amount of energy consumption, given the classroom with a temperature of 18 °C (WHO recommended temperature in classrooms).

4.2 The carbon dioxide concentration

The monthly CO₂ concentration distribution in the two classrooms from June to September is shown in Figure 2.

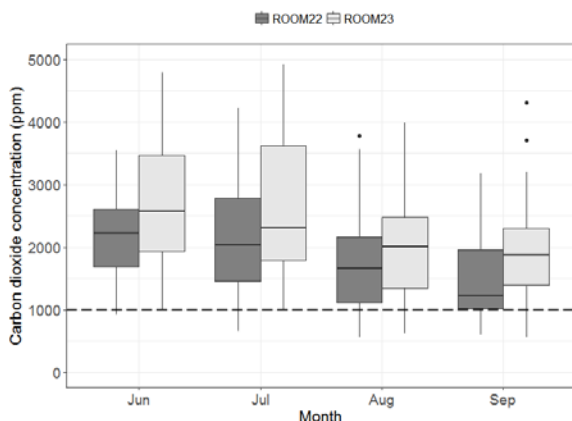


Figure 2: Carbon dioxide (CO₂) concentration in Room22 and Room23 during school hours from June to September (dashed line is NZS4303 recommends CO₂ level in schools)

The median CO₂ concentrations in both rooms in different months were all above 1000ppm (NZ Standard NZS4303 recommended CO₂ level in school environment). This was related to a low ventilation rate in classrooms. Figure 2 also showed CO₂ levels in Room22 was lower than in Room23. The CO₂ concentration in July was the highest, followed by August. The CO₂ concentration in September was lowest compared with the other three months. This could be explained with the warmer ambient temperature in September. As the ambient temperature increase, the amount of time that windows or doors were open was expected to be longer. This resulted in an increase of the natural ventilation and a decrease of indoor CO₂ level. The percentage of school hours with different CO₂ concentrations is shown in Figure 3. Based on EN 13779, CO₂ concentration was categorized into four groups to indicate the IAQ in classrooms. They are low IAQ with the CO₂ level above 1400ppm; moderate IAQ with the indoor CO₂ level from 1000ppm and 1400ppm; medium IAQ with the indoor CO₂ level between 800ppm and 1000ppm and high IAQ with the indoor CO₂ level less than 800ppm (CEN, 2007).

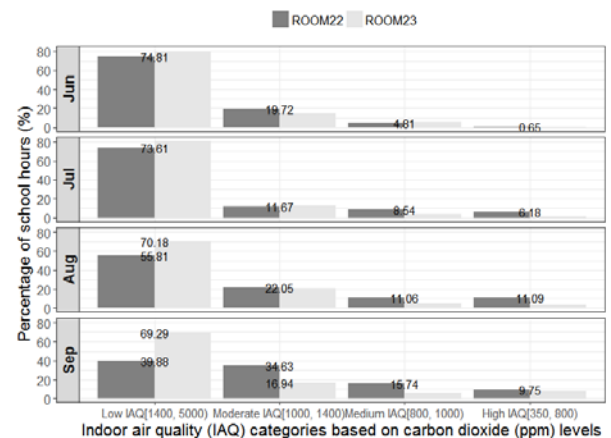


Figure 3: Percentage of school hours with different indoor air quality based on carbon dioxide levels from June to September

As shown in Figure 3, CO₂ levels between 1400ppm and 5000ppm were found for around 70% of the school hours in both rooms in June and July. This figure occurred in August and September as well in Room23. In Room22, this figure reduced to 56% and 40% in August and September. The percentage of school hours with CO₂ levels below 1400ppm in June (25% in Room22, 21% in Room23) was about half of the figure in September (60% in Room22, 31% in Room23). Percentage of school hours with CO₂ levels found in this study was different from McIntosh (2011). McIntosh (2011) investigated the CO₂ concentration in 35 New Zealand naturally ventilated classrooms; founding 29 out of 35 classrooms with the daily CO₂ levels below 1000ppm for more than 30% of school hours. However, this result was from one day measurement. The classroom routine and the teacher behavior both affect the result.

4.3 The ventilation rate

Figure 4 shows air change rate (with 95% confidence interval bars) at different school hours in different months in Room22 and Room23. New Zealand standard (NZS4303) recommended 8 liters of fresh air per second per person should be provided. Comply with this standard, around 850 m³ of fresh air per hour should be supplied, assuming 30 children occupied in the classrooms. Room22 and Room23 both had a volume of 175.8m³. This means to meet ventilation requirement, the air in the classroom should be refreshed at least 4.8 times per hour. The horizontal dashed line in Figure 4 is the recommended acceptable ventilation rate in

classrooms from NZS 4303.

