Exploring factors that cause adoption of new technologies: A study of the New Zealand Construction Industry

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Civil Engineering

Field of Construction Engineering and Management

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ABSTRACT

Earthquakes have influenced New Zealand over the years, and mostly they caused severe damages to the economy of the impacted regions, especially in the construction sector. The construction industry has introduced several methods and technologies to reduce the damage and the associated repair costs. One type of these technologies is seismic resistant technologies. However the slow process of adoption of these new technologies has become a significant issue. This study attempts to address a series of interrelated issues around the low process of adoption of new seismic-resistant technologies in the New Zealand construction industry.

In the literature review, the factors that influence the adoption of the new technologies were identified. These factors were categorised into four main groups, cost, market, organisation and project-related factors. Based on the identified factors, an online questionnaire survey was designed and released to the construction industry experts in New Zealand. The results of the survey, revealed the important factors facilitating the adoption of seismic-resistant technologies in the industry.

Another round of online questionnaire survey was conducted to explore the roles of the identified factors in enabling or preventing the process of adoption.

The results were cross-checked by conducting expert interviews where the effects of enabler and barrier factors were investigated from the perspective of developers and users of the seismic-resistant technologies. The interviews involved finding their challenges in relation to cost, project, organisation and market (the findings from survey one) when implemented these new technologies. They were also requested to provide their views about the impact of enabler and barrier factors on the process of adoption (the findings from survey two). Finally, they ranked their choice of the top three enabler and barrier factors that influence the process of adoption to new seismic-resistant technologies.

The findings put *the expertise of consultants in using new technology, experience with the new technology and structural engineer's recommendation* as the most influential enabler factors in the adoption process. Also, the *cost of new technology, the client resistance to change and complicated design and construction* were indicated as the top influential barriers of adoption to seismic-resistant technologies in New Zealand.

In the final part of this research, the recommendations and suggestions that make new technology adoption more straightforward related to users, policy and regulations, products, and design were suggested.

The findings of this research can help to improve and develop a path to facilitate the uptake of new seismic-proofing technologies in earthquake-prone countries.

To:

The love of my life and my best friend Ashkan

And Liana the star of our life

Acknowledgements

Foremost, I would like to express my sincere gratitude to my main supervisors, Professor Pierre Quenneville and Professor Suzanne Wilkinson, for their spectacular guidance, dedication, clarity of vision and patience that has led to the successful completion of this research. I could not have imagined having better mentors for my PhD study. I would like to extend my appreciation to Dr. Mani Poshdar for his advice and inspiration as my co-supervisor. Above all, he has always been a great friend throughout my journey to complete my PhD.

I am incredibly grateful to my mom Shahnaz Kamrani for giving me the love and support to follow my dreams and to make them a reality as my first teacher in life, and the one who taught me to be strong in life. In addition, I would like to thank my sisters; Shila And Nazanin for their love and support throughout my life.

Special gratitude to my fellow colleagues and friends: S.Rezaeefard, S.Hadjikhani, N.Valizadeh, R.Masoudnia, B.Asadi, Z.Karami, F.Mirjafary, M.Babaeian Jelodar, A.Valyashko, A.Ahmadi And N.Ghadirivala for their positive encouragement and endless support throughout his study.

Also, I gratefully acknowledge the Earthquake Commission (EQC) of New Zealand for providing financial support for this research work.

I have appreciated the incomparable joy of my adorable daughter and angel Liana, who brought happiness to our life. Her smile always filled my heart with assurance and pleasure.

Above all, my deepest gratitude and appreciation is for my beloved husband, Dr. Ashkan Hashemi with me through good and bad; taught me how to be patient, giving me unconditional love. I never felt lonely since the day I met you. Thank you for your understanding and always supporting me. This PhD has been started because of you and your encouragement.

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CO-AUTHORS

Name	Nature of Contribution
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The undersigned hereby certify that:
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CHAPTER 1

INTRODUCTION

1.1 Overview and research motivation

New Zealand has been affected by significant seismic events over the years. The earthquakes that hit Wairarapa in 1855 and the shallow Hawke's Bay in 1931 were among the most severe cases documented causing severe damage and considerable casualties before the standards institution of New Zealand was formed to regulate the construction methods and systems [1] [2] [3]. Despite all the improvements introduced by developing the codes, regulations and standards since 1932, the country still suffers extensive losses after each earthquake. The series of seismic events that hit Edgecumbe earthquake in 1987, Christchurch in 2010 and 2011 (Figure1.1) [4][5][6], Wellington and Marlborough in 2013 [7], and the Kaikoura earthquake in 2016 (Figure 1.2) [8] all resulted in substantial building damage and economic losses.

Figure 1.1: City Mall after 22 February earthquake 2011

Figure 1.2: Kaikoura earthquake 14 of November

Successive earthquakes have cost New Zealand dearly. After the 2007 Gisborne earthquake on January 14th 2008, the Earthquake Commission (EQC) had received over 3,100 insurance claims totalling approximately $16 million [9]. It was earlier evaluated that the cost of damage caused by the seismic event could rise only to a maximum of $30 million [10]. Over 750,000 insurance claims were received by EQC for the land and contents [11]. Of these, nearly two-thirds had been closed by June 2014 [11]. Insured losses totalled more than NZ$30 billion, considering disruption expenses and contents damage [12].

Protecting cities from earthquakes is still an enormous challenge that needs addressing. Recently, significant progress has been made in understanding seismic activity and developing building technology[13]. Today, anti-seismic technology is considered quite advanced for new buildings, and sufficient to build individual structures that can withstand the vast majority of recorded earthquakes [14]. For example, dampers designed to reduce the vibrations of structures induced by earthquakes have been successfully employed in the design of new buildings for providing life safety and preventing the collapse of buildings, new design methods using seismic technologies will allow structural engineers to design buildings with ductile behaviour. The possibility of economically designing buildings that can resist severe shakings with controlled/limited or insignificant structural damage has only been recently recognised worldwide [14]. Base isolation and damage-resistant designs are two different ways of designing buildings with ductile behaviour during an earthquake. Base isolators absorbed the shock between the building and the ground motion, letting the building slide back and forth while remaining upright. The amount that the building moves is significantly reduced. By using energy dissipation technologies, damage-resistant design can be implemented in several concepts and variations. Energy dissipation technologies consist of rocking walls and a variety of energy dissipating devices (dampers) connected to the building in alternative locations. Seismic dampers dissipate the energy of seismic waves moving through a building structure. A Damper can be formed from any material and can be any device that absorbs vibrations.

The type of technology would be selected based on the design and the location of the building. The selection of technology with respect to the conditions and circumstances of the build construction is a novel and sophisticated concept. The impacts of using new seismic technologies in buildings may result in undamaged structures after earthquakes.

Earthquake damage and costs can be decreased by using new methods and new technologies such as seismic technologies in buildings. However, introducing a new technology or a new method is a process of change. It can cause resistance to change behaviour and as a result, the process of adoption of new technologies slows down [15]. Also there is a direct connection between change and the acceptance of innovation technologies [16].

Change in the construction industry is required to balance the slow state of evolution [16]. The construction sector plays a crucial role in the New Zealand economy. Construction industries are used to dealing with change mostly at the project-level such as design changes and not at the organisation-level (for example adopting new technologies) [17]. Dealing with organisational–level changes may be hard for companies because of geography, size, nature of the project and organisational structure [16]. Ten percent of the total employment is in the construction field. Statistics NZ [18] also reported that investment in expansion was in close to half (43%) of the construction businesses, based on the business operation survey 2017 report. The New Zealand construction industry is characterised by some factors that may discourage its ability to adopt new technologies, such as the boom and bust nature of the industry. A Westpac report [19] explained that this boom and bust nature caused less focus on operational issues, which leave less time available for adopting new technologies. Besides, the New Zealand construction industry mainly consists of small firms. Based on Westpac report [19], these firms have five or fewer employees, so, as a result, these small firms are less likely to innovate because fewer resources are available to them. The skill level of the workers may be another reason that impacts the ability to adopt new technologies. Westpac report [19] identified that the New Zealand residential building industry hires relatively unskilled or semi-skilled people.

As has been discussed above, for protecting cities from earthquake damages and costs, there is higher demand to have buildings that can withstand seismic behaviour during and after earthquakes; especially in New Zealand. This seismic behaviour can be achieved by implementing new seismic technologies. However, by considering the characteristics of the New Zealand construction industry, it is evident that, without change, the sector will not meet the demands. New private sector and government demand should be accommodated, especially in the residential sector in future, to overcome the housing shortage issue in Auckland and of the government's ambitious Kiwi Build scheme [19]. Adoption of new technologies, new methods and improving productivity are needed to meet current and future demands for buildings with seismic behaviour. The aim of the research work presented in the subsequent chapters is to achieve factors that facilitate adoption of new seismic technologies in New Zealand construction industry, to find the enablers and barriers in its way and how to reinforce enablers and overcome the obstacles.

1.2 Problem statement

As a consequence of a large number of earthquakes which have occurred, the economy of the country has been disturbed. Several solutions have been considered for addressing earthquake damage. One of the best ways which has recently gained attention is the use of new technologies such as energy absorption technologies. These technologies are implemented in buildings to partially absorb and dissipate the earthquake energy in order to reduce the damage.

For the new technologies to be adopted and used, trust needs to be established so they can be accepted by the construction industry. The overarching research question is what factors influence the speed of adoption of innovative seismic-proofing products into the NZ building industry. In order to address this question, the study will examine the following sub-questions. First, we are looking to explore factors favouring the new technologies and new methods being adopted around the world. We are looking for the general factors helping the process of adoption of new technologies.

1. *What factors allow new technologies to be adopted into the building industry?*

To reduce earthquake damage, many new technologies and methods have already been introduced in to the New Zealand construction industry. However, the slow process of adoption of new technologies has become a serious problem. Consequently, in question two we look into the factors that increase the speed of adoption to new technologies for the New Zealand construction industry.

2. *What are the essential factors that influence the adoption process of the new technologies into the New Zealand construction industry?*

Research question three was designed to identify the roles that factors from the previous question play as enablers or barriers to the process of adoption of new technologies

3. *What are the barriers and enablers for adoption to these new technologies into the New Zealand construction industry?*

The four most recent and favourable seismic-resistant technologies introduced in New Zealand were considered as case studies. The enabler and barrier factors were evaluated from two perspectives, first, from developers of the case studies point of view and second, from users who had been involved in developing and the use of the selected technologies. Research question four was designed to cross-check the impacts of enablers and barriers on the process of adoption by drawing on the experience of users and developers.

4. *What are the experience of the users and developers of the new technologies about the enabler and barrier factors?*

And finally, suggestions and recommendations for the New Zealand construction industry are offered to improve the process of adoption of new seismic-resistant technologies.

5. *What are the recommendations that can be made to speed the adoption process of the new technologies by the New Zealand construction industry?*

1.3 Research Objectives

In answering the above questions, the study is set to achieve the specific main objectives and listed below:

1. To identify factors that allow new technologies to be trusted and adopted into the building industry.
2. To identify essential factors that speed up the adoption process of new technologies into the New Zealand construction industry.
3. To determine the barriers and enablers of adoption of these new technologies by the New Zealand construction industry.
4. To assess the significance of the enablers and barriers factors from the perspective of the users and developers of the new technologies
5. To make recommendations about approaches to speed the adoption process of the new technologies by the New Zealand construction industry.

1.4 Research methodology

This doctoral thesis is structured based on a number of submitted and accepted journal and conference papers which preceded this research. Although each chapter of the thesis consists of a detailed methodology section, a brief overview of the overall research methodology is given below to make the research approach more clear.

This research reviews the general method that was applied to fulfil the defined five research objectives. Four main sequential phases are designed to start from a broad literature review on the research topic, continue with identifying the important factors that facilitate technology adoption in the New Zealand construction sector, then finding the enablers and barriers to technology adoption and finally determine the recommendations to speed the adoption process of new technologies by the New Zealand construction industry (Figure 1.3). Each of the designed stages comprises a number of chronological stages that are discussed in the following sections.

The function of this section is to provide an overview of the research stages and the strategies used in each research stage. Further details on the methods adopted to achieve the research objectives will be described in their respective chapters.

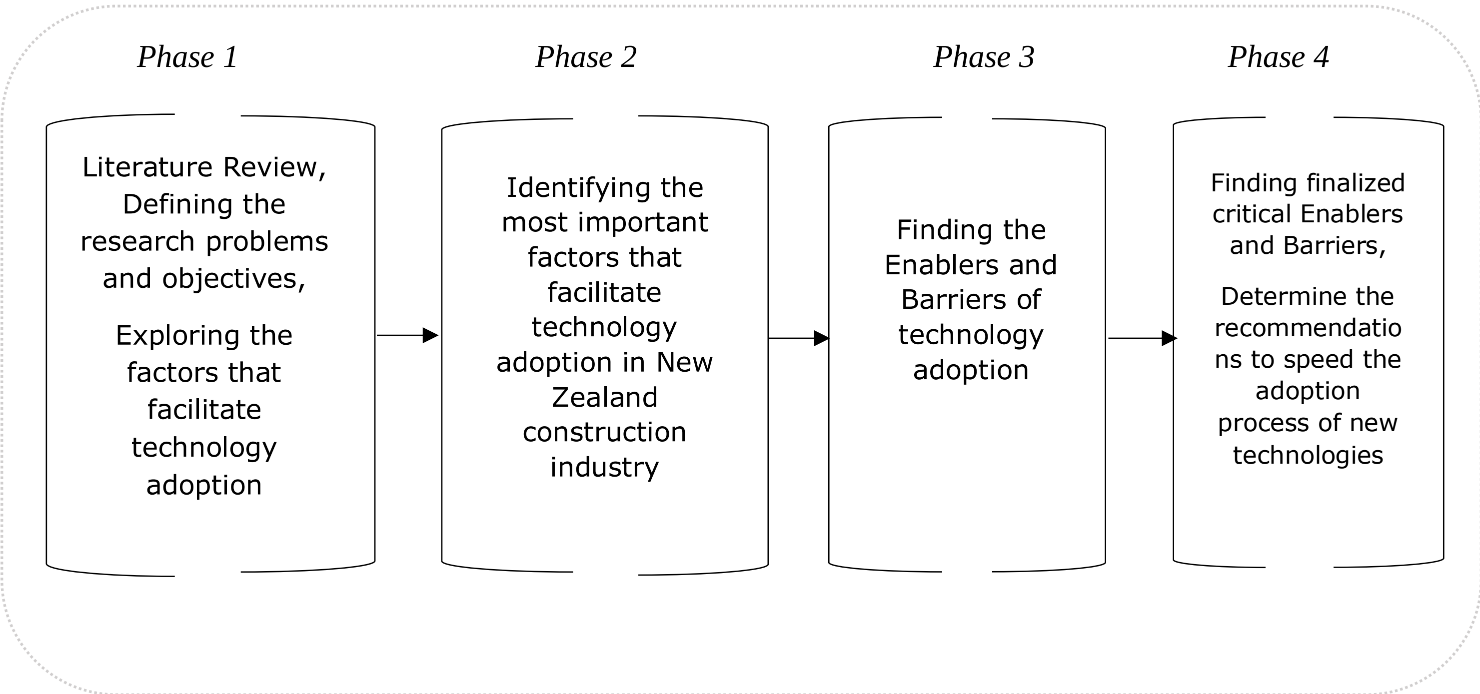


Figure 1.3: Research Phases and Methods

1.4.1 Phase one

In *phase one,* the literature review, a comprehensive review of the relevant literature from well-respected sources was carried out to explore the factors that facilitate trust for new technologies and getting them generally adopted around the world. The outcome of this stage of the study which addressed the first objective of the research is discussed in Chapter two.

1.4.2 Phase two

Given its unique culture and characteristics, the NZ construction industry may have unique adoption factors which are different in nature or relative level of importance from those of other countries. The factors identified from the literature needs to be prioritised according to their relative levels of importance in the NZ context. In the absence of specific NZ research on the subject, in *phase two,* the relevance of the factors identified to the NZ context were evaluated. The second stage has five parts. The first part used the factors which have been explored in the literature review in stage one, to develop a questionnaire survey. The survey was aimed at finding the most important factors that facilitate adoption to new technologies for New Zealand construction industry. By considering all ethical aspects of the research, an application has been submitted to the University of Auckland's Human Participants Ethics Committee for releasing two surveys and expert interviews. The application was approved on July 16 2018 for three years with the reference number of 021049. For each interview, a participant information sheet (PIS) and a consent form (CF) had to be designed for the respondents of the interviews. All the ethical documents are in Appendix 1.

The questionnaire survey was released on the Survey Monkey web site, and the respondents from the construction industry, including clients, contractors and consultants were invited to participate as representatives of different trades in a typical construction project. A round of random sampling was applied (the details are covered in Chapter three). Conceptual and relational analyses were performed on the collected results. The conceptual analysis determined the existence and frequency of concepts in a text, and relational analysis developed the conceptual analysis further by examining the relationships among results, which are explained completely in Chapter three (Figure 1.4). The conclusion of this stage fulfilled objective 2 of the study.

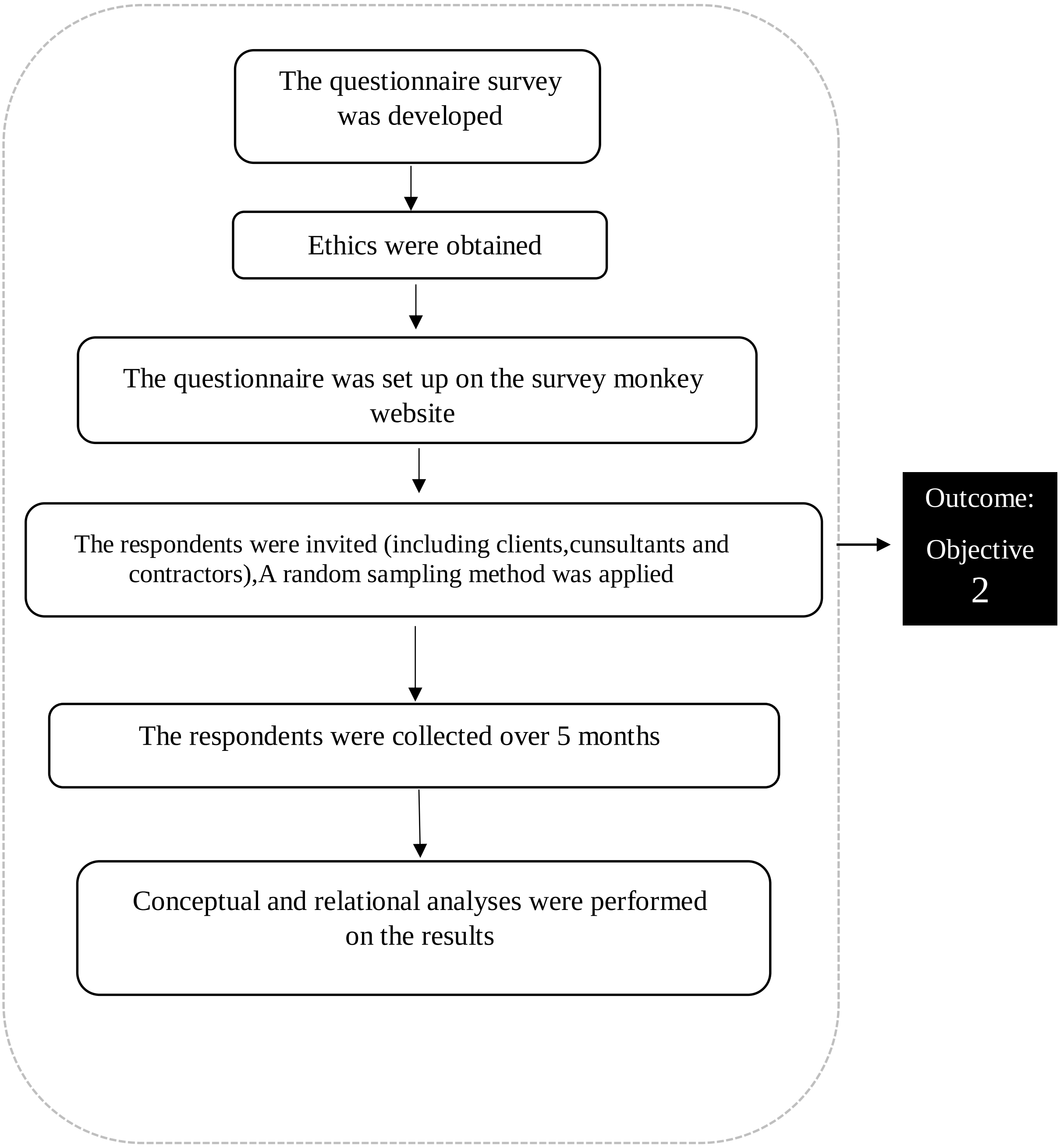


Figure 1.4: Designed stages within phase two

1.4.3 Phase three

Phase three is designed to identify the barriers and enablers of technology adoption in the New Zealand construction industry by using the results of survey one (phase ?). This phase included five stages. A questionnaire survey was designed on Survey Monkey and a web link generated and electronically distributed. The respondents from the construction industry, including client, contractors and consultants were invited as a representative of different trades in a typical construction project. Another round of random sampling was applied (the details are given in chapter 4). The respondents were asked to rank the factors as enablers or barriers. Frequency analysis has been done on the collected data to explore the significance of the difference between results; these are explained in detail in Chapter 4. The results of this stage fulfilled objective three as presented in Chapter 4.

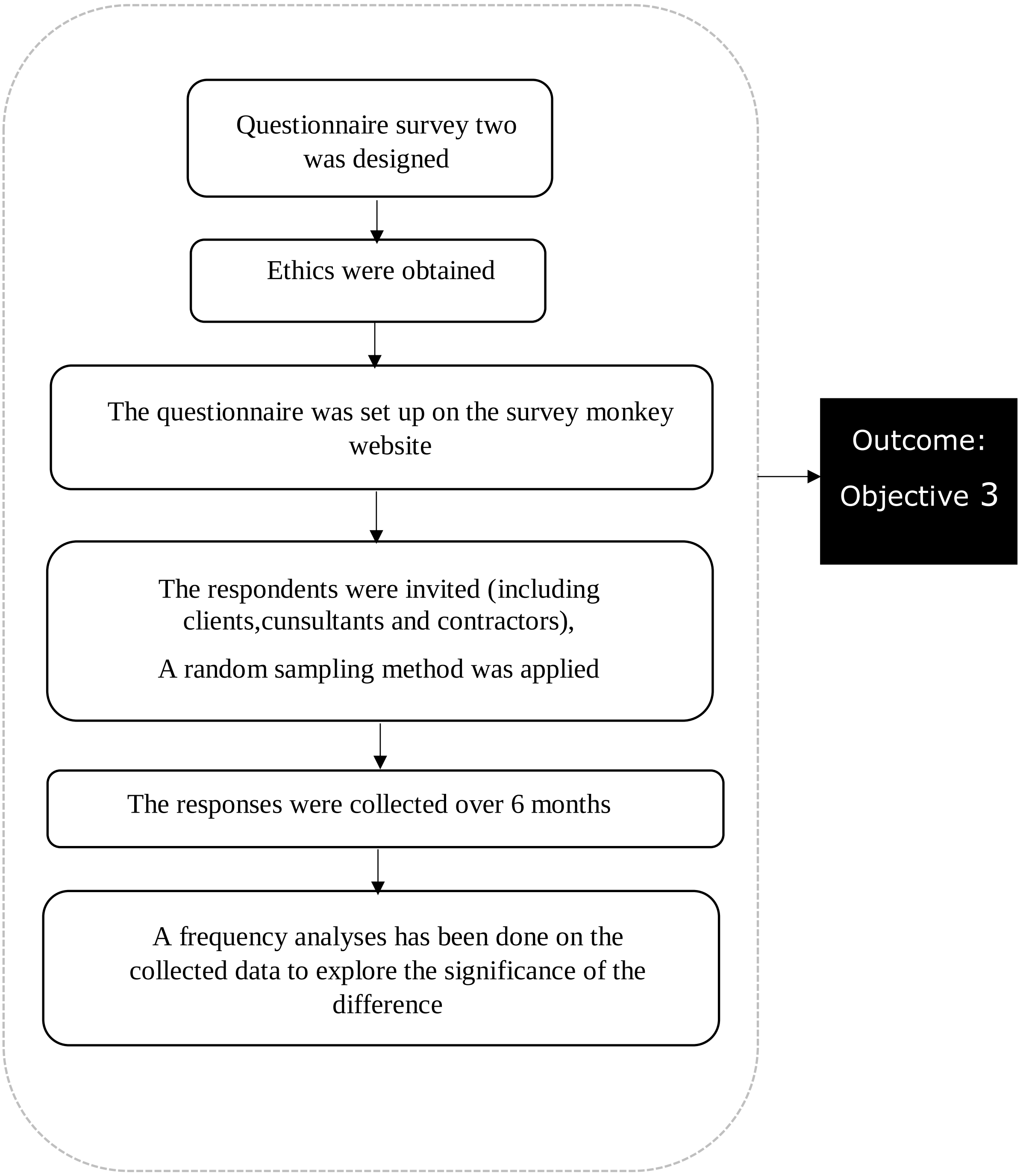


Figure 1.5: Arranged stages within phase three

1.4.4 Phase four

Phase four was designed to cover objectives 4 and 5 and has two parts. Firstly, to identify the significance of the enabler and barrier factors determined in stage 3, from the perspective of the users and developers of the new technologies. And secondly to make the recommendations to speed the adoption process of new technologies by the New Zealand construction industry. At the first part, four types of seismic technologies were considered as case studies exploring the impacts of enabler and barrier factors on these case studies from the perspective of the developers and users. Simultaneously, an expert interview approach was adopted to explore these impacts (Figure 1.6). The results of this stage are presented in Chapters 5 and 6.

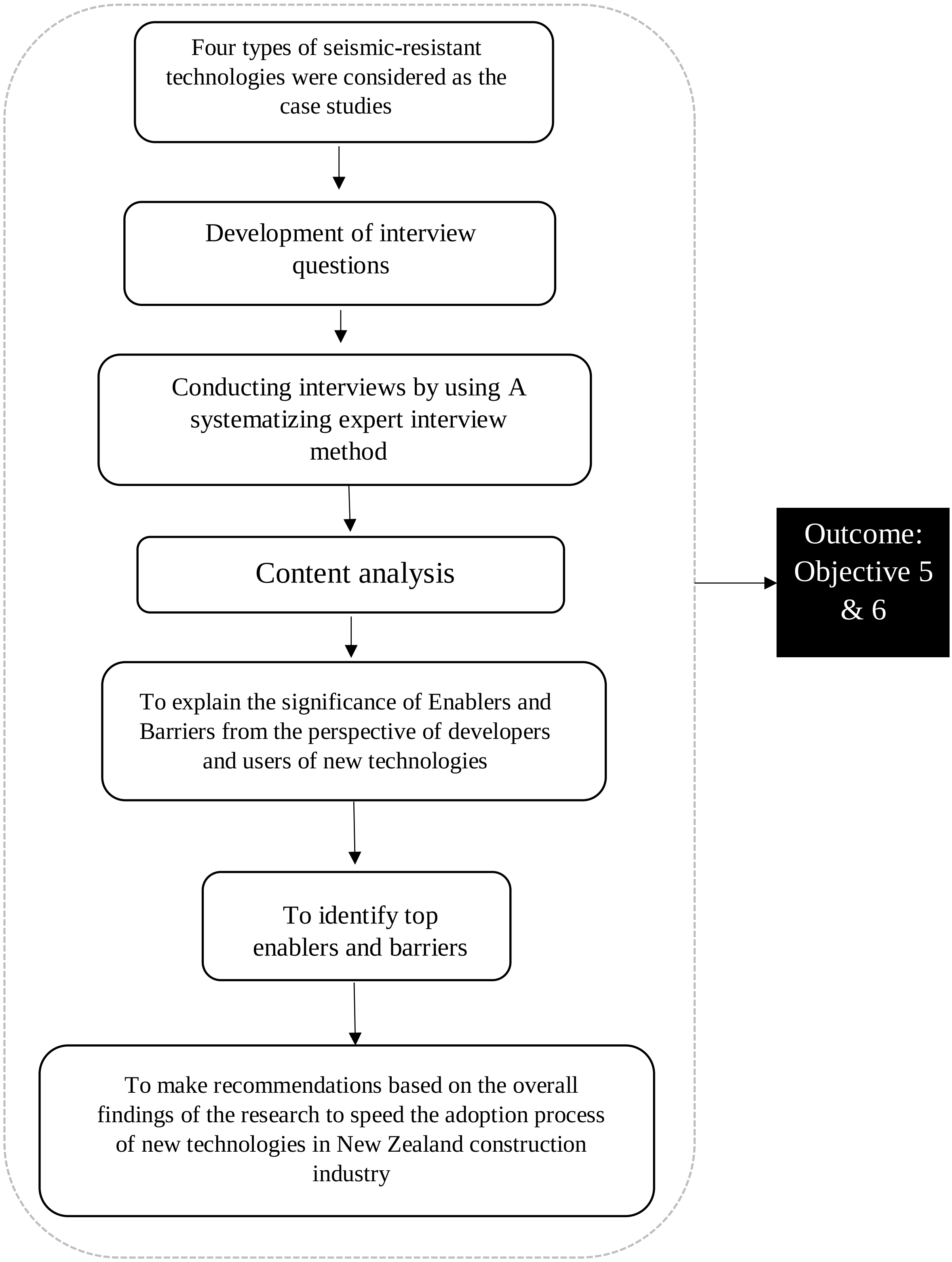


Figure 1.6: Arranged stages within phase four

1.5 Thesis Organisation

This PhD thesis consists of one introduction chapter, five core chapters and one conclusion chapter. The core chapters are designed to address the research objectives. The chapters and related manuscripts are listed below.

Chapter 1: Introduction

Chapter 2: A literature review

Manuscript: *S. Zarinkamar, M. Poshdar, S. Wilkinson, and P. Quenneville, "An overview of the economic impact of resilient seismic technologies on earthquake insurance in New Zealand," New Zeal. Soc. Earthq. Eng. Conf. Auckland, New Zealand, 2018. pp. 1–6, 2018.*

Chapter 3: Decision factors for adopting a new technology in construction

Manuscript: *S. Zarinkamar, M. Poshdar, S. Wilkinson, and P. Quenneville,(2020) "*

Decision factors for adopting a new technology in construction ". International Journal of Construction Management. (revised and under final review)

Chapter 4: Enablers and barriers of seismic-resistant technologies adoption in the New Zealand construction industry

Manuscript: *S. Zarinkamar, P. Quenneville, S. Wilkinson, and M. Poshdar "Enablers and barriers of seismic-resistant technologies adoption in the construction industry: A New Zealand case study" 2020 World Conf. Earthq.Eng.*

Chapter 5: Qualitative study findings

Manuscript: *S. Zarinkamar, M. Poshdar, S. Wilkinson, and P. Quenneville, "The top enablers and barriers of technology adoption in construction," New Zeal. Soc. Earthq. Eng. Conf. Christchurch, New Zealand, 2021.(Submitted)*

Chapter 6: General discussions and summary of findings

Chapter 7: Conclusion and future work

CHAPTER 2

Literature review and the motivation for the research

The current chapter is based on the following article:

S. Zarinkamar, S. Wilkinson, and P. Quenneville, "An overview of the economic impact of resilient seismic technologies on earthquake insurance in New Zealand," New Zeal. Soc. Earthq. Eng. Conf. Auckland, New Zealand, 2018., pp. 1–6, 2018.

2.1 Introduction

Earthquakes have hit New Zealand in quick succession with no respite expected in their frequency in the future. Therefore, several new methods and technologies are proposed to the construction industry that aim to reduce the side effects of damages, economic losses, including seismic-resistant technologies. However, a low level of trust of the performance of these new technologies poses the main challenge that could also affect their adoption process.

Another issue is that the construction industry globally is not highly productive. Currently, the New Zealand construction industry needs to significantly increase its productivity to meet expected demands for residential and non-residential construction. Innovation is the key answer to achieve productivity, in the New Zealand construction industry [20].

Barbosa et al.[21] explored ten main reasons for the low level of productivity in the global construction industry:

- Extensive regulations
- Increasing project complexity
- Contractual structures are misaligned
- The design process and investment are inadequate

- Poor project management
- Insufficiently skilled labour
- Industry underinvests in digitisation, innovation and capital
- Informality and potential for corruption distort the market
- Construction is highly fragmented
- Suboptimal owner requirements

The Ministry of business, innovation, and Employment (MBIE) productivity partnership identified possible reasons for low productivity in New Zealand construction field specifically, the following:

- Resistance to using new technology
- Construction sector workers typically earn higher wages than workers in other sectors with similar skills, which may be a barrier to acquiring skills that could enhance productivity.
- Significant differences in practice between businesses of different sizes
- Competition and market conduct, particularly at a regional level
- Significant variations in productivity within the construction industry between construction services/civil sectors and the residential/non-residential sectors

Another recent review of building quality issues in New Zealand [22] identifies some core underlying aspects relating to industry performance and its effects on building quality as:

- smaller firms' inability to implement changes
- perception of the industry being an undesirable career pathway – compounded by existing capability
- Competition encouraged over cooperation
- Fragmentation of industry structure

They also identified things that affect the quality and suggested priority areas for change:

- The regulatory environment
- The construction workforce
- Building materials
- The construction process
- Knowledge and information

Housing demand is not being met in New Zealand. While there is pressure to build more buildings, better and faster, the question of adopting new technologies in the industry, or not, is particularly important. New technologies and new methods have the ability to give a better response to the current and future demand. But this adoption process was slow in the past, and it has become one of the most critical issues of the New Zealand construction industry.

Following discussions provided above, first, a comprehensive literature review has been carried out on previous earthquakes in New Zealand, because earthquakes have happened continuously in the past and are expected to happen as frequently in the future because New Zealand is a seismically active country. The background history of the New Zealand earthquakes would aid better understanding of the risk of future events and how to more efficiently withstand and recover from their effects.

2.2 Earthquake risk and damage in New Zealand

New Zealand has suffered from many significant earthquakes over time. The most powerful quake was recorded on January 23, 1855; the M8+ Wairarapa earthquake took place around 9 pm on Wellington's Anniversary Day, 15 years to the day after the first immigrant ships anchored at Petone and the early European settlers stepped ashore. The event left a lasting influence on the lives of the people who experienced it, especially those in the Wellington region, which bore the brunt of what is recognised now as New Zealand's largest seismic event in the last 165 years [1]. A large part of the country from Auckland to Dunedin and beyond felt the earthquake. Severe damage occurred throughout the southern half of the North Island, especially in the settlements of Wellington, Hutt Valley and Wanganui, and throughout the northern part of the South Island [1]. The number of reported casualties in the earthquake was low for the magnitude of the event. Fatalities are variously put at between five and nine, one in Wellington, 4-6 in the Wairarapa, and possibly 2 in the Manawatu area [1].

The powerful (M 7.8) shallow Hawke's Bay earthquake on the morning of February 3rd 1931, the most damaging in the country’s history, had a direct impact on the two towns of Napier and Hastings. It resulted in the most casualties of an earthquake in NZ, significant fires and there was much damage to the built and natural environments [2]. The event almost entirely destroyed the city of Napier. It resulted in damage from Taupo to Wellington and left 30,000 people homeless. The official number of casualties was 256, and the event remains the most damaging disaster of any type to occur in New Zealand [23]. The extent of damage related to the 1931 earthquake prompted the New Zealand Government to develop a national building code, with the New Zealand Standards Institution formed in 1932. This institution has endured to the present day and is now known as Standards New Zealand [3].

The 1987 March Edgecumbe earthquake (ML6.3, depth 8 km) took place within the Whakatane Graben where the northeast-striking rift of the Taupo Volcanic Zone (TVZ) intersects the north-south trending North Island Shear Belt. The majority of the observed damages was in the towns of Edgecumbe, Te Teko, Kawerau, Matata and Thornton, where poorly constructed houses were severely damaged [4]. The most significant hit was Edgecumbe, with damage to nearly 50% of its homes. There was considerable damage to the milk factory, with many storage tanks toppled [4]. The foreshock which took place seven minutes before the mainshock had cut the power supply, and many people had moved away from heavy machinery out of buildings that then collapsed in the mainshock [4].

The 2007 Gisborne earthquake occurred about 50 kilometres under the Pacific Ocean off the eastern coast of New Zealand's North Island at 8:55 pm on December 20. The event had a magnitude of 6.7 and maximum Mercalli intensity of VIII (*Severe*); it mainly affected the city of Gisborne but was felt extensively across the country from Auckland in the north to Dunedin in the south [24].

On September 4 2010, a M_w 7.1 seismic event occurred approximately 40 km west of Christchurch [25]. In general, low to moderate building damage was reported within Christchurch. A second, more devastating earthquake occurred on February 22 2011. While this earthquake was of lesser magnitude (M_L 6.3, M_w 6.1), its epicentre was located within 10 km of the city centre [26] and accordingly, substantial building damage occurred throughout the CBD.

The Canterbury earthquake sequence left a significant and enduring influence on the social, built, economic, and natural environments in the region [5]. The earthquakes and aftershocks caused a substantial change to the natural environment, including liquefaction, lateral spread near waterways, land level alterations, and numerous landslides and rock falls. Air and water quality were also affected, with water-based restoring activities halted until November 2011 [27]. Air quality lessened in Christchurch city in 2011, beyond the national air quality standard on 32 days. This was partly related to an increase in airborne silt and dust from liquefaction deposits, as well as dust, resulting from earthworks and demolition [27]. The amount of waste more than doubled compared to what it was before the seismic events due to the demolition process [27]. Many buildings were severely damaged during the September 2010 and February 2011 shakings, mainly unreinforced masonry buildings [6]. Physical health and safety were affected in a number of ways by the earthquakes. One hundred and eighty-five people were killed in the February 2011 event [28]. The effects on the education system continue to go beyond the initial school closures following both the September 4, 2010, and February 22, 2011, earthquakes [27]. In response to the seismic events, local Māori recovery initiatives were collaborative, effective and formed by cultural values, including the principle ‘Aroha Nui ki te Tangata [29]. Marae (meeting houses) opened throughout the South and North Islands to accommodate Maori refugees and provide support places [30]. The September 2010 shaking resulted in an estimated retrofit and rebuilding cost of about NZ$5 billion, and the financial markets were adversely affected [12]. The cost of repairing damage resulting from the aftershock sequence is considerably higher. The New Zealand Treasury estimates the capital cost of the Canterbury sequence to be around NZ$40 billion, or approximately 20% of the New Zealand Gross Domestic Product [31]. Businesses within the Christchurch Central Business District (CBD) and surrounding areas were affected differently by the Canterbury seismic events. The cordon around the Christchurch CBD meant that businesses inside it were shut down, and could not be accessed even to collect necessary items that were inside the premises. In a survey of Canterbury organisations affected by the September 2010 earthquake, 64% were forced to shut down at least for the time being [32]. **Employment** in Canterbury was influenced by the Canterbury earthquakes, with an impact especially on Christchurch City itself. Considering the fact that there was severe business disruption, people either lost their jobs or were forced to alter their working circumstances (e.g., move to different locations for work,). There was a significant decrease in the employment rate following the two earthquakes; the employment rate fell from 67% in September 2010 to 63% in September 2011 [27].

The 2013 Cook Strait earthquake sequence indicated on July 18 2013 with two foreshocks of *Mw* 5.7 and *Mw* 5.8 and ended in the *Mw* 6.6 Cook Strait and Lake Grassmere events on July 21 and August 16, respectively. Located approximately 50 km south of New Zealand's capital, Wellington, the seismic events generated the most substantial ground shaking in the Wellington and Marlborough regions in the last 40 years [7]. The incident resulted in damage to thirty-five buildings within the Wellington CBD (different degrees) with broken glass falling onto the main streets of Lambton Quay, Featherston, and Willis. Damage was also observed in Paraparaumu, Wainuiomata, Porirua and the Hutt Valley in the North Island [33]. The Wellington Region emergency management office was started on the evening of July 21, as were those in the lower part of the North Island [33]. On July 22 parts of Wellington's central business district were closed to the public to allow for inspections to buildings with damaged and potentially dangerous façades [34]. Four people were injured in the shaking, which lasted for 20 seconds, exploding windows, cracking concrete and swaying buildings [35].

The 2016 Mw, 7.8 Kaikoura earthquake continued a notable decade of damaging seismic events in New Zealand. The affected areas were wide-ranging across the upper South Island and included two fatalities, a tsunami, thousands of landslides, the collapse of one residential building, and damage to several structures and also to infrastructure [8]. The 2016 Kaikoura shaking directly influenced transport margins, businesses and tourism expenditure ("Economic Impact of the 2016 Kaikoura Earthquake" 2016). Tourism expenditure (domestic and international) in the Kaikoura District decreased the most compared to other areas (down $NZ 21 million for November and December), with international spending decreasing to zero for the first five weeks ("Economic Impact of the 2016 Kaikoura Earthquake" 2016). The estimated loss to the New Zealand economy over two years for the quick reconstructing scenarios is $NZ465 million of GDP (Gross Domestic Product), of which $NZ 117 million is in Canterbury and $NZ 348 million is in the other parts of New Zealand ("Economic Impact of the 2016 Kaikoura Earthquake" 2016).

2.3 Post earthquakes costs in New Zealand

After the 2007 Gisborne earthquake on January 14 of 2008, the Earthquake Commission (EQC) had received over 3,100 insurance claims totalling approximately $16 million [9]. It was earlier evaluated that the cost of damage caused by the seismic event could rise only to a maximum of $30 million [10].

The Canterbury shakings damaged almost three-quarters of the housing stock in the region [12]. About 9,100 of these were evaluated as uninhabitable [27]. Of the total of 150,000 homes that were affected, about one fifth surpassed NZ$100,000 in damage [12]. Nearly 30,000 houses that have been cleared to be retrofitted or reconstructed require significant structural or land corrective work [12]. In sum, there is an estimated cost of 13 billion New Zealand dollars (NZ$) to retrofit or replace damaged residential property [12]. Many households and business had experienced up to five severe seismic events over the extended earthquake sequence resulting in difficulties in the settlement processes, disruptions over the apportionment of claims between the multiple events and postponements due to a range of interrelated factors. As an example, it took Housing New Zealand almost two years to obtain its insurance settlement of NZ $320 million, only after which it could progress the retrofit and rebuild programme for over 5,500 homes [27]. Up until June 2014, the EQC had completed renovations on 55,500 houses, with 14,500 remainings [11]. This protracted sequence and the associated uncertainties have placed enormous stress on individuals, households and communities (e.g., [27]). To reduce the mentioned impacts of earthquakes, new methods and new technologies were introduced into the construction sector, but the low progress of adoption of these new technologies have become a major issue. Regarding this, in this research, we looked at the impacts of using new technologies in buildings.

2.4 The impacts of using new technologies in buildings

Implementing modern technologies in designing and building constructions has a variety of descriptions and interpretations. Undeniably, architects contend that such uses of technology depend on circumstances, contextual characteristics and the presumptions of the design and the location. The precise and appropriate use of technology may result in the formation of perfect and flawless structures. Therefore, the sensible use of technology along with the application of local civilisation is the resolution to the current challenges in design [37]. One category of these new technologies are the seismic resistant technologies that were introduced to the construction industry to reduce during and after earthquake damages and costs.

2.4.1 Seismic-resistant technologies

Modern methods of seismic design (since the 1970s) allow structural engineers to design new structures with the aim of predictable and ductile behaviour during severe shakings in order to prevent collapses and loss of life. However, some controlled damage is allowed, which may actually result in the structure being damaged beyond economic repair after a severe seismic event. Structural seismic mitigation systems have seen significant advances in recent decades due to the development of new technologies and advanced materials. Generally, there are two alternative ways of designing buildings to avoid considerable/permanent damage in severe seismic events: base isolation and damage-resistant design.

Base isolation systems require the structure to be separated from the ground by isolation devices which also can absorb the seismic energy. This is a proven concept which adds to the initial cost of the building but is demonstrably less expensive in the long term.

Damage-resistant design methods which use energy dissipation technologies are developing fast, in several different concepts and variations. These include (but are not limited to) rocking walls or rocking frames, with or without post-tensioning elements, and a variety of energy dissipating devices (dampers) connected to the building in different locations and forms. The dampers themselves can be categorised into serious damage where the devices are designed to yield during the design level earthquakes and low damage where the device would not yield (or be severely damaged) and can potentially tolerate multiple events (including aftershocks). If not already the case, the damage-resistant seismic design will soon become no more expensive (or cost positive) than the conventional design for new builds.