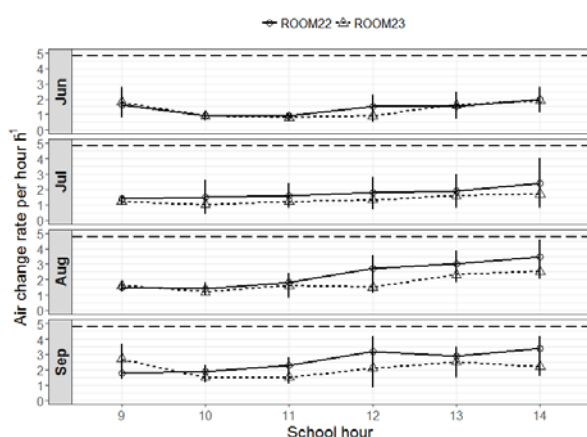


Figure 4: Air change rate (h^{-1}) at different time of school day in Room22 and Room23 in June, July, August and September. Dashed line is the recommended acceptable ventilation rate in classrooms from NZS 4303

The air change rates in Room22 and in Room23 were consistent with the CO_2 levels reported in Figure 3. The mean daily air change rate over the different months was 2.2 h^{-1} (standard deviation: 1.7 h^{-1}) in Room22 and 1.8 h^{-1} (standard deviation: 1.4 h^{-1}) in Room23. This level was below the recommended value from NZS4003 (4.8 h^{-1}).

As shown in Figure 4, air change rate at 10am was the lowest (range: 0.9 h^{-1} to 1.9 h^{-1}). From 11am to 3pm, it was slightly increased. This result was consistent with the ambient temperature increase and the lunch time break activity. This result illustrated an inadequate ventilation rate in classrooms. The air change rate found in this study was similar to Canha et al. (2016). Canha et al. (2016) found the mean air change rate during school hours ranged from 0.3 h^{-1} to 3.1 h^{-1} among 51 classrooms from 17 primary schools, with a mean value of $1.4 \text{ h}^{-1} \pm 0.6 \text{ h}^{-1}$. Haverinen-Shaughnessy et al. (2011) investigated the ventilation rate in 100 classrooms from two elementary schools. They found 87 out of 100 classrooms with a ventilation rate below the ASHRAE-62 recommendation. The mean ventilation rate was 4.25 l*s^{-1} per person (standard deviation: 2.26 l*s^{-1} per person) among all the classrooms. These studies illustrated an inadequate ventilation rate in classrooms.

4.4 Index of Air Stuffiness in Schools (IASS)

The IASS over 12 weeks in Room22 and Room23 was 3 and 4 respectively. IASS score 3 and 4 mean high air stuffiness and very air stuffiness respectively as presented in Table 2. The mean IASS was 3.48 (the

nearest integer is 3) in Room22; Six weeks had IASS of 3 and six weeks had IASS of 4. In Room23, 11 of 12 weeks had IASS of 4. The extremely air stuffiness (5 score) was found in one week.

Canha et al. (2016) found the IASS score in naturally ventilated primary school during heating seasons ranged 1 to 4 in eight different schools. In three schools, all the investigated classrooms (8) were with the IASS scores of 3 and 4. Overall, air stuffiness in New Zealand classrooms was estimated for the first time using the methods from a French study. The result showed the air stuffiness in the two classrooms were at high or very air stuffiness conditions. This might be resulted from the inadequate ventilation.

5 Conclusion

This study showed an inadequate ventilation rate in the two investigated naturally ventilated classrooms during the heating season. Results of ventilation rate were consistent with the air stuffiness. The small sample size limits the power of the conclusion that the ventilation rate in New Zealand primary schools fails to meet the recommended IAQ levels. Future research should focus on investigating ventilation rate in a large amount of schools and finding low cost efficient solutions to increase the ventilation rate.

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Procurement method selection in construction

A conceptual literature review

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Abstract:

Public procurement is different from private procurement as it strongly focuses on rules and predictability. Recognizing that an effective way to deliver “value for money” is better than traditional procurement approaches (Egan, 1998), the government has begun to explore collaborative procurement approaches, such as alliance and Public-Private-Partnership (PPP). Despite the increasing trend of considering alternatively procurement strategies, the procurement method selection remains a challenge task (Love et al., 2008). The selection process is being extremely complex, and the classic criteria of time, cost and quality are too simplistic in the context of modern construction environment (Naoum and Egbu, 2015). Many researchers have identified procurement method selection criteria during the last three decades. However, there is limited research focusing on the New Zealand market.

This paper seeks to explore “how and why” a public sector selected procurement methods, and understand how a selected procurement method influences the project success as well as current methods used. A conceptual literature review of procurement method selection is presented. Moreover, this paper explores the trend in procurement method selection criteria over the last twenty years, specifically in New Zealand market.

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