2.4.1.1 Base isolators

Also known as **seismic base isolation** [38] or **base isolation system** [39], is one of the most popular methods of protecting a building against seismic forces [40]. This technology is a combination of structural components that should substantially isolate the main structure from the foundation resting on a shaking ground, thus protecting building integrity. Base isolation is one of the most efficient technologies earthquake engineering refers to passive structural vibration control technologies. It is meant to enable a building or structure to survive a potentially damaging earthquake impact through a proper initial design or subsequent modifications. In some cases, the use of base isolation can significantly enhance both a structure's seismic performance and its earthquake sustainability [41]. This technology can be used for both new structural design and seismic upgrading. Base isolation is also implemented on a smaller scale, sometimes down to a single room in a building. Moreover, isolated raised-floor systems are used to protect essential equipment against earthquakes [41].

2.4.1.2 Energy dissipation devices

Energy dissipation devices are used to introduce ductility to the structures in such a way that the damage is controlled and localised in these devices. These devices are actually acting as 'fuses' for the structure that can be repaired or replaced after the earthquake. Also, some of them are damage avoidance which means they do not need to be replaced or repaired and are good for multiple seismic events.

Using new seismic technologies for buildings may result in the formation of earthquake-resistant buildings with less cost and damage after earthquakes. However, introducing these types of new technologies to the organisations would be a stressful procedure of change for the individuals. The stressed process of change may cause resistance to change behaviour and resistance to adopting new ways by company employees, which will result in the slow process of adoption to the new technology.

Complete literature has been carried out in connection with the discussion above by considering one type of existing innovation diffusion model to explore the factors facilitating the adoption process in individuals and organisations.

2.5 AN INNOVATION DIFFUSION MODEL

The definition of innovation refers to a new tool, a new product or method that is designed to improve the performance of the company or offer a better solution to solve existing problems [42], [43]. In this research, the new product refers to seismic technologies which have been introduced into the construction industry to reduce the impacts of earthquake damages and costs. To get new technologies introduced into the construction industry, users should go through the stages to get adapted to the new technology.

Several theories exist related to innovation acceptance and adoption process; some of the most popular theories are as in below:

Theory of Reasoned Action (TRA)

This theory was developed in 1975 by Fishbein and Azjen [44], more for psychological researches. In this theory, every human behaviour can be predicted by considering three main factors, including attitudes, social influence and intentions. The disadvantage of this theory is not assuming some essential roles such as habitats, cognitive deliberation and moral factors.

Theory of Interpersonal Behavior(TIB)

Regarding predicting human behaviour, this model has all the aspects of TRA plus considering habits, facilitating conditions and affect to clarify humans behaviours affected by social and emotional factors [44][45]. TIB consisted of three levels. At the first level, based on the previous experiences and personal characteristics, the personal beliefs would be shaped. At the second level, the effect of social factors on a particular behaviour would be described. And finally, at the third level, a possibility of performing a unique behaviour in a situational condition would be determined. This theory has the disadvantage of complexity compared to TRA, and there is no simple procedure among the operational definitions of the variables [45].

Technology Acceptance Model (TAM)

This model is derived from the TRA model. TAM model has reduced users' subject norms due to uncertain theoretical status in the TRA model [46]. The three main factors considered in TAM theory to encourage users have perceived usefulness, perceived ease of use, and attitude toward use. TAM is one of the most acceptable models in technology acceptance theories [47]. However, this theory disregarded the influence of social factors on technology adoption, which makes limitations in using this theory. Additionally, all the external factors need to be added to TAM theory for a more consistent system prediction [46][47].

Social Cognitive Theory (SCT)

This theory is used for the prognostication behaviour of users and groups by considering three main factors of environment, performance and personality [48]. Environment factors such as social and physical factors both are external factors for the individual. Although the performance factor only focused on the adoption issues, the personality factor considered demographic aspects characterizing a person. These three main factors steadily affected each other [48].

In this research, these stages have been considered based on *Rogers innovation diffusion theory* (Everett M. Rogers 1976, 1995). Since this theory is more comprehensively focused on system characteristics, organizational attributes and environmental aspects, which align with our research.

The theory was developed by Rogers in 1962 [42]. In this theory, Rogers explained that the innovation-decision process consists of a user or a decision-maker receiving information about the new technology, wanting to trust it or not, deciding to adopt or reject it, trying to use it and finally, being sure of using it [49]. Rogers innovation-decision process consists of five steps: (1) knowledge, (2) persuasion, (3) decision, (4) implementation, and (5) confirmation. This process is shown in Figure 2.1.

The first step, knowledge, happens when the individual or the organisation becomes aware of the existence of the new technology and understands exactly how it would work. The speed of this process is impacted by the characteristics of the decision-making unit, such as socio-economic characteristics, personality variables and communication behaviour. The second step occurs when an opinion is formed about the innovation on the individual or company, and the persuasion happens. The rate of this process is impacted by the characteristics of the innovation such as relative advantage, compatibility, trialability and observability. The third step is when the decision-maker decides to adopt it or reject the innovation. At the fourth step, if innovation is accepted by the decision-maker, the implementation occurs. And finally, when the decision-maker sees the success or failure of the new technology or innovation, the confirmation would happen. A comprehensive literature evaluation has been done based on the stages discussed.

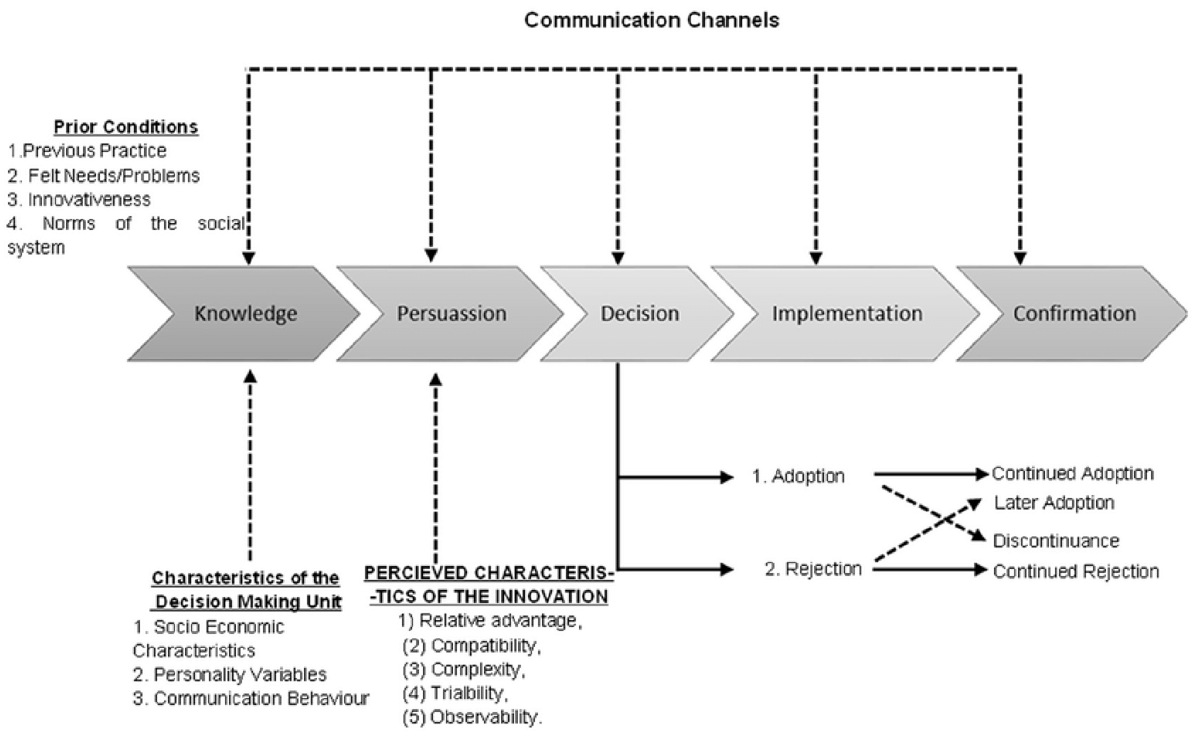


Figure 2.1 A Model of five stages in the innovation-decision process [50]

2.5.1 Knowledge about the new technology

At the first level of the introduction of the novel technology, the user discovers the existence of the new technology using little detail [49]. Discovering the information on the existence of new technology can be accidental. Alternatively, for some cases, traditional methods are not efficient enough, so they need to be replaced by new methods and new technologies. In other words, dissatisfaction makes the client search for new, more satisfactory methods [49], [51], [52].

2.5.2 TRUST

The lack of trust and resistance to change are the main barriers to progression in the construction industry. The industry is frequently pleading for change, which has been constantly reflected through various reports over the recent decades. There are significant indications that link these progress deficiencies to the lack of trust [53]. Accordingly, trust in construction projects has been acknowledged as a critical element for the successful completion of the projects [48],[49].

Moreover, the appropriate/inappropriate technology use and the acceptance/rejection of the technology are the main reasons that significantly affects the trust in new technology [56]. This section gives an insight into the concept of trust in construction from various viewpoints.

2.5.2.1 Trust: definition and role

Trust is a complex concept with a wide variety of definitions, depending on the situation and problems. In an effort to aggregate the definitions, Rosseau [57] asserted trust is a disposition and attitude concerning the willingness to rely upon the actions of or be vulnerable towards a phenomenon, under circumstances of contractual and social obligations, with the potential for collaboration. Trust is also defined as "a belief that a specific technology has the attributes necessary to perform as expected in a given situation in which negative consequences are possible" [58].

2.5.2.2 Trust and the construction industry: definition and role

Davidson and McFetridge [59] tested three hypotheses on developing trust and adopting new technology. These hypotheses are related to three potential factors that affect technology adoption, including characteristics of the individual technology, parent corporation, and the host country. They studied a sample of 1,226 technology cases, which resulted in strong support for the hypotheses regarding the effects of the characteristic of the technology and its parent, and mixed support regarding the effect of the characteristics of the host country on the trust patterns. Akintoye [60] collected the perspectives of contractors in the United Kingdom about the influential factors of trust. They identified factors included in the complexity of design and construction, scale and scope of construction, method of construction, tender period and market condition, site constraints, client's financial situation and budget, type of client, buildability, location of the project, and availability and supplies of labour and materials. Shaojie Cui et al. [61] explored the effects of market and cultural environments on trust to technology. They studied the relative influence of two factors of the market environment, i.e., competitive intensity and market dynamism, and two factors of the cultural environment, i.e. national cultural distance and organisational cultural distance. The results found the influence of market dynamism stronger than the competitive intensity. The organisational cultural distance was also identified to exert a stronger influence on the cultural environment compared to the national cultural distance. Khalfan et al. [62] studied the influence of communication, reliance and delivery of trust in the construction projects. It was found that honest communication can guarantee a better delivery. Reliance applies when the project has to trust development and believe it will deliver the standards as expected. The delivery needs to be functional for the client. Jafarzadeh [63] explored the effects of building characteristics and local site condition on forming a trust. Adafin et al. [64] discussed the risk aspects of trust factors through risk management, which included contract condition, procurement system, inflation, change in owner's requirement, type of cost, underestimation and type of bidding. Kai Lu [65] examined the influence of contractual control and managers' propensity to trust the processes that foster trust in China. The examination collected survey data on 260 architect–contractor project-based relationships. The results showed that both factors positively correlate to forming a trust in new technology. Zuppa et al. [66] studied the factors that impact the establishment of Trust in construction projects and the effects of Trust in developing projects in the US. They surveyed the top 400 contractors that are members of the American Engineering News-Record. Their findings showed that face-to-face communication, electronic documentation, and supporting timely and adequate feedbacks help to build up trust. Adafin [67] listed eight cost factors that affect trust. The study addressed a change in an owner's requirements, the complexity of design and construction, quality of information and flow requirements, availability of design information, the expertise of consultants, market condition, project team's experience of the construction type, site investigation and inadequate tender documentation as the key factors.

2.5.3 Technology adoption

Technology adoption is when an individual or an organisation decides to use new technology for a large-scale project. Mainly, it is about a shift from mental acceptance to the practical acceptance of the technology [51], [68].

2.5.3.1 Community responses to adopting new technologies

Resistance to change in the way of doing things is part of the human characteristic [69]. Change refers to the process through which something becomes different based on the Oxford dictionary definition. When a new technology is introduced, the process of change can be very stressful for a company. So, resistance to change would be the best-known attitude towards new ideas [70]. Change can be huge or small; the scale of the change is important because of two reasons first, how it should be managed, and second how people will react to it.

2.5.3.2 Relation between change and innovation

The acceptance of innovation is linked to the change, trust and adoption of new technologies. Innovation, which is a result of the implementation of new ideas, is described as a positive change by Gambatesa and Hallowell [71],.

2.5.3.3 Adopting new technologies in the global construction industry

The unique nature of the construction industry has been discussed before, especially compared to other industries. The construction industry is not viewed as a single industry; it is considered as a meta industry involving multiple participants [72]. It is also different from other industries because every construction project is one of a kind, can be implemented in different locations and there are different teams for each project [72]. These characteristics cause low productivity of the construction industry both globally and locally. And the slow evolution of the industry may increase this low productivity.

2.5.3.4 Barriers to adopting new technologies in the global construction industry

It is evident that change in the global construction industry will not happen soon (Barbosa et al. [20]). As mentioned above, resistance to change and absence of trust are the main barriers for improvement in the construction industry.

It is time to explore the barriers to taking up these changes and the solutions for overcoming them. The reasons for poor performance and failure in the UK construction industry were identified by Farmer [73]; two of those related to adopting new ways including lack of research and development, and lack of collaboration and improvement culture.

Another barrier to change, as mentioned by Farmer [73] is risk. Getting new products to market at any scale have difficulties due to the subjective perception of risk within the broader supply chain. He also identified a lack of collaboration as a critical barrier to the UK construction industry's change inertia. Prevention in industry of scaling up, of sharing risk more appropriately and adopting new ways are the results of lack of collaboration in UK construction industry [73].

The appropriate use and the acceptance or rejection of the technology are reasons that cause trust in new technology [56].

Davidson and Mcfetridge [59] analyse three hypotheses on developing trust and adopting new technology. These three hypotheses are considered based on three main factors that influence technology adoption, including aspects of the new technology, parent cooperation and the host country. Akintoye [60] explored the contractor's point of view factors in relation to trust and the adoption of new technologies. They included the complexity of design and construction, scale and scope of construction, method of construction, tender period and market condition, site constraints, client's financial situation and budget, type of client, buildability, location of the project, and availability and supplies of labour and materials. Khalfan et al. [62] studied the influence of communication, reliance and delivery on the trust in construction projects. The effects of building characteristics and site condition on trust have been identified by Jafarzadeh[63]. Adafin et al. [64] paying attention to the risk aspects of factors cause trust in the risk management sector, including contract condition, procurement system, inflation, change in owner's requirement, type of cost, underestimation and type of bidding. Zuppa et al. [66] studied the factors that impact the establishment of trust in construction projects in the US. The results showed that face-to-face communication, electronic documentation, and supporting timely and adequate feedbacks could build up better trust and bettor adoption to new technologies. And finally adaffin studied the cost-related factors that affect trust, such as change in an owner's requirements, the complexity of design and construction, quality of information and flow requirements, availability of design information, the expertise of consultants, market condition, project team's experience of the construction type, site investigation and inadequate tender documentation

2.5.3.5 Enablers to adopting new technologies in the global construction industry

Based on the literature, there are factors that enable change and should be reinforced. Enabling factors motivate and influence the adoption of new methods.

One of the most significant enablers is upper management in the construction industry [74]. It means that by having collective responsibility for change and adopting new technologies within the building and construction industry, the speed of the adoption process would be increased and be more achievable [73].

Clients can lead the change and adoption of new technologies; in other words, the change would not happen, unless there is a demand from customers [43]. Also, Blayse and Manley [69] explored manufacturing companies, and found that customers are the key industry participants in making the motivation for technology adoption. To reinforce this factor, clients should properly, and stimulate awareness of new technologies and advantages of new methods which may provide a valuable enabler to the industry adopting new ways.

Employing youth is another factor which affects change in the building and construction industry. Youth in the industry have an open mind, and they do not limit themselves in adopting new ways because of having prepossessed ideas. To improve productivity and adopt new ways, hiring a new generation of workers who have grown up in a digital world would be very useful and motivate change in the construction industry [73].

Training is another key factor which should be considered. As Barbosa et al. [75] mentioned, construction companies and works need to be aware of and trained continuously about the latest types of equipment and digital tools. This training would be very practical because of the fast speed of technological innovations experienced by the construction industry.

Metropulus researched [76] on the adoption process of two commercially available technologies that availability of technologies, site engineers who had a background in using the new technology, and design files was enabler factor in the adoption process of them.

However the nature of the barrier and enabler factors is very context-dependent and can be different for every industry and for every country,

2.5.3.6 Technology adoption and construction industry

How managers and decision-makers of the construction companies decide to adopt new technology, what the processes are for this decision making and what are the factors affecting these processes are considered in this part. Mitropoulos [77] worked on eight case studies covering the adoption of two commercially available technologies. Firstly, he concluded that the sophisticated facility design to the end-users is a barrier in technology adoption for construction contractors [77]. Secondly, most of the times, the higher cost of new technologies compared to traditional ones exceeds the project budget. This deters project managers from implementing the new technology in their projects. And finally, the availability of the technology, design files and site engineers who had experience in working with the technology in the past are considered as enablers for technology adoption [77].

2.5.4 Implementation

Implementation refers to a stage that a user or a decision-maker of the company decides to implement the innovative technology on a project [42]. Often, implementation takes more time than the other stages [42]. At the implementation stage, the new technology adoption process shifts from the mental and deciding stage to a practice adoption stage [42].

2.5.5 Confirmation

At the confirmation stage, the decision has already been made by the decision-maker in respect of the new technology, but he is looking for support for his decision at this stage [50]. If a decision-maker receives conflicting messages about new technology, she may change her mind regarding that. The attitude of the individual is very important at this stage because most of the time, they prefer to stay away from conflicting messages and mostly prefer to receive messages which confirms their decision[42],[49].

There may occur two types of discontinuance in this stage. Firstly, when the decision-maker rejects the new technology because he is not satisfied with its performance, this is called disenchantment discontinuance. Another type is replacement discontinuance, which means individuals replaced the innovation with another technology to adopt better innovation [49][50].

2.6 Summary

This research aims to explore the factors that facilitate the adoption of new technologies in the New Zealand construction industry. In the literature review section, the history of earthquake risk and damage and the post-earthquake costs in New Zealand have been discussed. Also, it has been discussed that earthquake damage and expenses can be reduced by innovation, new methods and new technologies such as seismic-proofing technologies. However, the process of adoption to new technologies in New Zealand has been slow.

Another round of literature review was carried out on the innovation-decision process by examining types of diffusion innovation models (see Figure 2.1). The first step is the introduction of the new technology to the individual or the organisation. The second step is forming an opinion to trust in or reject the new technology by the individual or organisation. During this step, the factors that lead to a faster and more straightforward way of trust in new technologies around the world were identified.

In the third step, the process of adoption of the new technology has been discussed. The elements that make the adoption process more accessible and faster, the enabler and barrier factors in a global vision, were explored.

Finally, at the fourth and fifth steps, the implementation and confirmation procedure in a project has been discussed.

CHAPTER 3

Decision factors for adopting a new seismic-proofing technology

The current chapter is based on the following article:

S. Zarinkamar, M. Poshdar, S. Wilkinson, and P. Quenneville,(2020) "Decision factors for adopting new seismic-proofing technology,". International Journal of Construction Management. (Submitted)

3.1 INTRODUCTION

Failing to meet owners' demands has become one of the biggest concerns in the construction industry. Projects fail to meet owners' expectations of cost, time and quality [78], [79]. The use of traditional methods and tools in construction has been one of the main sources of unsatisfactory outcomes [80]. New technologies are introduced mainly to compensate for these issues. A new technology refers to a product or a process which has not previously been used by a field or a company to improve performance [76]. It can be a software package, a piece of equipment, device, material or technique. However, the process of adoption is lengthy and complicated. Most of the time, this process is protracted over several years from the introduction of technology to its adoption [49][54]. Construction has been recorded among those industries as having high resistance to adopting new technologies [81]. Several academic studies have investigated the features of this industry and the primary reasons for the observed inertia in it [55], [81], [82]. They have provided a substantial body of evidence that confirms the process of adoption of the new technologies as a crucial issue, which has resulted in the overall inefficiency and quality defections [55], [81], [83]. Therefore, an exploration of the factors that speed up the adoption process is necessary to get a clear picture of the problem and its potential solutions [76]. Given the clear and global impact of seismic events over the years, the Seismic-Proofing Technologies (SPTs) and methods have been a crucial part of these innovations. SPTs address two main targets, first to maintain the life-safety criteria and second, to reduce the damage and provide the possibility of post-event functionality [14].

The objectives of this chapter are divided into two parts:

Objective 1: Identifying the factors facilitating or slowing down the adoption of new seismic-proofing technologies in the New Zealand construction industry.

An enhanced understanding of the factors can play an important role for researchers in designing policies to leverage the adoption of new technologies. This study uses the Resilient Slip Friction Joint (RSFJ) as a case study that represents the novel SPTs and explores the factors affecting the perception of construction professionals about the product and its acceptance.

Objective 2: Discuss the state point of view about the reasons of importance for the factors.

By understanding the significance of these factors, the researcher can explore the ways to reinforce the enablers and the means to change and overcome the barriers.

A comprehensive literature review has been carried out in the previous chapter to explore the trust factors influencing the adoption process to the new methods and new technologies in construction. However, in the absence of specific research on the subject, this chapter evaluates the degree of the importance of the explored factors from the literature review in respect to the case study (RSFJ) as a representative of the new SPTs.

The data for the study were collected through a questionnaire survey completed by more than 80 practising industry members.

3.2 RESEARCH METHOD

The study involved a questionnaire survey with construction experts in New Zealand to assess their perception of the relative importance of the factors discovered from the literature review processes. The study used a newly introduced seismic-proofing technology as a case study to capture the general viewpoint of the industry professionals. The (RSFJ) [84] was used as the technology sample for the case study. This technology was introduced to the market in 2016 and represented a new generation of resilient seismic technologies that offer a significant damage reduction in the structural and non-structural elements in the building [14]. It provides a possibility of immediate occupancy after the seismic event [85].

Out of the 200 professionals who were invited, 130 responses were received with 81 complete and valid—the questionnaire comprised four sections created on Survey Monkey. The first three sections collected the demographic information of the respondents including their role as a client, contractor or consultant, years of experience and their geographic location; the type of their organisation (public or private); and finally, the type of construction projects they have been involved in. The respondents could assign themselves to one of the five main professional groups in construction, including architects, structural engineers, planners, quantity surveyors and project managers. The ones who did not belong to any of these pre-defined categories were provided with an option to add their role.

A short explanation of the case study concept was included in the first part of the survey. In the second part of the survey, the respondents were requested to rate their perception about the importance of the factors on a five point-Likert scale from 1 (Extreme impact) to 5 (No impact) in the process of adoption of the new seismic proofing technologies. The respondents were also given the option to add any factor perceived to be missing from the list.

Conceptual and relational analyses were performed on the survey responses. The conceptual analysis determines the existence and frequency of concepts in a text, and relational analysis develops the conceptual analysis further by examining the relationships among concepts [86]. At stage one, the factors were categorised into four groups (see Figure 3.1) including:

- Project-related, which involves the way in which the series of tasks are defined and carried out to maintain the project goals.
- Organisational-related, which involves the way in which activities are directed to achieve the goals of their enterprise.
- Market-related, which involves the consumers' needs and preferences.
- Cost-related factors, which involves the monetary value of goods and services.

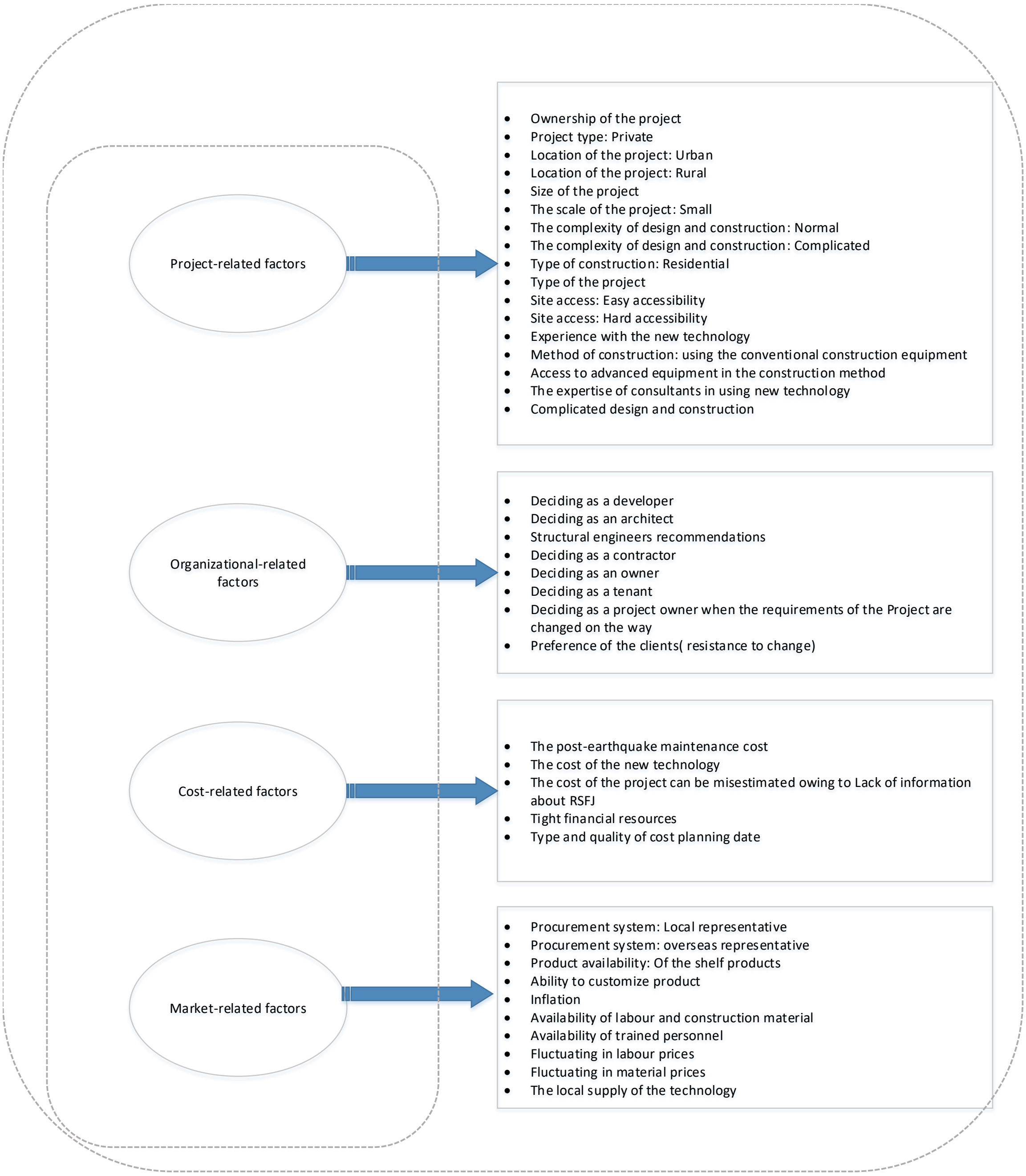


Figure 3.1: Stage one

A quantitative comparison of the size of the identified categories presented the project-related factors at the top among the other three by 16 factors based on the provided definition, and the cost-related factors stood at the bottom involving only five factors.

Next, the study covers a statistical analysis that determines the most imperative factors affecting the adoption process in the sample new technology.

3.3 FINDINGS

An analysis of the 81 valid responses indicated that 16% of the respondents were clients, 9% were contractors, 68% were from the consultants' category background, and the other 8% consisted of surveyors, building controllers, regulators and structural designers (see Figure 3.2 (a)). The range of the professional working experience reported by the respondents was between five and 20 years (Figure 3.2 (b)). An independent sample t-test was used to assess the statistical significance of the differences among the factors in each group. As shown in Table 3.1, the significance of the difference was close to zero, which confirms the homogeneity of the samples.

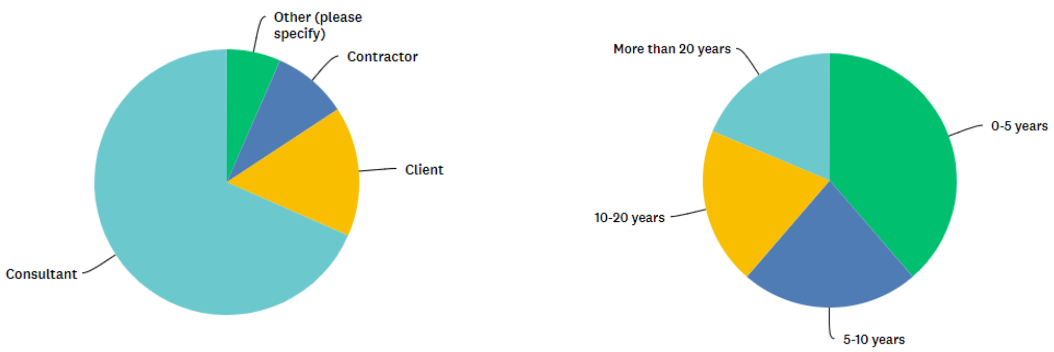


Figure 3.2: (a) respondents population, (b) respondents working experience

Table 3.1: One sample t-test result

Factors affecting Trust in new methods and new technologies in the construction industry	Mean	t-value	SD	Significance (2-tailed)
(I) Organisational-related factors				
Deciding as a developer	3.3	19.3	1.1	0.000
Deciding as an architect	3.1	22.5	0.9	0.000
Structural engineers recommendations	3.8	21.2	1.1	0.000
Deciding as a contractor	3	16.2	1.2	0.000
Deciding as an owner	3.3	17.8	1.1	0.000
Deciding as a tenant	2.4	12	1.3	0.000
Deciding as a project owner when the requirements of the project are changed on the way	3.3	20	1	0.000
Preference of the clients(resistance to change)	3.5	17	1.3	0.000
(II) Project-related factors				
Ownership of the Project (government projects)	4	21.1	1.2	0.000
Project type: Private	3.3	21.5	1	0.000
Location of the project: Urban	3.2	20.4	1	0.000
Location of the project: Rural	2.4	16.7	1	0.000
Size of the project	3.6	20.5	1.2	0.000
The scale of the Project: Small	2.7	18.5	0.9	0.000
The complexity of design and construction: Normal	3.3	23.8	0.9	0.000
Type of construction: Residential	2.8	15	1.3	0.000
Type of the project	3.6	21.5	1.1	0.000
Site access: Easy accessibility	3.1	16.8	1.2	0.000
Site access: Hard accessibility	3	16.3	1.2	0.000
Experience with the new technology	3.8	22.7	1.1	0.000
Method of construction: using the conventional construction equipment	3.3	20.6	1.1	0.000
Access to advanced equipment in the construction method	3.5	21.3	1.1	0.000
The expertise of consultants in using the new technology	3.7	21.5	1.1	0.000

Complicated design and construction	3.5	20.5	1.1	0.000
(III) Cost-related factors				
The post-earthquake maintenance cost	4.1	31.9	0.9	0.000
The cost of the new technology	3.8	38.5	0.7	0.000
The cost of the project can be miss-estimated owing to Lack of information about RSFJ	3.4	26.7	0.9	0.000
Tight financial resources	3.4	23.7	1.1	0.000
Type and quality of cost planning data	3.2	18.9	1.2	0.000
(IV) Market-related factors				
Procurement system: Local representative	3.6	24.2	1.1	0.000
Procurement system: overseas representative	3.3	21.3	1.1	0.000
Product availability: Off the shelf products	3.4	27.7	0.9	0.000
Ability to customise product	3.8	27.4	1	0.000
Inflation	3.3	22.7	1	0.000
Availability of labour and construction material	3.6	22.3	1.2	0.000
Availability of trained personnel	3.7	29.6	0.9	0.000
Fluctuation in labour prices	3.2	21.3	1.1	0.000
Fluctuation in material prices	3.3	22.3	1	0.000
The local supply of the technology	3.7	21.3	1.2	0.000

The survey analysis can be answered by more than one statistic method. A one-way between-groups ANOVA test was conducted in spss based on sample ratings. As shown in Table 3.2, the significance of the difference was again close to zero, which confirms the homogeneity of the samples again.

Table 3.2: ANOVA test results

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Deciding as a Developer	Between Groups	40.765	2	20.383	75.218	.000
Deciding as an Architect	Between Groups	21.330	2	10.665	32.593	.000

Structural engineer recommendations	Between Groups	43.898	3	14.633	31.632	.000
Deciding as a contractor	Between Groups	46.962	2	23.481	52.682	.000
Deciding as an owner	Between Groups	46.019	2	23.010	69.257	.000
Deciding as a tenant	Between Groups	58.717	2	29.359	98.977	.000
Deciding as a Project owner	Between Groups	35.362	2	17.681	59.371	.000
Preference of the clients	Between Groups	57.905	2	28.952	90.331	.000
Government projects	Between Groups	50.257	3	16.752	35.345	.000
Private projects	Between Groups	43.754	3	14.585	67.057	.000
Location of the project: Urban	Between Groups	40.841	3	13.614	41.531	.000
Location of the project: Rural	Between Groups	36.460	3	12.153	47.105	.000
Size of the project	Between Groups	48.387	3	16.129	34.390	.000
The scale of the project	Between Groups	36.930	3	12.310	59.475	.000
Normal design	Between Groups	31.987	3	10.662	43.389	.000
Complicated design	Between Groups	48.559	3	16.186	40.499	.000
Type of construction	Between Groups	64.747	3	21.582	77.412	.000
easy accessibility	Between Groups	60.262	3	20.087	55.033	.000
hard accessibility	Between Groups	55.361	3	18.454	46.824	.000
Experience with the new technology	Between Groups	40.277	3	13.426	29.462	.000
Using the conventional construction equipment	Between Groups	47.453	3	15.818	74.743	.000
Access to advanced equipment	Between Groups	53.078	3	17.693	163.025	.000
The level of expertise in using the new technology	Between Groups	38.659	3	12.886	23.878	.000
Post-earthquake maintenance cost	Between Groups	29.429	4	7.357	78.859	.000
The cost of the new technology	Between Groups	18.148	4	4.537	42.869	.000
Miss estimation in the cost of the project	Between Groups	45.513	4	11.378	158.220	.000
Tight financial resources	Between Groups	55.048	4	13.762	64.515	.000
Type and quality of cost planning data	Between Groups	73.032	4	18.258	82.546	.000
Procurement system: local representative	Between Groups	53.247	4	13.312	62.036	.000
Procurement system: overseas representative	Between Groups	59.381	4	14.845	66.533	.000
Product availability: off the shelf product	Between Groups	41.468	4	10.367	77.521	.000
Ability to customise product	Between Groups	44.481	4	11.120	59.371	.000
Inflation	Between Groups	56.860	4	14.215	204.989	.000
Availability of construction material& labour	Between Groups	65.798	4	16.450	84.254	.000
Fluctuating in labour prices	Between Groups	59.413	4	14.853	112.714	.000
Fluctuating in material prices	Between Groups	51.398	4	12.850	69.742	.000
The local supply of the technology	Between Groups	77.172	4	19.293	111.531	.000

3.3.1 The top critical factors in technology adoption

The factors with a mean score of more than 3.5 were chosen as the top critical factors. (see Table 3.3).

Table 3.3: Ranking order of the top critical factors in technology adoption in the New Zealand construction industry

Rank	Factors affecting the choice of RSFJ	Mean	Factor cluster
1	The Post-earthquake maintenance cost	4.1	Cost
2	Ownership of the project	4	Project
3	Experience with the new technology	3.8	Project
4	Structural engineers recommendations	3.8	Organisation
5	The cost of the new technology	3.8	Cost
6	Ability to customise the product	3.8	Market
7	The local supply of the technology	3.7	Market
8	Availability of trained personnel	3.7	Market
9	The expertise of consultants in using the new technology	3.7	Project
10	Size of Project	3.6	Project
11	Type of Project	3.6	Project
12	Availability of labour and construction material	3.6	Market
13	Procurement system: Local representative	3.6	Market
14	Preference of the clients (resistance to change)	3.5	Organisation
15	Access to advanced equipment in the construction method	3.5	Project
16	Complicated design and construction		Project

3.4 DISCUSSION

In this section, the top factors of the four categorical clusters and the potential reasons for their significance are provided in detail

3.4.1 PROJECT-RELATED FACTORS

Figure 3.3 presents the results of the statistical analysis of the factors clustered in this category.

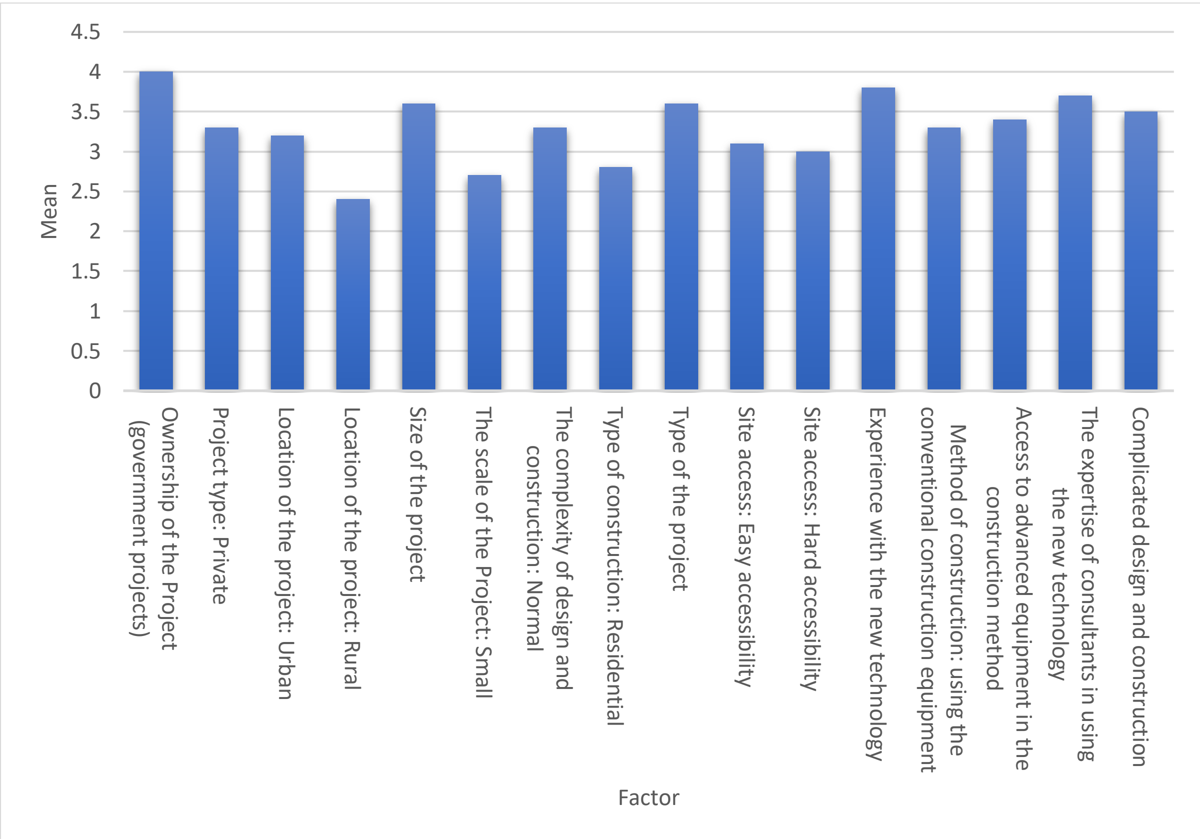


Figure 3.3: Project-related factors

3.4.1.1 Ownership of the project and the role of government

The government can play a key role in supporting the adoption of new technologies. This has received considerable attention in the literature. Governments set the regulations, and having regulations in place that support the use of the new technologies can help in speeding up the technology adoption process [87]. The conducted case study used technology with self-centring capability [14]. Based on the regulations and standards mandated by the New Zealand government, each building is associated with a design importance level between 1 and 4. This importance level is determined depending on the risk that the building damage could impose on human life and the importance of the post-disaster functionality of the building [88]. The features provided by the sample technology could fit well into the requirements of the regulations. It demonstrates the importance of regulations and `government support' for new technology or a new method, so the technology transfer and technology adoption journey will be more successful.

3.4.1.2 Experience with the new technology

The existing experience with the new technologies can affect the level of acceptance because concerns and perception about a given technology and lack of experience with the new technology can be negative [89]. The importance of experience has been discussed by Rogers [42].

Rogers has explained the adoption process for each user based on their unique characteristics. The first group is the small population of innovators which accept new technology straight away. The second group is called 'early adopters', which is a larger group that are forward thinkers and like to use new technologies; they can encourage their peers to motivate better adoption of the new technologies. The third group is people who wait to see if the second group makes a decision to adopt new technology because they do not have any experience with the new technology. The problem is that half of the population belongs to the third group, which is not eager to start using new technology.

Maughan et al. [90] suggest how to tackle this issue. First, the developer of the technology should improve the knowledge about the technology by emphasising cultural and social values to change the adopters' perception and raise the level of enthusiasm for the acceptance of the new technology. This goal can be achieved only when excellent communication between the developer and the user is established. Developers should share all resources and capabilities needed to use the new technology with users so they can customise the products they need as desired using these resources [90].

3.4.1.3 The scale of the project

There is a proportional dependency between the ratio of the cost of the new technology and the total cost of the project. In large projects, the ratio tends to be small. Therefore, new technologies can better be substantiated in the cost-benefit analysis. As mentioned above, the case study presented to the respondents was able to minimize the post-earthquake maintenance cost. For such types of new technologies, taking the costs of post-earthquake repairs into account could encourage initial investments in the new technologies in small to medium size projects.

3.4.1.4 Type of Project (operational purpose of the project)

The survey results indicated a strong association between the operational function of the project and the level of intention to adopt new technology. This association was clear for projects with business and industrial functionality, in particular. The foundations of national economies are businesses [91]. Disasters such as earthquakes affect the economy by causing unemployment and loss of income. The financing of business recovery and dealing with the damage are the most significant challenges for business owners after an earthquake event [92]. The post-event business downtime can result in a financial loss even higher than the cost of building repair [93]. Simultaneously, it is critical that industrial buildings remain functional during and post the events [94]. The functionality of industrial facilities such as electricity providers, water providers and even internet and communication providers have both a direct and indirect influence on the economy and the society [93]. Therefore, these buildings are usually designed with a high importance level [94]. In these situations, seismic proofing technologies such as the one in our case study that minimises the damage can provide a lower risk of post-disaster financial loss and maintain the functionality of the buildings during and post-disaster.

3.4.1.5 Complicated design and construction

The survey results demonstrated that the *complicated design and construction factor* is one of the important factors which affects the choice of new seismic technology. Dodgson [47] pointed out that a suitable configuration of technology will result in a more natural and faster adoption process to the new technologies. This suitability can be achieved by the scientific advancements embedded in new technologies [95]. Based on Dodgson's point of view, by having an easy implementation process, one could promote the acceptance of new seismic technologies in New Zealand. In such cases, a design-ready pack of the technology can significantly reduce the designers' efforts to meet codes and regulations and can promote trust and adoption levels[96]. A simpler configuration associated with a simpler seismic design makes the technology more favourable for the designers [14].

3.4.2 ORGANISATIONAL-RELATED FACTORS

Figure 3.4 presents the order of the factors found by the survey that are involved in the organisational-related group.

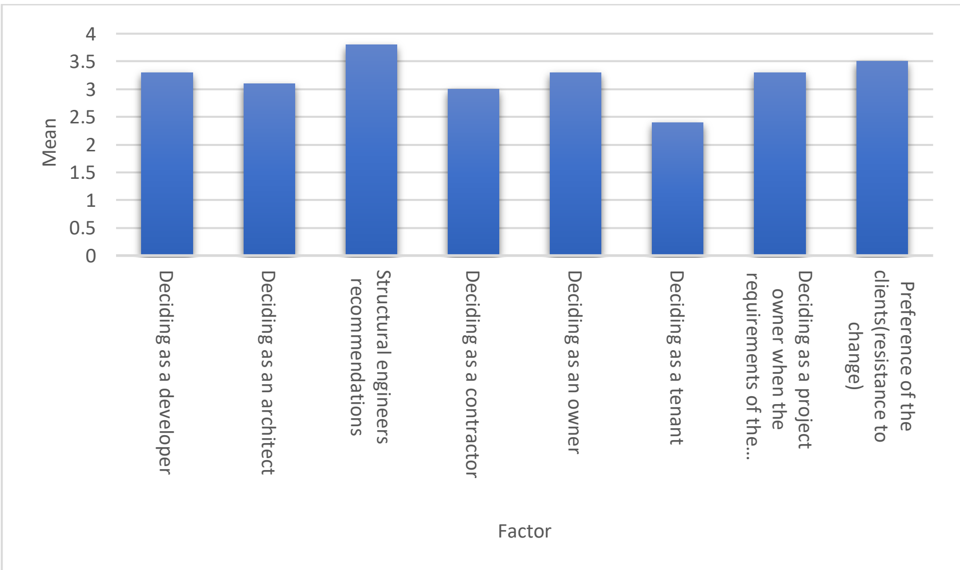


Figure 3.4: Organisational-related factors

3.4.2.1 Preference of the structural engineers and clients (project owners)

The survey identified that structural designers and project owners play an instrumental role in promoting the use of new technologies in construction. Structural engineers are the key characters deciding on the adoption of a specific structural solution or new structural technology [97][81]. It is imperative for structural engineers to be satisfied with the technology. Efficient knowledge transfer between those consultants that have already adopted the new technology and the potential adopters can play a crucial role in the adoption process [98]. The ultimate solution can be to inform the structural engineers about the advantages of the new technologies and make them familiar with the design tools that support incorporating these new products into their designs [99]. This can be achieved through technical presentations, workshops, seminars and conference/journal publications [99].

The results of the survey identified the preference of the project owners as another crucial organisational factor in the adoption process. Project owners or, more generally, clients are typically resistant to change in the adoption process to new technologies. This result conforms with the findings of Grant [96], who showed the significance of 'managing change'. Their research asserted the fact that sometimes resistance to change inside of the organisation may even result in the closing of a company. The problem is at the decision-making process; that the information and advantages of new technology have not been correctly introduced [100], [101]. To tackle this issue, project owners should understand the continual benefits of new technologies and how these benefits are gainable [100]. It is expected that if the clients become more familiar with these concepts, there is a higher chance for them to be convinced to adopt the new technologies. Thus, the observed resistance to change may reduce.

3.4.3 COST-RELATED FACTORS

The identified orders for the factors categorised under the cost-related group are presented in Figure 3.5.

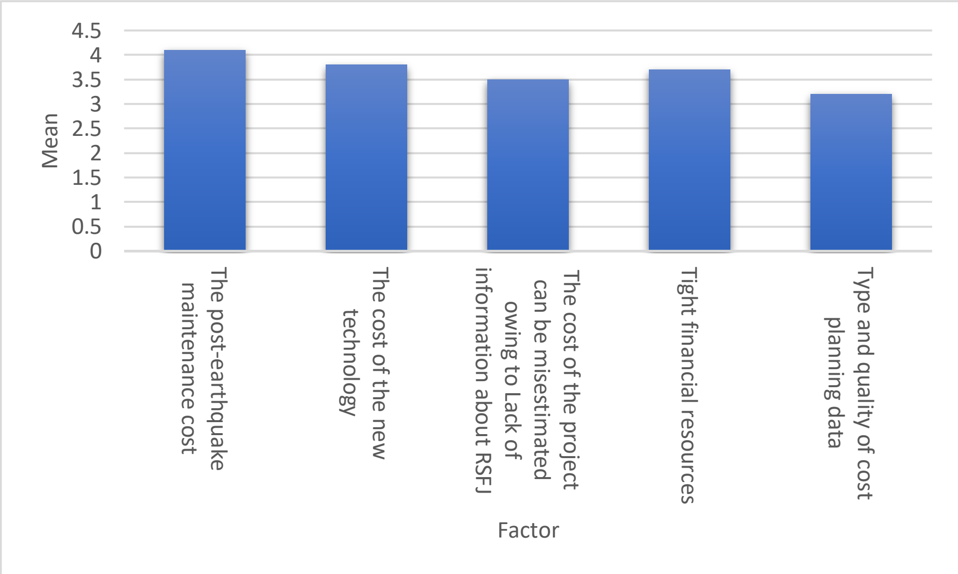


Figure 3.5: Cost-related factors

3.4.3.1 Future savings provided by the new seismic technology (the post-earthquake maintenance cost)

Based on the survey, the post-earthquake maintenance cost was selected as the first significant cost-related factor by respondents. The reason may be the impact and consequences of the recent seismic events on the economy and society of the country (particularly the Canterbury earthquake sequence and Kaikoura events). It is no surprise that a maintenance-free seismic-proofing system with immediate functionality after the earthquake has been well received by the new technology adopters. This maintenance-free characteristic of the case study can also be interpreted as insignificant structural repair costs after the earthquake [14].

3.4.3.2 The higher cost of utilising a new technology

The decisions about the use of new technology in a project involve a comparison between the new technology and the conventional ones concerning the advantages and disadvantages each can provide [95], [102], [103]. A higher initial cost can be a crucial item for projects with limited capital. In such projects, conventional technologies are a preferred choice [104].

The reason for the higher cost of the new sophisticated technologies and methods is that they require highly accurate manufacturing and implementation processes. A reference to the overall lifecycle cost of the project compared to the cost of the new seismic technology may boost the attraction of the new technology for the decision-makers. For example, at the time of the survey, the technology referred to in the survey was already used in some major projects such as an airport terminal and a medical clinic. According to the developer of this technology, for these projects, the initial additional cost of the sampled technology to the overall cost of the project was around 2 percent.

3.4.4 MARKET-RELATED FACTORS

The results of the statistical analysis of the market-related factors are listed in Figure 3.6

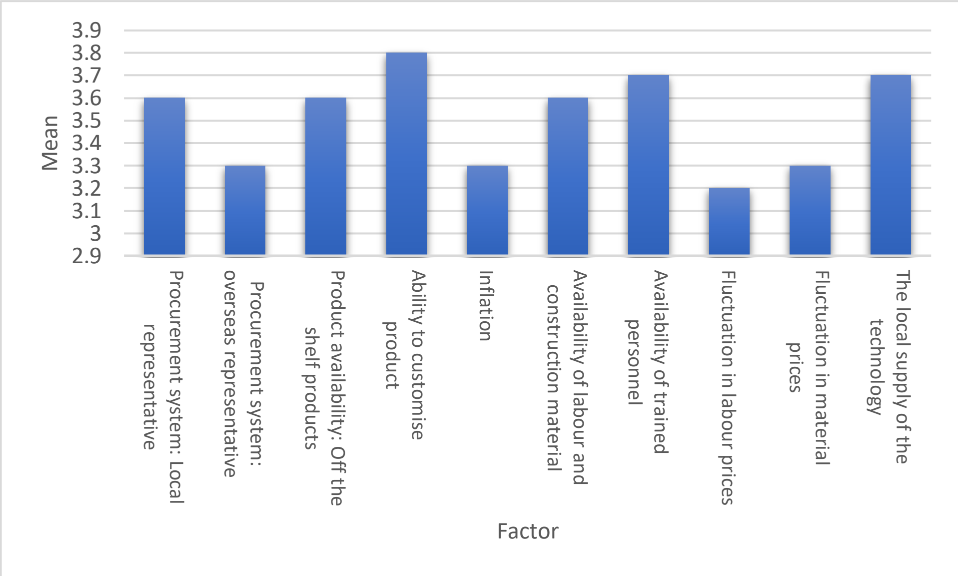


Figure 3.6: Market-related factors

3.4.4.1 Ability to customise the product

The survey responses also showed the importance of the customisation ability of technology in promoting its adoption. When a product is called compatible, it refers to how closely it fulfils the needs of the adopters and the extent to which it is homogeneous with the existing values [42]. *Compatibility* is the degree to which the innovation is seen as consistent with existing values, previous experiences, and needs of the user [50]. "Customisation" refers to a company's ability to efficiently "mass" produce products that meet individual consumer desires and needs. A common way to carry out "mass customisation" is to offer a basic package for a product and then offer customers a range of features they can add or subtract. "Customisation" carries the "benefits" of high product sales associated with "mass" production, and by offering a foundation product and giving customers a range of models or the option to add features of their choice, it increases customer satisfaction and provides a business with increased sales [105]. The technological abilities of suppliers have been identified as an essential enabler of Technology Transfer (TT)

[106]. Technical skills to deliver useful and technically sound output should be the main characteristics of the organisation which take the honour of developing a new technology or a new product. For example, if a company has insufficient resources, it may not be able to deliver quality products [95]. It is demonstrated that a reliable technology provider company with good quality support can produce customised products. When a product can be customised based on customer needs, it means that it can be produced in any size, and it can be used in any part of the construction [105]. This adaptability makes the product more desirable in the market compared to other technologies [105]. Most of the time, new technologies and products can be customised based on customer needs. When a product can be manufactured based on customer needs, the adoption process for this technology rises sharply [105]. In future, designing new technologies with the advantage of being customised based on customers need may result in better and faster adoption process.

3.4.4.2 Availability of labour and construction material

The availability of a trained workforce and construction materials on the construction site has been identified as an important factor for technology adoption by the respondents of the survey. This result is consistent with the findings of Branson's study [107]. Their study demonstrated that the use of materials which are locally available for producing new technology could significantly increase the likelihood of its adoption. It enables a shorter lead time for the projects that increase the level of adoption. Unskilled labours, non-availability of resourced and lack of training for the new product will reduce the speed of technology adoption. As an example, the installation procedure of the case study is rather simple and can be handled by the mid-level skilled labourers that properly fits into the skill sets available in the New Zealand market.

3.4.4.3 Local representatives

When a product is manufactured locally, it should be aligned with the culture of that society [95]. For the purpose of having a more successful technology adoption process, it would be helpful for the host to gather relevant information in relation to the international technology experience [108]. The appropriate nature of the new technology would smooth the way to adoption. Delivery time is another significant factor for the success or failure of new technology; successful technology adoption occurs when the technology is delivered to a project or a user on the optimum time [109]. With a local product representative, technical and procurement support is readily available [109]. This ensures the availability of the responsible person if there is a query or a special request (e.g. for maintenance and support). Furthermore, if the adopter desires a change in specifications, the matter can be communicated with the local representatives more easily, and the queries can be addressed faster. This attribute has been suggested as the seventh most important factor in facilitating the adoption of new technology.

3.5 CONCLUSIONS

New methods and technologies are introduced to decrease the impact and consequences of earthquake and aftershocks. However, the low level of trust in these new methods and technologies poses a serious barrier for the adopters. This research explored the factors that contribute to the adoption of new seismic-proofing technology. The analyses revealed four main categories of factors that can significantly affect the uptake of the new technologies. The first category was project-related factors such as project type, the location of the project, the scale of the project, type of the construction, site accessibility, the level of expertise of consultants, method of construction and the complexity of design and construction. The second category is organisational-related factors dealing with the role of the decision-makers. The third category is cost-related factors such as the decrease in the post-earthquake maintenance cost, cost of the new technology if higher compared to the conventional technologies, misestimation of the cost of the project if the project is targeted to reduce cost as much as possible, and type and quality of cost planning data. Finally, it is the market-related factors such as the procurement system, product availability, inflation, availability of construction material, availability of labour, fluctuating in labour price and material price and finally, ability to customise products.

The findings highlighted the importance of sixteen factors. This chapter discusses the most important factors which speed up the process of the adoption of new technologies for the construction industry and addresses the reasons for all of them. These findings can provide technology developers with a baseline to form a pathway to improve the adoption process. Given the unique culture and characteristics of the New Zealand construction industry, the nature or relative level of the importance of the factors influencing the technology adoption may vary from other countries, so this research covers a restricted geographical scope (New Zealand) that can be expanded at further stages.

CHAPTER 4

Enablers and barriers of seismic-resistant technologies adoption in the New Zealand construction industry

The current chapter is based on the following article:

S. Zarinkamar, P. Quenneville, S. Wilkinson, and M. Poshdar "Enablers and barriers of seismic-resistant technologies adoption in the construction industry: A New Zealand case study'' 2020 World Conf. Earthq.Eng.

4.1 Introduction

New Zealand has been affected by significant earthquakes over the years. Despite all the improvements introduced by developing the codes and standards since 1932, the country still suffers substantial losses after each earthquake. As a consequence of a large number of earthquakes that happened before, the economy of the country has been impacted. A lot of solutions have been considered for addressing this issue, such as introducing new seismic technologies. Modern methods of seismic design (since the 1970s) allow structural engineers to design new buildings with the aim of predictable and ductile behaviour during severe earthquakes to prevent collapse and loss of life. The adoption process for these newly introduced technologies is prolonged and turns into a significant challenge for the construction industry [110]. A comprehensive literature review has been carried out to identify the factors which cause the adoption of new technologies. Forty factors have been chosen based on the literature. A questionnaire survey was conducted among the construction field experts to refine the list of the factors to the most significant ones. As a result, 16 factors were detected that are presented in table (4.1). These important factors are the findings of chapter 3, which has been explained completely in the previous chapter.

Table 4.1: The most significant factors in the process of adoption based on the survey one in chapter 3

Factors	Significance level
The post-earthquake maintenance cost	1
Ownership of the project	2
Experience with the new technology	3
Structural engineers recommendations	3
The cost of the new technology	3
Ability to customise product	3
The local supply of the technology	4
The expertise of consultants in using the new technology	4
Availability of trained personnel	4
Size of project	5
Type of project	5
Procurement system: Local representative	5
Availability of labour and construction material	5
Complicated design and construction	6
Access to advanced equipment in the construction phase	6
Preference of the clients	6

The role that these, factors played as an enabler or barrier in the adoption process of the New Zealand construction industry will be discussed in this chapter. The following four different seismic-resistant technologies have been considered as case studies because most of these seismic-resistant technologies have been introduced recently to the New Zealand construction industry and the adoption process for these technologies is slow:

1. Resilient Slip Friction Joint (RSFJ) is a newly introduced seismic resistant technology which dissipates earthquake energy, restores the structure after each seismic event; there is no need for sacrificial components, and no post-event maintenance is required [14].

1. Pres-lam is a method of mass engineered timber construction that uses high strength unbounded steel cables or bars to create connections between timber beams and columns, or between columns and walls and their foundations. As a pre-stressed structure, the steel cables clamp members together creating connections which are stronger and more compact than traditional timber fastening systems [111].

3. Lead Extrusion Damper (LED) is another type of damper which utilises the hysteretic energy dissipation properties of metals [112], and

4. Sliding Hinge Joint (SHJ) is a low damage alternative to the traditional beam-column welded connections of the seismic Moment Resisting Steel Frames (MRSFs) [113].

Enablers can be defined as equipment and methodology that, alone or in combination with related technologies, provide a way to generate giant leaps in performance and capabilities for the user. By finding enabler factors and reinforcing them, the process of adoption of the new technologies will be sped up [114].

Barriers to adoption are all the things that prevent you from using a new product. They may range from inconveniences, the need to buy ancillary products, the difficulty getting it to work or the learning curve. By finding barriers to adopt to new technologies and try to fix or improve them, the speed of the adoption process will increase.

4.2 Research design

The industry adoption of new technologies is slow in the New Zealand construction field. To address the low process of adoption of the new technologies first, a literature review has been done to explore the factors that facilitate technology adoption from previous researches. Second, a survey was designed to seek the most significant factors that enable technology adoption in the New Zealand construction industry. At this stage, another survey has been designed to find the roles these factors played as enabler or barriers.

4.2.1 Survey design

The factors which can influence trust and adoption in new construction technologies and methods in New Zealand were identified in a previous survey. Another survey was conducted to explore the type of impact of each factor. Do the following factors enable the uptake of new technology, or are they a barrier to new technology?

The questionnaire survey was designed by Survey Monkey and a web link was generated. The weblink has been sent to 215 respondents from New Zealand by email. The survey consisted of two parts. In the first part of the survey, the case study was explained completely, and in the second part, it was asked from respondents to rank the factors as enablers or barriers in the process of technology adoption., The last question of part two asked respondents to add any enabler or barrier factor in the technology adoption process which they considered had been missed from the survey.

4.2.2 Data collection and analysis

The survey was designed in Survey Monkey and released to the construction industry experts in New Zealand. The experts, including clients, contractors and consultants, were representative of different trades in a typical construction project. Their years of experience were more than five years, and they would have experience in working with new technologies. A total of 215 experts were invited, 90 responses were received. Among these, 15 replies were disregarded because of non-completion. Random sampling was used. The collected data were analysed by using the binomial test. We expected the factors to have an equal chance in being enabler or barrier, so the test proportion was set to 50%. A sample model of the result is shown in table (4.2). The results of the binomial test showed there was no significance of differences because there was general agreement about which one is the enabler and which one is a barrier.

Table 4.2: Binomial Test

		Category	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Governmental project	Group 1	Enabler	68	.91	.50	.000
	Group 2	Barrier	7	.09		
	Total		75	1.00		

4.3 Discussion

Technology adoption is an essential subject in the construction industry. It is no secret that technology is continually evolving and rapidly changing the landscape of the construction industry. This ranges from increasing the efficiency of day-to-day operations to manufacturing new and advanced high-tech products. Typically, it is the companies that can be adopted and embrace technological change that ultimately survive the competitive business climate [115]. Based on the conducted survey, the enabler and barrier factors are shown in Table 4.3. Strict quality control, certificate of performance factors were added as enabler factors, and the origin of the component factor was added as a barrier to the survey by respondents. The following sections discuss the reasons for being chosen as an enabler or barrier and discuss how to reinforce enablers or fix the barriers.

Table 4.3: The chosen enabler and barrier factors by New Zealand construction industry users

Enablers	**Barriers**
Access to advanced equipment in the construction method	Preference of the clients (resistance to change)
Ownership of the project	Complicated design and construction
Type of projects	Origin of the component (place of the manufacturer)
Ability to customise products	Cost of the new technology
A local supplied technology	Lack of time to complete a project
Availability of trained personnel	
Structural engineer’s recommendation	
Post-earthquake maintenance cost	
Experience with the new technology	
Availability of labour and construction material	
Size of the project	
The expertise of consultants in using new technology	
Strict quality control	
Certificate of performance	

4.4 Enablers of technology adoption

The 14 following factors were identified as enablers in the survey, the reasons for and how to reinforce these factors for technology adoption in future is discussed below.

4.4.1 Using advanced equipment in the method of construction

Grange and Buys [95] identified that the technology adoption would increase by the scientific changes which happened in newly introduced technologies and products and cause these scientific changes to make them simpler to work with and be less complicated to implement. In our case studies using more advanced equipment in for construction has been identified as one of the most important factors which cause easy and quick adoption of these new technologies [116]. Construction methods refer to the procedures and techniques that are used during the building process [117]. For example, one of our case studies(RSFJ) can be easily installed in a building because it is a pre-fabricated product, which increases the acceptance of this newly introduced seismic technology by construction industry users [14]. In such cases, introducing the pre-fabricated types of construction products will enhance the adoption level of these new technologies [118]. These types of new technologies and new products will be more accessible to a wide range of users and to a wide range of constructions, and it will result in more flexibility in these types of products [118]. Another way is in anticipation of mechanisation and intelligent automation in new markets to solve the issue of construction works which up until now have been limited to being done by hand [119]. It is believed that the pace of work can be increased while reducing the required man-hours [119]. For instance, work that currently requires three people to work for three days can be completed by two workers in two days. As we know, every client wants the work to be completed as quickly as possible. Thus, mechanisation and intelligent automation can reduce the labour cost, and ultimately the overall cost [119]. It should considered that the method of construction of structures differs between the Western countries and Asia, as does the type of onsite work for renovation projects. However, by making the following three concepts a common feature no matter where they are employed, it may be able to create the construction equipment which can be used on any worksite anywhere in the world [119]:

1. The equipment size can be mounted onto a hoist 2. Superior versatility with interchangeable attachments, 3. Automation [119]. These reasons may be the cause that, in our case study, using more advanced equipment in the method of construction has been chosen as an enabler for technology adaptation.

4.4.2 Ownership of the project: governmental projects

If a product or a technology addresses the specific needs of the market or customer, the chance of it being accepted will increase rapidly in the market compared to its competitors. De la Tour recognised the market factor as one of the most critical enablers in technology transfer [120]. A market factor refers to any external agent that affects the demand for or the price of a good or service [119]. Using a new method or an innovative technology sometimes may secure business in the market [95].To speed up technology adoption, if there are some regulations and standards for buildings set by the government, a more suitable platform may be provided. So, for the governmental projects, designers will be encouraged to use newly introduced seismic resistant technology to provide life safety which will also reduce the post-earthquake costs [121]. As a result, seismic-resistant technologies play a significant role in keeping these types of buildings functional during and after earthquakes. Respondents chose this factor as an enabler.

4.4.3 Type of construction projects: Commercial and industrial

Based on our survey, the commercial and industrial types of projects are enablers for the adoption of new technologies. First, life safety is a priority in both of them, which some of the seismic-resistant technologies can guarantee achievement. Second, by using these technologies in a commercial building, the post-disaster financial loss will decrease significantly, which is most essential for business owners [122]. After disasters such as earthquakes, essential industrial buildings such as power providers or water providers should stay functional and provide basic needs of the community [122]; this is made possible by using some of the newly introduced seismic-resistant technologies.

4.4.4 Ability to customise products

Customisation refers to a company's ability to efficiently mass-produce products that meet individual consumer wants and needs. A common way to carry out mass customisation is to offer a basic package for a product and then offer customers a range of features they can add or subtract. Customisation carries the benefits of high product sales associated with mass production and, by offering a foundation product and giving customers a range of models or the option to add features of their choice, increases customer satisfaction and gives a business increased sales [105].

The technological abilities of suppliers have been identified as an important enabler of technology transfer(TT) [106]. Technological abilities to deliver good and technically sound output should include the main characteristics of the organisation which takes the honours for developing a new technology or new product. For example, if a company does not have sufficient resources, it may not be able to deliver quality products [95]. As a result, a strong provider company with good quality of resources can produce customised products. When a product can be customised based on customer needs, it means that it can be produced in any size, and it can be used in any part of the construction [105]. This ability makes this product very desirable in the market compared to other technologies [105]. Most of the time, new technologies and products can be customised based on customer needs [105]. When a product can be manufactured based on the soil requirements or the location of the building, the adoption process for this technology will increase sharply [105]. In the future, designing, new technologies with the advantage of flexibility in production and implementation may cause better and faster adoption process to that kind of technologies.

4.4.5 A locally supplied technology

A new technology or new product which is produced in a country should be compatible with local society [95]. There is a direct connection between success or failure of a product in making its way to the local market with the local suitability of the technology [95]. Generally, technologies that are produced locally also have the advantage of minimum transportation cost. It facilitates a shorter lead time that enhances the adoption process [109]. One of our case studies (RSFJ), is a made-in-New Zealand technology that is compatible with the requirements of the local industry; it also benefits from providing local representatives which makes support easily available. It ensures the availability of the responsible person if there is a query or a special request (e.g. maintenance and support). As mentioned before, in future using localised products may minimise the transportation cost, and they can be delivered to the projects in minimum time. So, time and cost will be reduced. Also, certifying technologies which have been developed and fabricated in New Zealand is better, because they can be tested one by one in laboratories. To conclude, using localised technologies has the advantages of availability and minimum transportation cost, which cause speeding up in the process of adoption.

4.4.6 Trained personnel

For developing a new product or a new technology, we may need trained expertise personnel to more secure transfer of technology [95]. Jobholders themselves have internalised this insight: A 2016 Pew Research Centre survey, "The State of American Jobs," found that 87% of workers believe it will be essential for them to get training and develop new job skills throughout their work life to keep up with changes in the workplace [123]. Providers of technology are the best to hold workshops and seminars as an efficient solution to get the engineers familiar with the technology [123]. Presenting case studies of the real-life projects that have adopted the new technology could also be useful, and even knowledge of personnel in receiver organisations has been recognised as a vital factor in technology transfer processes [124].

4.4.7 Structural engineer's recommendation

End users are the main testers of the new methods, or new technologies and their feedback may result in speedier acceptance of a new technology[125]. Customers will be motivated to pay higher prices to new technologies for higher quality or easier installation [126]. For our case studies, structural engineers have been considered as the end-users who have the main responsibility for deciding about using these products in new constructions [125]. Given the importance of the role of the structural engineers in the design process of the structures, they are the key characters deciding about adopting a specific structural solution or new structural technology [81]. Therefore, it is imperative for them to be technically satisfied with the technology and be convinced about the cost-benefit of the technology compared to the overall value of the building [81]. Overall, when structural engineers, as a key role in deciding about using new technologies in projects, are happy technically about the advantages of new technology and are satisfied with the cost of new technology compared to the overall value of the building, they then will play the enabler role in the adoption process of new technologies. To achieve this goal, holding a technical presentation for structural engineers by suppliers of the new technology about the technical advantages of new technology, how to design, model and implement new technology in new projects or upgrade projects would be very effective [127]

4.4.8 Post-earthquake maintenance cost

The 2010–2011 Canterbury earthquake, which involved widespread damage near the Christchurch Central Business District, left this community with more than $NZD 40 billion in losses (*20 % GDP), demolition of approximately 60 % of multi-storey concrete buildings (3 storeys and up), and closure of the core business district for over two years [13]. Insurance coverage and policy wording are critical variables in the repair or demolition outcome for buildings [13]. While insurance plays an important role in disaster mitigation and provides funding for post-disaster reconstruction, a code-compliant building may end up being demolished even if it is technically repairable because of uncertainties in repair costs and insufficient insurance cover. In the Christchurch earthquake event, there were some cases when the insurer considered the replacement of the building where the cost of replacing the building was less than the cost of repairing it [13].

Appropriability approach follows the belief that ‘good technologies sell themselves’. Some of the newly introduced seismic-resistant technologies may cause post-earthquake maintenance cost decreases because the system enables damage avoidance. This maintenance-free characteristic can also be interpreted as zero or insignificant repair costs after the earthquake. Having this factor ranked as the essential determinant indicates the significance of individual experience in building trust when adopting new technology. Reliability is considered for a technology when it will pass testing thoroughly, and as a result, it will represent less uncertainly to the customer so it can be accepted more efficiently [50]. Given these types of new seismic-resistant technologies can be damage-free and capable of restoring the building to its original position, they could have a significant impact on minimising the costs associated with damage recovery as well as minimising business interruption after severe earthquakes. The main issue is that clients do not consider maintenance cost in their initial cost estimation of the project[128]. As a result, they may find the price of new technology relatively higher compared to more conventional technologies. However, by using seismic-resistant technologies having the advantages of self-centring and energy damping in construction projects, the post-earthquake maintenance cost will be decreased. These reasons together cause this factor to be chosen as the enabler for technology adaptation from construction industry people point of view in New Zealand.

4.4.9 Experience with the new technology

The adoption process for new technologies is extremely slow [129]. The speed of transferring the experience of using new technologies will be decreased because of poor communications inside and outside of the companies [95]. A high level of internal communication will result in better technology, adoption of the new technologies and familiarisation with their new advances which they will bring [95]. Holding high-tech workshops and preparing installation guide for construction industry engineers will promote knowledge about installation requirements [127]. Presenting case studies of the real-life projects that have adopted the new technology could also be effective [127]. Contractors with more experience in working with new equipment will have a higher trust in the new technologies and will adapt easier and faster to the new technology [127].

4.4.10 Availability of labour and construction material

In large projects, the availability of labour and construction material may cause difficulty in the technology adoption process [130]. Lack of experienced labour with experience in the installation of new technology or using new methods may lead to a high hurdle to technology adoption [130]. Also, as we discussed above, the use of materials which are locally available could significantly increase the likelihood of its adoption [130].

With the availability of labour and construction material, the speed of construction will increase sharply [131]. The process of installation for most of the newly introduced technologies is easy, so for the installation, we do not need highly experienced labourers to be easily available. Producing a new technology by using the type of manufacturing material which is locally available will be very quick compared to the technologies for which the material is not locally available and has to be imported. To achieve this target, first governments should encourage manufacturers of the new technologies to produce their technologies by using local material which is easily available, and they can cover part of the cost of the production to reduce the cost of production for the provider. Second technology providers can arrange for installation guide for labourers before the start-up of a new project to speed up the construction.

4.4.11 The scale of the project (size of the project)

Large projects usually have a higher level of importance, so their earthquake performance is considered as an essential factor by the decision-makers [132]. Good examples are schools, universities, hospitals, airports, etc. Also, for many large projects, the developer/owner's intention is not just selling the building to the customers but also that the service the building provides is essential [132].

In large scale projects, the cost of new technology compared to the overall cost of the project is almost negligible. In recent years, newly introduced technologies, especially seismic-resistant technologies, can provide high-quality buildings by using them in the structure. Most of the time, the funding of large projects is almost unlimited, and there are not many limitations for spending on high-quality buildings with earthquake-resistant properties [132].

4.4.12 The expertise of consultants in using new technology

When construction industry experts and consultants become familiar with the advantages of new technologies, the adoption process may be sped up [133]. To achieve this goal, holding workshops and seminars, or presenting case studies of the real-life projects that were adopted using the new technologies could be effective. Having more knowledge about new seismic-resistant technologies will encourage decision-makers to adopt such technologies in their projects and enable the process of adaptation [127].

4.4.13 Strict quality control and certificate of performance

An important advantage derived by strict quality control is the satisfaction of consumers [134]. Consumers benefit as they get better quality products because of quality control [134]. This gives them satisfaction [134]. By producing better quality products and satisfying customers' needs, quality control raises the goodwill of the concern in people's minds [134]. Based on the survey result, if this factor is considered for new technology or new product, it will play the role of enabler. A certified product may display a trademark indicating that the product has undergone evaluation and testing to verify that the product will perform as indicated. Product certification, by definition, denotes the process through which a product is subjected to verify that it has passed quality and performance tests. Product certification assures that the product is suited for distribution and public consumption. Each of the seismic-proofing devices, and especially our case study (RSFJ), is tested individually and a certificate from the supplier is issued with the test result and a serial number of the device confirming its target performance. New technologies or new products which have strict quality control, tested in the laboratory and given a certificate of performance will get adopted by customers faster and easier.

4.5 barriers to technology adoption

Based on the survey, the five following factors were identified as barriers; we are going to describe the reasons for, and discuss the methods to fix, them below.

4.5.1 The client resistance to change (preference of the clients)

Resistance to change is an important issue within the company, more so than from the outside, and sometimes this reluctance to change results in 'end of the organisation' (ceasing to trade) [95]. So the decision-makers within companies should be persuaded to use new technologies to improve success [135]. In our case study, despite the higher initial cost, the new technologies could significantly reduce the post-event repair and maintenance costs, which give companies more advantages compared with the conventional solutions [14]. As a result, if the clients become more familiar with the advantages of these new technologies, they will be more likely to be convinced to adopt the new technologies. Thus, the observed resistance to change may be reduced. The other issue is that, even though the designers may be happy with the technology and its advantages, the contractors may hesitate to use new technology because of the potential risk related to the schedule. In other words, the contractor concerned if they use the new technology, they may not be able to deliver the project on time. To resolve this issue, providers of the technology must make their technologies compatible with the current installation and implementation procedures. This means that no special installation should be required for new technologies or, if there is, there should be a clear implementation guideline in place for contractors, so the contractors will be encouraged to use new technologies in their projects and accept changes.

4.5.2 Complicated design and construction

Complexity may be an integral part of using new technologies in designing construction [50]. Using new methods may require more complicated and updated designs. To solve this issue, a design-ready pack of new technologies and new products can help designers to design complicated projects [136]. Most of the time, newly introduced technologies have more effective advantages, and these can be very helpful for designers to use during their designing process.

4.5.3 Origin of the component

Country of origin is the country of manufacture, production, or growth where an article or product comes from[137]. There are differing rules of origin under various national laws and international treaties, which may result in different quality of products. In the past few decades, China has grown to become a major economic power. The main reason to consider manufacturing in China is almost always the lower manufacturing cost, especially for mass-market products [137]. However, this factor has been chosen as a barrier to the adoption process because of many reasons. First, customers are almost always willing to pay less for something even if it's manufactured in China. Second, China has quite a bad reputation for poor quality in manufacturing. Third shipping can be a real pain. This leads to long lead times and high shipping costs. By doing strict quality control for each product or each technology by providers of the technology, customers may be encouraged to better adoption of the new technology and also by having a certificate of performance for each device, the lack of trust issue for made-in-China products will be minimised.

4.5.4 The cost of new technology

In some cases, the cost of new technology will be higher compared to old ones, which can harm the adoption process. More scientific changes have been added to new technologies which result in higher cost, and therefore decision-makers prefer to use conventional technologies in their projects [138].

To tackle this issue, firstly, the overall lifecycle cost of the new technology should be presented to the decision-makers, which may motivate decision-makers to adopt it. Second, if customers are convinced to bring in the post-earthquake maintenance cost into account, the higher cost of the new technologies will be more acceptable to them. Another suggestion can be for governments to cover some part of the cost of new technologies or new products to have better and safer buildings and encourage contractors to use new technologies in their projects [138].

4.5.5 Lack of time to complete a project

Becoming familiar with new technologies needs time; some managers may see this as lost time. However, they should be convinced about the advantages that a new technology or new method will bring to the company compared to the conventional methods, specifically in implementing technology transfer projects [95]. Using advanced technologies and products in projects is much more complex and takes more time compared to conventional methods. The reason can be a difficult process of installation. Most of the times construction projects are behind schedule and have the issue of lacking time [139].

4.6 Conclusiones

There are several enablers and barriers to the adoption of new technologies. There have been very few studies of the construction industry in New Zealand. This study was undertaken to find the enablers and barriers to technology adoption in New Zealand. A questionnaire survey was conducted by using the most important factors which cause the adoption of the new technologies in New Zealand and has been sent to construction industry experts. In this research, we used the binomial test for analysing data. The results show that among considered factors, 14 of them can play the role of enabler in the process of adoption of new technologies. The enabler factors are using advanced equipment in the method of construction, post-earthquake maintenance cost, ownership of the project, ability to customise the product, a local supplied technology, trained personnel, structural engineer's recommendation, commercial and industrial types of projects, post-earthquake maintenance cost, experience with the new technology, availability of labour and construction material, the expertise of consultants in using new technology, strict quality control and certificate of performance. Five of them were identified as barriers, which are lack of time to complete a project, cost of new technology, the origin of the component, complicated design and construction and client resistance to change. The findings of this research will help technology developers to speed up the adoption process to new technologies by supporting the enabler factors and mitigating barrier factors.

CHAPTER 5

The perspective of developers and technology users

The current chapter is based on the following article:

Manuscript: *S. Zarinkamar, M. Poshdar, S. Wilkinson, and P. Quenneville, "The top enablers and barriers of technology adoption in construction," New Zeal. Soc. Earthq. Eng. Conf. Christchurch, New Zealand, 2021.(Submitted)*

5.1 Introduction

As discussed in Chapter 2, the low rate of adoption of new technologies has been identified as a major issue for the construction industry [85]. An example of these new technologies is the seismic-resistant technologies which were introduced to the construction industry in order to reduce the consequences of earthquake damage and their associated repair costs. However, the low rate of adoption of these technologies has become a significant concern for industries in New Zealand [110]. To overcome the low rate of adoption, the adoption of influencing factors favouring innovative seismic resistant technology has been identified as represented in Chapter 3; these can increase the low rate of adoption [116]. At the next level, the factors representing enablers and barriers in technology adoption have been explored and described in Chapter 4 [140]. This Chapter will examine the results of the previous comparison through a "systematising expert interview" method for the four seismic-resistant technologies which were selected as the case studies, namely:

- Resilient Slip Friction Joint (RSFJ) is a seismic-resistant technology that dissipates earthquake energy, restores the structure after each seismic event, and no post-event maintenance is required.

- Press-lam is a method of mass engineered timber construction that uses high strength unbonded steel cables or bars to create connections between timber beams and columns or between columns and walls and their foundations
- Sliding Hinge Joint (SHJ) is a low damage alternative to the traditional beam-column welded connections of the seismic Moment Resisting Steel Frames (MRSFs).
- Lead Extrusion Damper (LED) is a powerful vitality energy dissipation device used for seismic protection of structures.

A summary of the general characteristics of the case studies is provided in table 5.1.

Table 5.1: Summary of general characteristics of the case studies

General characteristics of seismic technologies	**Case 1: Sliding Hinge Joint**	**Case 2: Resilient Slip Friction Joint**	**Case 3: Press-lam**	**Case 4: Lead Extrusion Damper**
behaviour During earthquake	High stiffness before earthquake- Highly flexible during the earthquake	High stiffness before earthquake- Controlled Flexibility- Self-centring	High stiffness before earthquake- Controlled flexibility-self-centring	High stiffness before earthquake- Highly flexible during the earthquake
Technology manufacturing material	Steel	Steel	Timber and Steel	Steel
Particular advantage	Large energy dissipation capacity	Actively self-centring	Actively self-centring	Large energy dissipation capacity and easily repairable

Senior structural engineers, planners, contractor and top researchers from the construction industry in New Zealand were interviewed. After the interviews, the collected responses were analysed. The results showed the extent to which the discussions about the comparison between the four different technologies were correct. Accordingly, the final three top enabler and barrier factors for technology adoption in the New Zealand construction industry were identified from the perspective of the developers and end-users.

5.2 The interview design

Interviews present an appropriate way to achieve a comprehensive understanding of a particular construct within a defined context [141]. By conducting expert interviews, the data collection process is minimised, and the researcher can obtain clear and practical answers to the questions [142].To understand the impact of enabler and barrier factors in the process of adoption of the new seismic-resistant technologies in real construction projects, a series of face-to-face interviews were designed with the developers and the users of the respective technologies who had close experience with the design and implementation of new technologies in their projects. In order to achieve completely natural communication with the participants during the interview, a systematising expert interview method was employed, which has been recognised as a comprehensive method in interview-based research [143]. One of the most reliable data collection approaches is to conduct a face-to-face interview which has been implemented for this part of the research [144]. The interviewees were four developers of the case studies' technologies and eight users who had direct experience with these technologies and the research used purposive sampling to choose the four seismic technologies. The interviews consisted of two phases. In the first phase, the perspectives of the developers of the technologies (case studies) were collected. The second phase involved the end-users, who had close experience using the technologies in a recent project. The study made a comparison between these two sets of data.

A combination of open-ended and closed questions was used to develop an in-depth understanding of the perceptions of the participants.

5.3 Interview sampling

The respondents were chosen by using a *qualitative sampling* approach. This method has proven to be able to provide high-quality results[145]. Qualitative sampling can be applied by using different strategies [146]. In this research, we employed the *expert sampling* strategy, which is typically used for representing the general view of experts in a particular field of question [145]. This method is a theoretical sampling method in which participants will be selected based on their specific characteristics.

To achieve a good-quality outcome, the interviews should have these attributes and qualifications [147]:

- Be knowledgeable to answer the questions
- Provide efficient solutions for the problems
- Give clear reasoning for solving the problems or give advice if there is no solution to the problem

Having sufficient expertise related to the questions plays a vital role to ensure the rigour of their analyses [142].

The following criteria was considered to select the appropriate participants:

- For phase one of the research, the developers of the seismic-resistant technologies who designed the technologies of the case studies and released them to the industry were considered. They have many years of experience in working closely with the construction industry.
- For phase two, the users should have had broad knowledge and understanding of seismic technology and have recent/ongoing projects with the respective technology implemented.

5.4 The interview questions

The interviews were conducted in two sections. It included five open-ended questions and two closed questions. The open-ended part allowed the respondents to give descriptive answers about the pros and cons of each technology. The first question was framed as follows and has been asked of both the developers and users:

1- "Please explain the characteristics of your developed technology."

The next four questions are enabling the respondents to explain the challenges encountered in relation to cost, market, project and organisation:

2- "What challenges have you faced in relation to cost?"

3- "What challenges have you faced in relation to market?"

4- "What challenges have you faced in relation to the project?"

5- "What challenges have you faced in relation to the organisation?"

Two closed questions were also involved requiring more specific answers. The question requested the participants to share their opinion about the three top enabler and barrier factors in the adoption process.

6- Please rank the level of significance of each factor in the following table (Table 5.2) by selecting the top three critical barriers and the top three critical enablers from your point of view.

Table 5.2: Table of identified enablers and barriers

Enablers	**Barriers**
1- Access to advanced equipment in the construction method	1- Preference of the clients (resistance to change)
2- Ownership of the project	2- Complicated design and construction
3-Type of project	3-Origin of the component(place of the manufacturer)
4- Ability to customise products	4- Cost of the new technology
5- A local supplied technology	5- Lack of time to complete the project
6- Trained personnel	
7- Structural engineer's recommendation	
8- Post-earthquake maintenance cost	
9- Experience with the new technology	
10- Availability of labour and construction material	
11- Size of the project	
12- The expertise of consultants in using new technology	
13- Strict quality control	
14- certificate of performance	

The seventh question was only asked of the developers of the case studies about the changes in relation to the insurance cost of the building:

7- How do insurance companies value your new technology or describe how the insurance process has worked for your new technology which has been implemented in a building before? (process and problems)

5.5 Interview session

Face-to-face interviews were designed to have a duration of one and a half hours, and were recorded; however, due to ethical requirements, the interviewees had the right to ask to stop the recording at any time during the interview session. No time limit was considered for the respondents to address the open-ended questions. A half-hour was allocated for answering the closed questions.

5.6 Demographics of the respondents

- We had 12 face-to-face interviews, which are regarded as the most reliable method of data collection in researches [148]. The sampling profile consisted of twelve males.

The respondents of the first phase included the developers of the four case studies. The target samples at the second phase included eight highly experienced and knowledgeable construction professionals who were generally architects, engineers, planners and surveyors who have used the case studies' technologies in their recent projects. The collection of these interviews made a strongly relevant sampling population.

At the first round, five short questions were asked for a judgment of the construction industry participants toward their working relationship. Table 5.3 showed detailed information of the participants.

Table 5.3: Participants' profiles

Participant	*Role*	*Years of experience*	*Sector*	*Type of construction work*	*Profession in the construction industry*
Developer 1	Researcher	21	Public	Residential/industrial/Commercial	Engineer
Developer 2	Researcher	11	Public	Residential/industrial/Commercial	Engineer
Developer 3	Researcher	25	Public	Residential/industrial/Commercial	Engineer
Developer 4	Researcher	24	Public	Residential/Commercial	Engineer
User 1	Consultant	21	Public/Private	Residential/industrial/Commercial	Engineer
User 2	Consultant	10-Jan	Public/Private	Residential/Commercial	Engineer
User 3	Consultant	20	Public/Private	Industrial/commercial	Engineer
User 4	Consultant	15	Private	Industrial/Commercial	Engineer
User 5	Researcher	5	Public	Residential	Engineer
User 6	Researcher	14	Public	Commercial/Industrial	Engineer
User 7	Consultant	13	Public/Private	Residential/Commercial	Engineer
User 8	Consultant	22	Public/Private	Residential/industrial/Commercial	Engineer

5.7 Analysis and Qualitative Findings

The qualitative answers presented in this chapter only focused on the participant's points of view and their involvement and experience in developing and using the seismic-resistant technologies in their projects. The thematic analysis method has been applied to the explored data to closely examines the results to identify common themes, topics and patterns.

These findings provide information about the importance of technology adoption factors from developers and users. Besides, they present possible ways to reinforce the enabler factors and overcome the barriers in technology adoption. The viewpoints of developers and users are compared and contrasted collectively.

5.7.1 Analysis of Research Question One

Research question one: *Please explain the characteristics of the technology that you have developed*

Research question one seeks to understand the general attributes of each technology, including its constitutional materials, its place of use in a building, and its pros and cons observed. But first, the technologies and their general features have been discussed below.

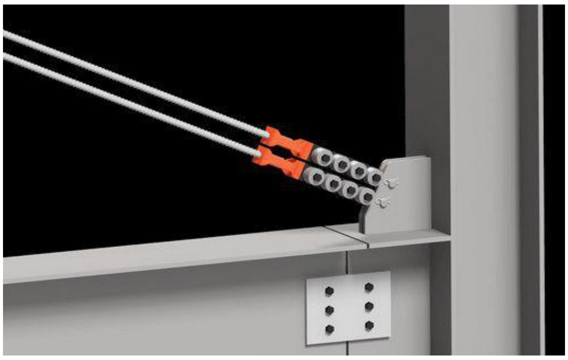
Resilient Slip Friction Joint (RSFJ)

Resilient Slip Friction Joint (RSFJ) is a newly introduced seismic resistant technology which dissipates earthquake energy, restores the structure after each seismic event, no need for sacrificial components and no post-event maintenance required [14] (see figure 5.1). This damage avoidance technology not only provides life safety but also minimises the earthquake-induced damage so that the building can be reoccupied quickly. RSFJ is a product that provides a system that does not need repair or replacement following an event, and it provides long term structural protection. Earthquakes pose a great threat to social and economic welfare – costing society at every event. Traditional seismic systems often require costly post-event maintenance or complete replacement following a seismic event – in some cases leaving the structure at risk from aftershocks whilst awaiting maintenance. Through effective energy dissipation and self-centring functionality of the RSFJ, structures are able to withstand earthquake sequences without replacement or structural repairs. The RSFJ's compact and scalable configuration offers design freedom for any application. The compact joint is exceptionally scalable and can be implemented in all types of projects of various materials and configurations.

Figure 5.1: Resilient Slip Friction Joint (RSFJ)

Some key points and advantages of the RSFJ are detailed below:

- Effectively dissipates energy
- Self-centring
- Continued damage avoidance
- No post-event maintenance required
- Applicable to all types of buildings
- Cost-effective
- It can be used in retrofit projects
- Scalability: it can be installed in groups to increase the capacity
- Easy implementation: it can be installed in any part of the building, and it arrives on site ready for installation (see figure 5.2 (a) and (b))
- Structural health monitoring



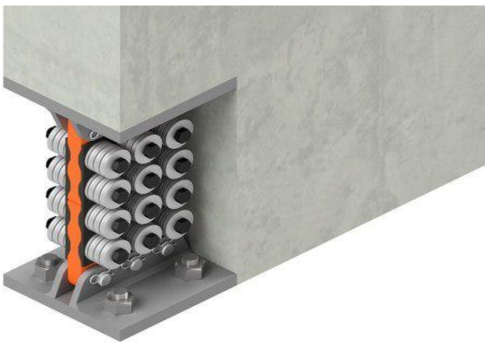


Figure 5.2: (a) RSFJ-Brace, (b) RSFJ-Shear wall

RSFJ is a seismic technology that will revolutionize how we can live and prosper in earthquake-prone zones. By protecting people and infrastructure from earthquakes and aftershocks, disruption to communities and businesses and nations can be reduced. This technology will provide life safety, minimise business disruption and self-centering every time [14].

Post-tensioned timber (PRES-LAM)

Pres-Lam is a method of mass engineered timber construction that uses high strength unbounded steel cables or bars to create connections between timber beams and columns, or between columns and walls and their foundations. As a pre-stressed structure, the steel cables clamp members together creating connections which are stronger and more compact than traditional timber fastening systems [111].

In earthquake zones, the steel cables can be coupled with internal or external steel reinforcing which provides additional strength and energy dissipation creating a damage-avoiding structural system. Pres-Lam can be used in conjunction with any mass engineered timber product such as Glue Laminated Timber, Laminated Veneer Lumber or Cross Laminated Timber [149].

Some key points about the Pres-Lam system are shown below:

Design. A building constructed using the Pres-Lam system requires fewer internal columns and walls, resulting in more attractive and more desirable places to live and work.

Weight. Timber is lighter in weight with easier transportation of components and less expensive foundations.

Cost. Pres-Lam timber buildings are potentially faster and less expensive to construct, through good design and extensive prefabrication.

Performance. Pres-Lam timber buildings can be easy to heat and cool, with excellent acoustic performance.

Resistance. Pres-Lam timber buildings have very high resistance to earthquakes, extreme weather, and wind.

Fire safety. Pres-Lam timber buildings are safe in a fire and other emergencies.

Environmental impact. Manufacturing of timber materials is far less energy-intensive than steel. Pres-Lam timber buildings will last for many hundreds of years with attractive and weather-tight exterior cladding systems [150].

The implementation of press-lam can be seen in figure 5.3 below.

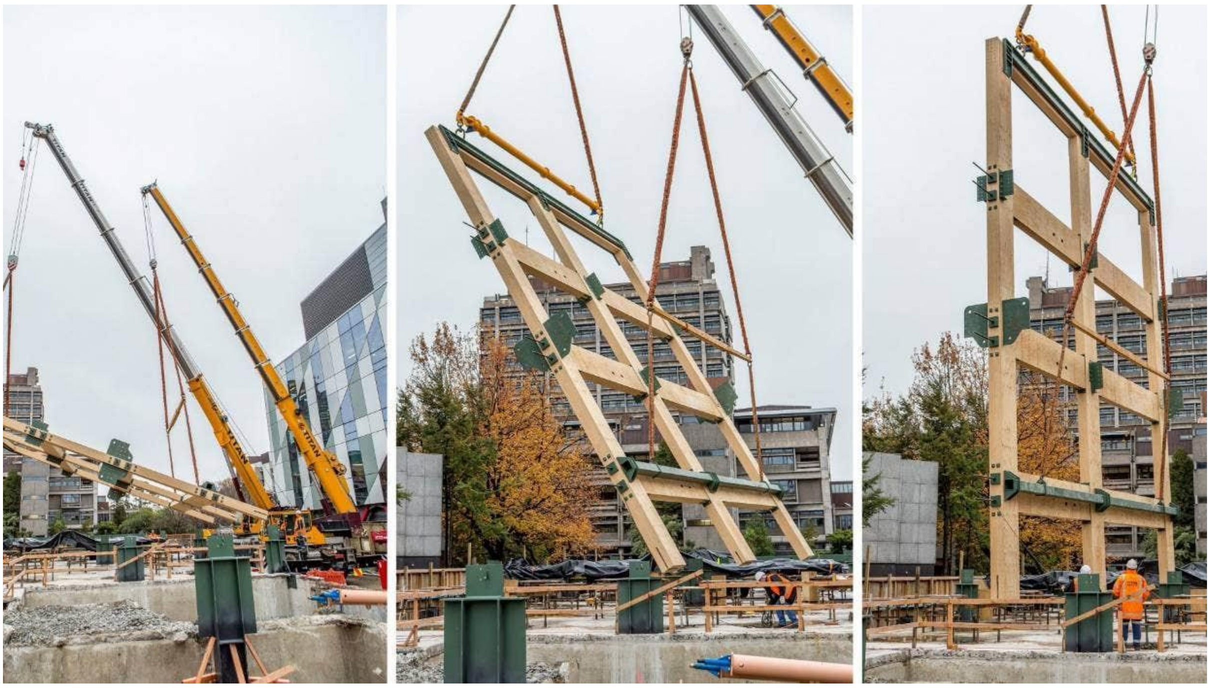


Figure 5.3: The implementation of Pres-lam technology

Lead Extrusion Damper (LED)

Another type of damper that utilises the hysteretic energy dissipation properties of metals is the lead extrusion damper (LED) (see figure 5.4). The process of extrusion consists of forcing material through a hole or an orifice, thereby altering its shape. The extrusion of lead was identified as an effective means of energy dissipation [112]. This technology does not need to be replaced or reset after an earthquake, which results in both time and cost savings.

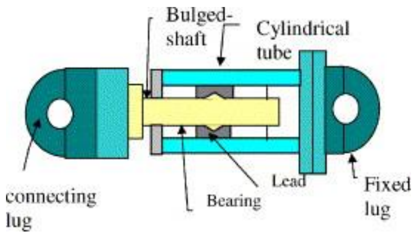


Figure 5.4: Lead Extrusion Damper

LED is a powerful vitality energy dissipation device used for seismic protection of structures. LED absorbs vibration energy by plastic deformation of lead, and in this way, mechanical energy is converted to heat. Both groups of LED (the constricted tube type and the bulged shaft type) use the similar fundamental concept of retaining the resistive force by plastically expelling the lead through an orifice created by the annular restriction [151]. Lead extrusion damper (LED) is one such device considered in the present study because it greatly increases the system damping obtained from large and stable hysteresis loops. The vibration energy is absorbed by way of extruding lead back and forth through an orifice. On being extruded, lead recrystallizes immediately at room temperature, thereby recovering most of its mechanical properties under plastic deformation resulting in reduced fatigue problem in the damper structure.

The sliding Hinge Joint (SHJ)

The Sliding Hinge Joint connection (SHJ) is a low damage alternative to the traditional beam-column welded connections of the seismic Moment Resisting Steel Frames (MRSFs) (see figure 5.5). The SHJ was initially proposed and developed from 1998 to 2005 by Clifton in 2005 and has been further developed at the Universities of Auckland and Canterbury [113].

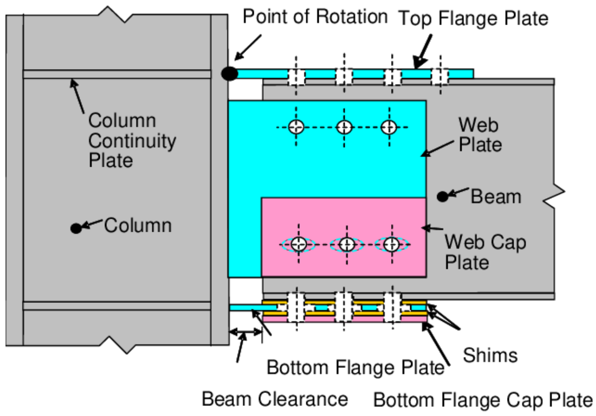


Figure 5.5: Sliding Hinge Joint side elevation

SHJs with Belleville springs (BeSs) are energy-dissipating components of the building which act similar to a circuit breaker in an electrical wiring system. They remain rigid under minor earthquakes to provide building's integrity, stably slide under severe earthquake to dissipate high energy and prevent other damage to the building's members, return to their initial position to again provide the building's integrity following the earthquake, and return the building to its pre-earthquake as-built condition. By this means not only is the building collapse prevented, but immediate functionality and occupancy are achieved following a major earthquake. This will eliminate heavy economic losses due to post-disaster repair as well as eliminate the cost of the building's closure downtime [152].

This research explores the New Zealand building and construction industry's perception regarding the uptake of new ways of doing things. By 'new ways of doing things,' this research includes a range of processes, technologies, systems and skills. Because they are different from the traditional methods of construction utilised in the building process, they are referred to as "new".

This question was addressed from two perspectives. First, from the developer's point of view who invented the technology. Second from the user's point of view who implemented the new technology in at least one of their projects.

5.7.2 Answers to research question one

The interviewees were allowed to discuss generally the characteristics of each technology. Their answers are presented under the following three main themes: technology material, behaviour during and after the earthquake and particular advantages of the technology.

5.7.2.1 The constitutional material of the products and their implementation features

Compounding technology material plays a vital role in the process of adoption of new technologies. The availability of material and the price of material are the main factors that should be considered for developing each new technology. The answers are presented in further detail in the following paragraphs

Case study one: Sliding Hinge Join (SHJ)

The developer of this technology mentioned that the Sliding Hinge Joint connection (SHJ) is a low damage alternative to the traditional beam-column welded connections of the seismic Moment Resisting Steel Frames (MRSFs). Unlike the traditional beam-column connections, SHJ can tolerate cycles of shaking without any major damage to the connection of the structure. One of the users explained easy installation as a pro compared to other systems. It makes this technology predominantly cost-effective. The users and the developer of this technology all believed that the fact that this technology can be made of structural steel that is readily available in New Zealand is a very important factor in the adoption process. Furthermore, the fact that this technology can be fabricated on-site was described as another favourable factor for adoption.

Case study two: Resilient Slip Friction Joint (RSFJ)

This technology is mainly produced by using steel, according to the developer. The developer also described that the RSFJ could be easily implemented in different parts of the building as an important point that encourages its adoption. One of the structural engineers who had used this technology in one of their recent projects reported the technology as a quiet, distinct element so that one could implement it and hide it as required by the architecture. That makes the technology favourable to the architects too.

Case study three: Press-lam

One of the users of this technology explained it as specific to timber rocking wall systems. The primary compounding material of press-lam is timber. Timber is readily available in New Zealand. Also, it is lighter in weight; that facilitates the transportation of components and lighter foundations are needed, which, in turn, reduces the total cost of construction.

Case study four: Lead Extrusion Damper (LED)

The developer of this technology declared that:

"This technology is mainly produced from steel based on an *idea that been used by Robinson and a bunch of others in the 1970s".*

One of the users explained LED as an efficient technology to be implemented in the building. However, its considerable weight was identified as a challenge in the installation phase. The onsite handling of the devices made using this technology could be a potential drawback for adoption.

5.7.2.2 Post-earthquake behaviour

The participants unanimously identified the post-earthquake behaviour of these technologies as one of the main factors that inspire their adoption. The interviewee's point of views are provided in the following paragraphs:

Case study one: Sliding Hinge Join (SHJ)

The developer described the post-earthquake behaviour of this technology as follows:

"*Sliding Hinge Joint is a joint between beams and columns and under normal building condition, the joint is rigid. During a severe earthquake, the joint becomes flexible, and at the end of the earthquake again it becomes rigid after the earthquake*"

The ability of SHJ technology demonstrates flexible behaviour during an earthquake without significant damage to the frame. This ability was identified as an imperative characteristic by one of the respondents in the user group, who was working as a designer.

Case study two: Resilient Slip Friction Joint (RSFJ)

According to one of the interviewees in the user group, who was a structural engineer:

"*Low damage design and having better-performing buildings on the earthquakes have become significantly more critical after the Christchurch earthquake in New Zealand".*

The interviewee also referred to the point that RSFJ can absorb seismic energy so that it can minimise the damage to buildings. What was also described as one of the most central characters of the technology was self-centring, which enables the building to return to its original position after the earthquake.

Another member of the user group in related to this technology declared that this technology belongs to the third generation of seismic technologies where the earthquake energy is absorbed by the system with no damage. The self-centring behaviour and its importance were addressed by this interviewee too. As it was asserted, self-centring is a unique characteristic

compared to many other seismic-resistant technologies.

Case study three: Press-lam

The Press-lam technology provides damage avoidance and the energy dissipating by coupling the steel cables with internal or external steel reinforcing system during the earthquake. Because of this factor, interviewee one called this system a rocking wall system that integrates post-tensioning and dissipation energy technology during the earthquake. The fact that this seismic energy is absorbed decreases the damage to the building.

Case study four: Lead Extrusion Damper (LED)

During the earthquake, Lead Extrusion Damper (LED) dissipates energy without damage to the device as declared by the developer of this technology and also there is no stiffness or strength degradation in the device. One of the basic goals of designing seismic technologies is reducing damage during and after an earthquake [41]. This goal has been achieved in this technology as user two compared this technology with the conventional models and claimed:

"It has minimal damage, is easily repairable and has good strength/stiffness characteristics compared to the conventional construction methods."

5.7.2.3 Particular advantage of the technologies from developers and users point of view

Life safety during and after the earthquake is the primary objective in designing seismic-resistant buildings [153]. However, nowadays, there is interest to also minimising business disruption [153][154]. Thus, building designers intend to design low damage systems both for structural and non-structural parts of the buildings [153]. The final goal in designing such buildings is to provide life safety and also protect the economy [154]. The interviewees expressed their opinions about how the respective case studies can achieve this goal.

Case study one: Sliding Hinge Join (SHJ)

From the developer's point of view, being flexible during the earthquake is the particular advantage of this technology. One of the users was a building designer who declared that ductility is a fundamental characteristic of this technology and said:

"*I believe with introducing this system; we can have ductility in our designed projects without significant frame damage.*"

Case study two: Resilient Slip Friction Joint (RSFJ)

The developer and users of this technology had similar ideas about its unique advantage compared to the conventional models, which is self-centring. They mentioned that, if the building is self-centred at the end of the earthquakes, even if the building satisfied the life-safety criteria, it still could be demolished if the repair costs were higher than rebuilding.

Case study three: Press-lam

The developer of Press-lam declared that this technology contains steel 'fuses' that undergo damage during the earthquake and could be easily replaced after the event. This differentiates this system from conventional ones. Interviewee two explained the post-tensioning bars act to bring the structure back to its original position after the shaking that makes this technology actively self-centring. This self-centring behaviour is an important factor if immediate re-occupancy of the building is aimed for.

Case study four: Lead Extrusion Damper (LED)

A large energy dissipation capacity is one of the most significant pros of this system from the developer's point of view. Also, the developer mentioned that the process of energy dissipation energy is entirely reversible, so after ground shaking, the device does not need to be reset. The user two had opinions similar to the developer about the LED technology. He asserted to the fact that many seismic technologies absorb energy and prevent building collapse. Still, it usually results in significant structural damage that is expensive and time-consuming to fix or replace. Therefore, being easily repairable is an essential advantage for this technology which saves on post-event repair costs.

5.7.3 Answers to research questions two, three, four and five

Research question two: *What challenges have you faced in relation to cost/market/project and organisation?*

The literature review undertaken in Chapter 2 served as a comprehensive base of potential intrinsic and extrinsic factors that cause trust and increase the rate of the adoption process to new technologies globally. In Chapter 3, these factors were localised for New Zealand and were clustered into four main categories. At interview sessions, it was suggested to interviewees to consider design-related challenges in the interviews as well. As a result, these five main categories in relation to cost, market, project, organisation and design were discussed with the interviewees to explore the challenges they faced in their recent projects.

5.7.3.1 Cost-related challenges

Case study one: Sliding Hinge Join (SHJ)

The developer of this technology declared that this technology is cheaper compared to the conventional rigid frames, so because of that, they did not face any significant cost-related issue. One of the structural engineers who was interviewed asserted that the clients always have pre-assumptions when it comes to the cost. This user also indicated that if he price of the new technology is comparable to a well-established technology such as base isolation, a building designer would prefer to use it.

Case study two: Resilient Slip Friction Joint (RSFJ)

Participant one of the interview asserted that this technology has a higher cost compared to conventional solutions. However, they explained their reasoning as below:

"*In general, adding a new component to the building would be expensive. Because it is more high-tech and more recent, it will be more costly compared to the other ones.*"

They also confirmed that the process of justification to the clients was very challenging for the designer considering the fact that some building owners or clients want seismic-proof buildings, and some others do not wish to bear the extra cost. For those clients who were reluctant, it was a troublesome procedure to justify the new technology given the extra overall cost. However, it is easier to justify the technology for customers with essential building projects such as airports, hospitals etc. It is because those clients are normally looking for better-performing buildings.

Case study three: Press-lam

Participant one who has been interviewed in relation with the press-lam technology revealed that they do not have any cost-related obstacles given that this technology does not impose any specific extra cost to the project when compared with other seismic technologies. The only problem was that the clients normally prefer to use conventional methods because of the lower cost. But, the user asserted that this is a common issue for clients who are resistant to change and resistant to adopt new technologies given the potential higher cost in comparison with conventional construction.

Case study four: Lead Extrusion Damper (LED)

The first important fact that the developer of the LED pointed out is presented below:

> *"Cost is a huge challenge for the construction industry because it is a very cost-driven industry".*

They believed that the manufacturing cost of any device made with steel (such as LED devices) is higher than a simple piece of steel. More to the point, for steel products or technologies, there always be an extra cost compared to conventional steel components.

The second point that they highlighted was that with new seismic-resistant technologies, the designer would have a relatively better idea about the overall performance of the structures. In other words, the seismic proofing devices act as a limiting fuse. These fuses would cap the earthquake loads on the structure under well-predicted thresholds. "*Therefore, often a device might cost X$, but by spending more funds on the project, you actually will have a better idea on the peak loads through your structure, so you can save money elsewhere in terms of the scenario you used*."

Overall, they believed there is an extra cost with new devices but adopting the new technology offsets the extra cost since it saves a significant amount for the foundation and other parts of the building. The user believed that the answer to this question is a very complicated answer, and it is very case-specific. Finally, the user indicated that the cost is a huge driver and mentioned:

"*I think sometimes unnecessarily the broader picture has not been seen and that is the case then."*

It implies that the cost of the new technology is necessary to be considered in the overall cost of the project, and sometimes by spending fund on this part, the post-earthquake cost will reduce and saving on the project would happen because of that part.

The interviewee two claimed that a higher cost is predictable, first because of the additional design time required for developing the solution with the new technology and second, engineers are still learning how to use this technology in their projects. However, they revealed:

"*Cost of the technology is not so high and that we should consider it for our projects. If the extra cost is compared to the overall lifetime cost of the project, it can be disregarded.*"

5.7.3.2 Market-related challenges

Case study one: Sliding Hinge Join (SHJ)

One of the problems with new products is the unfamiliarity of the market. The developer of this technology dealt with this problem while developing this technology. They had been informing the potential market by monthly publications and receiving consultants from the audience. As a result, consultants encouraged the developer to finish the development of the technology and expressed their interest in adopting the technology. They mentioned that other technologies had had the opposite experience. The developer asserted that the demand for this technology was very high from the day of the introduction of this technology.

From the user of SHJ's point of view, the client's perception is known to be the only challenge related to the market. The new technology is more expensive and more challenging to build. If they can explain it as an engineer to the clients that those technologies are beneficial to the projects, and the clients trust them, then there are no other challenges related to the market. Moreover, cost comparability is essential for clients and can be considered as the second crucial market-related challenge.

Case study two: Resilient Slip Friction Joint (RSFJ)

The developer stated that the biggest market-related challenge for them was the unfamiliarity of the market to the product. Although it was not difficult to understand the function of how the device operates, its integration into the design of buildings was a different story. Nevertheless, they did not face any significant difficulty for the local or overseas representation of the technology because the technology is actually coming from the university. More to the point, technology has been verified before entering the market. Therefore, clients and engineers see that it works and the solution is feasible. It was not a troublesome procedure to convince the engineers that this is an excellent technical solution.

Interviewee one mentioned an interesting point that was related to the level of support the developer of this technology offered. He disclosed the reason for his decision:

"*I knew the developer of this technology, and I knew they would stand up for their product, and if we came up with issues, he would be there to solve them, and it gave me a lot of confidence."*

Case study three: Press-lam

Interviewee one, as a designer of buildings, claimed that the major market-related challenge they had was about the time that they wanted to use the technology. He revealed:

"When we wanted to use the technology, it was early, and the clients were not familiar with the technology. There was an appetite to use it, but the technology did not move on. We could not complete the design fast enough, so there was frustration about why we should use this product."

Case study four: Lead Extrusion Damper (LEAD)

From the developer of LED point of view, the biggest market related-challenge is simply the fact the adoption process was not the standard process. It requires a deviation from usual practice to add something like the LED. So, there should be a willing client and willing engineer, and it is potentially a less convenient path given the difference with the original design. Accordingly, they thought that probably the biggest challenge is the behavioural change required from engineers, developers, etc. to adopt the technology.

From the users' point of view, they both emphasised the issue of resistance to change. User 2 declared that the New Zealand industry people are quite fine with what they are doing now, and they prefer not to change, clients should be convinced about the new technologies and the advantages it is going to have. Even so, they see it as a change, and they find it inconvenient. Ordinarily, many people are involved in building businesses, and most of them are happy with the traditional methods, and so convincing them about new technologies is challenging. “*Why would they change? They are not willing to change unless they are forced to*”. The interviewee added:

"*First, we have to introduce this technology to people and make them familiar with the advantages of new technology. Second, releasing the design methods for this technology so the engineers will learn how to design by this technology. More details should be released for designers to understand how easy is to design with this technology. And finally, holding workshops as icebreaking events in order to reveal more information about this technology."*

5.7.3.3 Project-related challenges

Case study one: Sliding Hinge Joint (SHJ)

During the research on this technology, the research team received funding from the government to perform tests on the technology. Because of that, the developer of the technology declared, they did not face any specific project-related issues. However, user one as a structural engineer who implemented this technology in one of their recent projects highlighted several challenges they confronted. First, when the technology is introduced, not all the practical problems are addressed. As technology evolves over time, more issues could be uncovered. Moreover, as the technology is being implemented, engineers are learning more about it and so would have more questions. Second, the design tools are not readily available in the market for engineers to assist, and most of the software tools required are not open-source.

Case study two: Resilient Slip Friction Joint (RSFJ)

The developer of the RSFJ mentioned that they did not face any specific challenge in relation to projects, and the only problem was establishing a production line with the right quality during the beginning days of the development. Interviewee two found the design method in relation to the projects as a challenge for the designers. The interviewee declared:

"*The main challenge for me as a designer is the design method, because it is a new technology, and we need to learn how to model it and it will take time*."

Case study three: Press-lam

The second user addressed two main challenges that they had faced. First, the technology was new so, at the beginning of the project, everyone should have been convinced about the technology. Second, because the technology was new, every part of the design should be checked, which needs more time compared to conventional technologies where normally a routine procedure is followed.

Case study four: Lead Extrusion Damper (LED)

As a developer of LED described, the main project-related challenge was manufacturing the devices based on the design and delivering them. The interviewee explained:

"*There is a reasonable turnaround, and there is something that engineers don't always appreciate. Just how much time it takes, it's not that they understand. If you've got hundreds of tons of steel, that takes time, but because it's a small component. The engineers may assume a relatively quick turnaround but these are the constraints that you have to work with.*"

The perspective of the user one was consistent with the developer about the project-related challenges, with an example provided. The user declared that in one of their recent projects in China, and the dampers should have been delivered from New Zealand. The significant issue was the delay in transportation and the fact that they were not confident enough to fabricate this damper in China.

Interviewee two as a researcher pointed to a significant issue. It was explained thus:

"*Many research focuses on individual parts of the buildings and using the technology in the buildings, but engineers should design the whole building considering that technology. Therefore, the main challenge is how to integrate the technology into the design of the whole building.*"

It is the engineers that have to figure out how to design the connection between different components. If the end-users of the building want to have it with minimal damage and lower repair cost, the design must be holistic. That was the lesson learned after the Wellington and Kaikoura earthquakes. It demonstrated that, for some buildings, the engineers did not have any idea about what will happen after an earthquake. All of the connections, all of the components and all of the non-structural components should be considered for earthquakes.

5.7.3.4 Design-related challenges

Case study one: Sliding Hinge Join (SHJ)

From the developer's point of view, they had a concept which they wanted to make it work. The way of achievement was first developing a design procedure. Second, the prototype was physically fabricated, and an experimental test was conducted. Then they looked at the results to find out if it was what they were looking for. For the first rounds, they needed to go back and re-check the reasons for it not working and the required changes to be considered. Consequently, they would modify the design procedure to incorporate those changes, rebuild, retest and compare the performance and see if it is sufficient. Finally, a detailed design procedure for the technology was released, which allowed the engineers to use it in their designs. A summary of the design process for SHJ is provided in figure 5.6.

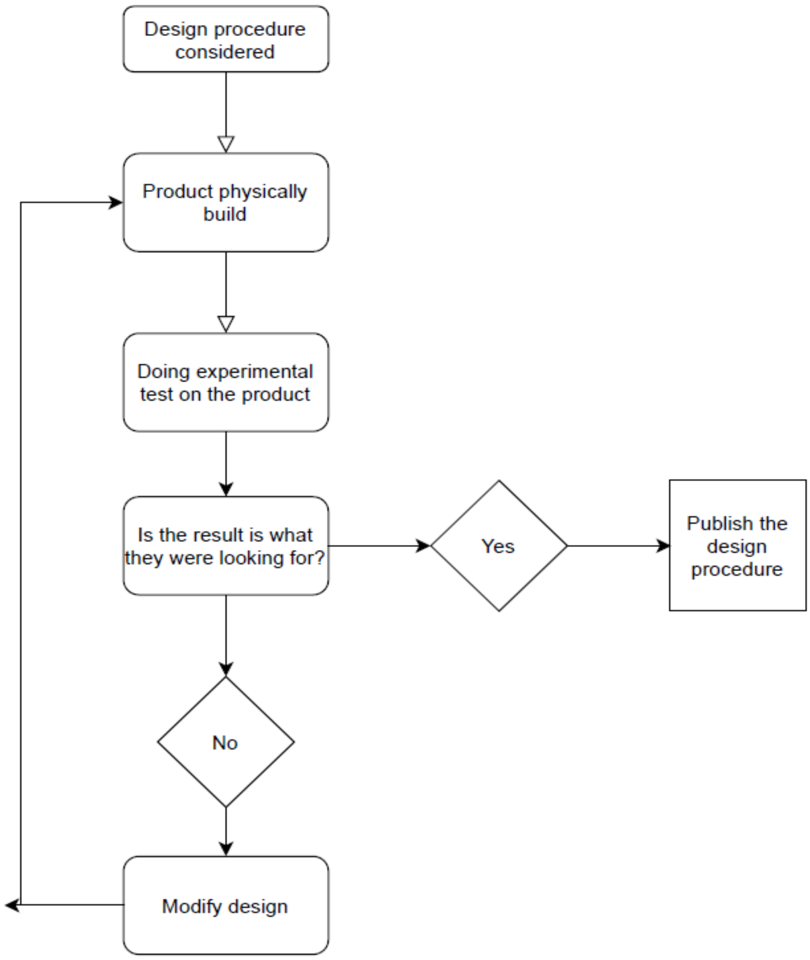


Figure 5.6: The design procedure for the SHJ technology

From the user's point of view, ***the*** lack of design tools and design work examples for the designers to follow or examples for the calculations for buildings are the main design-related challenges that they had to deal with.

Case study two: Resilient Slip Friction Joint (RSFJ)

Interviewee one as a structural engineer with regards to the case of RSFJ mentioned that:

"*Designing with RSFJ, and probably any other damping system requires more than usual efforts made by the designer.*"

Also, the interviewee added that, as a designer, there is a need to have a minimum level of modelling skills. Since these concepts are not codified (not specifically covered within the current building standards), building designers need to read more technical papers or notes, be ready to develop comprehensive numerical models and make time for learning the new technical skills required to complete the design. Also, considering the fact that for these new systems, the design will be peer-reviewed by another party, one would need to be engaged with other engineers to discuss and defend your design.

Interviewee two mentioned another important factor in relation to design. They mentioned that designing by using new technologies in the building can be challenging. If the producer of the technology is not local, it may be difficult to receive a design guide, and it is challenging difficult to discuss the design problems and to receive feedback quickly.

Case study three: Press-lam

One of the users who used this technology in their recent project declared that there were disagreements between the academics and engineers in relation to the design procedure. More to the point, it was mentioned that the analytical design with Press-lam was challenging and complex for them. Furthermore, the developers believed that the way the engineers used for the design was not correct; however, the engineers who completed the design believed that it was the only way that they could justify different aspects of the design.

Case study four: Lead Extrusion Damper (LED)

Interviewee two as a structural engineer declared that designers need alternative solutions for designing with these technologies. They have to go and learn beyond the standards, and they cannot simply follow the standards for their designs. Small firms may find it too risky to go after alternative solutions.

Many of the alternative designs could be introduced to the standard, and also it would be helpful for the firms to go through that process. Maybe at the moment, it is not a huge barrier, but it can be one of the main reasons that slow down the adoption process.

5.7.3.5 Organisation-related challenges

Case study one: Sliding Hinge Join (SHJ)

User one explained as a consultant that, when offering new technologies to customers, it is always challenging to explain the cost and benefits of the new technology and also it is not easy to remain within the allocated budget for the project. The developer of this technology mentioned that for some cases, dealing with the architects in relation to the SHJ devices was challenging. For example, in one case, the architect did not approve the extra space occupied by the devices.

Case study two: Resilient Slip Friction Joint (RSFJ)

Two users of this technology had a close opinion about the organisation related challenges. One main challenge that they both mentioned was that they received too much resistance to change from clients.

For the architects, accepting the technology was quite easy. For the clients, it was hard to accept that by using this technology, they need to spend more money given that there was no guarantee that money would give a return after the end of the project. What they declared means that the occupant does not care. If the owner wants to keep the building, maybe they would consider new technology, but if they want to sell it, engineers believed, they decline to invest. In the future, if more earthquakes happen, probably the owners of the buildings will want to spend more on new seismic technologies.

Case study three: Press-lam

Interviewee two declared that the lack of familiarity was a big challenge for the engineers in contact with stakeholders. They mentioned that:

"*It was frustrating when we speak about timeframes with stakeholders to get from the conceptual design to a buildable design. This is because it was a new technology, and there was a problem of lack of familiarity."*

Case study four: Lead Extrusion Damper (LED)

The developer of the technology explained that employing new technology in construction projects possibly requires a peer review for the design. Although peer-reviewing is good for the project, it comes with extra costs. User one who implemented this technology in his project declared that the main organisational challenge is that people do not have enough information about this technology, and they are not confident about it. When, for example, a builder or an owner does not know enough about this technology, how they can use it in a project? The most challenging part is how to convince the builder to use this technology. This problem is applicable to the designers, too, because they are inclined to use conventional design methods. After all, if they are going to use new technologies, they have to put more effort to learn how to design. The other user believed that "*recently, clients and developers have enough information about what an earthquake will do to their buildings. Thus, engineers can have easy conversations with them and tell them that they can design a building in the cheapest way, but they have to know that the building should be demolished after the earthquake. Nevertheless, if they want to have seismic-resistant buildings that are usable after the earthquake, they should pay more. The clients have a better understanding of new technologies compared to the past. And there are the learnings from the seismic events that occurred in the last ten years."*

The summary of different challenges related to the case studies are presented in table 5.4:

Table 5.4: Summary of challenges in case studies

Challenges \ Case studies	**Sliding Hinje Joint(SHJ)**	**Resilient Slip Friction Joint(RSFJ)**	**PRESS-LAM**	**Lead Extrusion Damper (LEAD)**
Cost	No challenge	Moderate challenge	No challenge	No challenge
Market	No challenge- High demand from Market	No challenge- It is coming from university	Moderate challenge	Moderate challenge- Resistance to change
Project	No challenge	No challenge	Moderate challenge- In introducing new technology	Moderate challenge- In manufacturing technology and delivering it on time
Design	Moderate challenge- Lack of design tools	Moderate challenge- Lack of design methods	Moderate challenge- Disagreement beeween engineers and academic people in design procedure	Moderate challenge- Needs in introducing alternative design methods
Organization	Moderate challenge- In offering new technology to the client	Moderate challenge- Resistance to change from client	Moderate challenge- Lack of familiarity with the technology	Moderate challenge- Extra effortto design with the new technology

5.7.4 Answers to research question six

Research question three*: The barriers and enablers in the process of adoption of the new technologies in New Zealand, please rank the significance and identify which one do you consider as the three critical barriers and three crucial enablers in the process of adoption of the new technologies (table 4.1).*

After establishing the enablers and barriers factors for the adoption process to the new technologies, the next step in this part is to identify the final critical enablers and barriers from the interviews with the developers of the case studies and the experienced engineers in New Zealand construction industry who implemented the respective technologies in their recent projects.

The results for the final enablers are presented in table 5.5 and figure 5.1

Table 5.5: Finalised critical enablers

Enablers	Frequency
1-Access to advanced equipment in the construction method	1
2-Ownership of the project	2
3-Type of project	2
4-Ability to customise products	3
5-A local supplied technology	4
6-Trained personnel	0
7-Structural engineer's recommendation	5
8-Post-earthquake maintenance cost	1
9-Experience with the new technology	6
10-Availability of labour and construction material	1
11-Size of the project	0
12-The expertise of consultants in using new technology	8
13-Strict quality control	3
14-certificate of performance	3

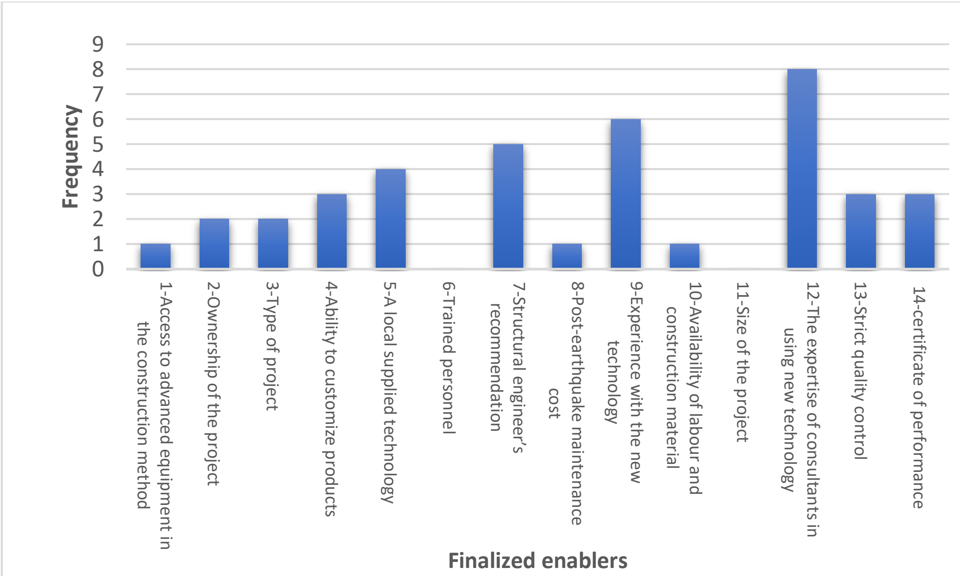


Figure 5.7: The frequency of answers for finalised enablers

As has been illustrated in Figure 5.7, the finalised enablers are:

1- The expertise of consultants in using new technology

2- Experience with the new technology

3- Structural engineer's recommendation

And the finalised barriers are presented in table 5.6 and figure 5.2:

Table 5.6: Finalised critical barriers

Barriers	Frequency
1-Preference of the clients(resistance to change)	9
2-Complicated design and construction	6
3-Origin of the component	5
4-Cost of the new technology	11
5-Lack of time to complete a project	5

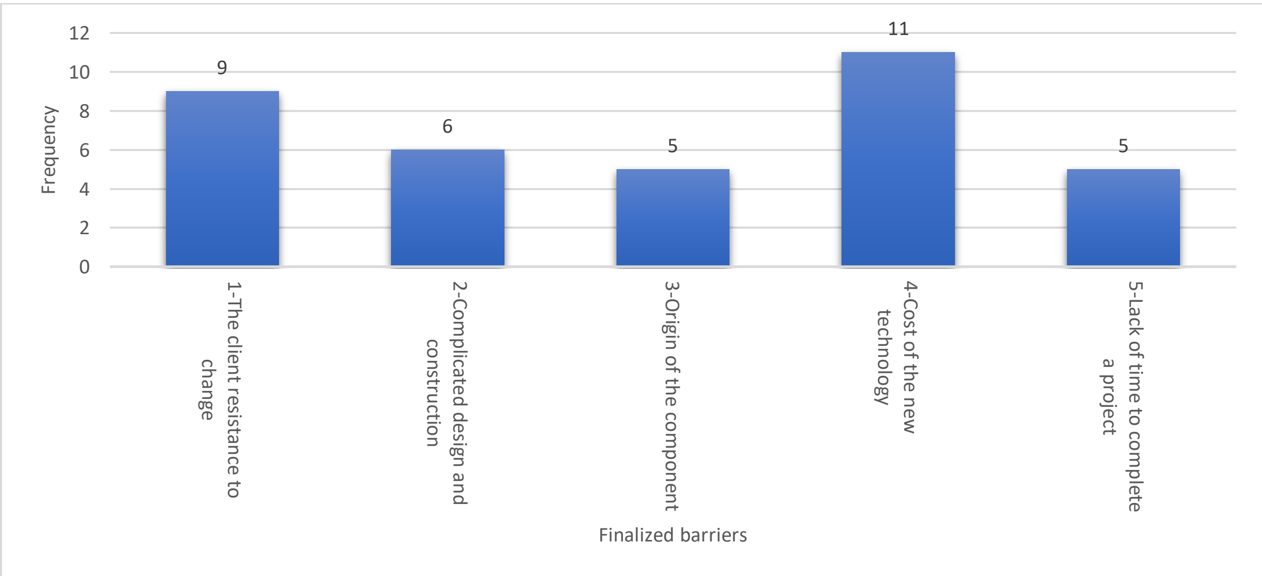


Figure 5.8: The frequency of answers related to the finalised barriers

As has been illustrated in Figure 5.8, the finalised barriers are:

1- Cost of the new technology

2-Preference of the clients (resistance to change)

3- Complicated design and construction.

5.7.5 Answers to research question seven

How do insurance companies value your technology or describe how the insurance process has worked for your new technology?

This question was asked with the purpose of exploring the process that insurance companies follow in relation to seismic-resistant technologies. We were looking to investigate if the insurance companies were willing to reduce premiums and pay-outs when the technology is used in a project. Or, more in general, have they considered any change in the process of insuring the seismic-resistant buildings?

Case study one: Sliding Hinge Joint (SHJ)

The developer of Sliding Hinge Joint believed that, after the earthquakes in 2014, the insurers' companies were encouraged to consider reducing the insurance costs for the buildings with low damage structural systems. He believed the New Zealand insurance market is relatively limited, and perhaps, outside of New Zealand, the impact on insurers of using this technology in the building would be more significant.

Case study two: Resilient Slip Friction Joint (RSFJ)

The developer of this technology declared that the first time they approached the insurers was around the year 2017, and the developer believed there was no appetite. It was because of the way that insurance companies work in New Zealand. New Zealand is a small country, so they consider everyone in one big pot. For example, in Auckland (with low seismicity), they just insure the buildings for fire but not for earthquakes. But, for the buildings in Wellington or Christchurch, the insurer has to act smarter and consider each building individually. They need to consider what will happen to the building after the earthquake. It might become necessary to demolish the building and they will need to have a full repay. However, they have recently started to be more intelligent and smart on how they approach premiums on different buildings. Now, they are aware that this technology offers resiliency and self-centring. He also declared:

"We are starting to see that the insurance industry is making a difference. The insurers are forcing clients to have resilient devices. Well, maybe eventually it will come for the structures. But right now, I do not see it yet. I can see a beginning of appetite, but I don't think it's significant enough."

Case study four: Lead Extrusion Damper (LED)

The developer of the LED technology believed that at the moment, the insurers are not differentiating insurance prices based upon specific building design. He thought they might say there has been some risk in the residential market to start moving towards a more distinguished pricing scheme. But at this stage, they did not find enough incentive for the insurers to reduce the premiums. However, there have been some discussions about it going on with base-isolated buildings potentially because they should have a much-reduced loss during the earthquake. Overall, the interviewee mentioned:

"I think at this stage that's quite near where there is a lot of scopes, but it might be some time before any trades industry starts to differentiate."

Based on all the developers' discussions related to insurers, it seems that insurers do not consider differentiation between typical buildings compared to the resilient buildings, especially in low seismicity areas such as Auckland. Maybe after a future earthquake, they will understand how many savings will be possible by implementing seismic technologies in buildings, so that, more than likely, there will be no need for demolishing. As a result, the reduction in insurance premiums and pay-out should be considered by insurance companies when assessing the buildings.

5.8 Conclusions

In this Chapter, we finalised the three critical enablers and barriers in the process of adoption of the new seismic-resistant technologies. The developers of the case studies' technologies and the most experienced engineers who used these case studies in their project were interviewed. Qualitative data from the interview findings were used to supplement the discussion of the results. Firstly, the general characteristics of each seismic technology were explained. Then, the cost, market, design, project and organisation-related challenges that the interviewees had faced during their projects were investigated. Finally, from the seventeen important factors which speed up the adoption process of new technologies for the New Zealand construction industry, the three most critical ones were chosen. The next chapter discussed how these enablers should be reinforced and how the barriers can be overcome. Another important aspect which has been investigated was about the changes related to the process that insurance companies follow for buildings with seismic advantage. The datasets collected from the developers of the case studies demonstrated that the way insurers in New Zealand operate has not significantly changed. Still, they all believed that there is evidence that this may change in the near future.

CHAPTER 6

General Discussions and Summary of findings

6.1 Introduction

This chapter will discuss the findings regarded to the adoption process of the new technologies in the New Zealand construction industry, making recommendations and suggestions for the low rate of adoption. Thus, it provides a discussion of the contributions of this research to the existing literature. It makes recommendations for how the New Zealand construction industry can improve the process of adoption of the new seismic-resistant technologies.

6.2 Discussions of main findings

New Zealand's location at a tectonic plate boundary implies its vulnerability to earthquake hazard. Earthquakes have caused significant damage to the built environment of the country and heavily disturbed its economy. Previous studies showed that the failure of construction projects to meet customer demands is related to schedule and cost mostly because of using traditional techniques and technologies [78][80]. New methods and new techniques have been introduced into the construction industry to solve this issue, but the rate of adoption is slow and sometimes takes several years [42][49]. Recently, a new generation of resilient seismic technologies is making their way into the construction industry, which offers a significant damage reduction in the structural and non-structural elements of buildings. Seismic resistant technologies have the advantages of providing life safety and reducing post-earthquake damage. However, the adoption process for these seismic technologies is prolonged for the New Zealand construction industry. Several benefits and advantages will be achievable after adopting and implementing new technologies related to cost, time, design, product and management [155]. A summary of these advantages is shown in table 6.1 below.

Table 6.1: Summary of the benefits of adopting new technologies

Cost	Time	Design	Product	Project
Reduced production cost	Reduced process cycle time	Solved technical problems	Reduced product defect	Increased labour productivity
Reduced overhead cost	Increased capability of delivery time	Improved capability to develop product design	Eliminated waste of material and energy	Improved working environment
		Increased flexibility	Increased productivity	Improved response to customer demand
			Improved production controlling	

The results of this research totally agree with Rogers's theory. As chapter two discussed, according to Rogers's diffusion of innovation model, users go through five main stages adopting new technology [50][49]. At the first stage "knowledge formation", the individual will become exposed to innovation with no in-depth knowledge about the innovation. During this stage, the individual has not yet been inspired to know more about the innovation. In the second stage, "persuasion", the client seeks more information about the new technology and becomes more interested in it. At the "decision" stage, an individual decides to accept or reject the new technology by considering the pros and cons of using it. Rogers considers this stage as the most difficult stage because of individuals' nature of behaviour. The next stage is about "implementation", the individual employs new technology in varying degrees based on the project, also at this stage, the usefulness of the new technology would be identified by the customer. And finally, there is the "confirmation" stage, where the client would finalise their decision in regard to continue with the use of the new technology [42], [49], [50] (see figure 6.1)

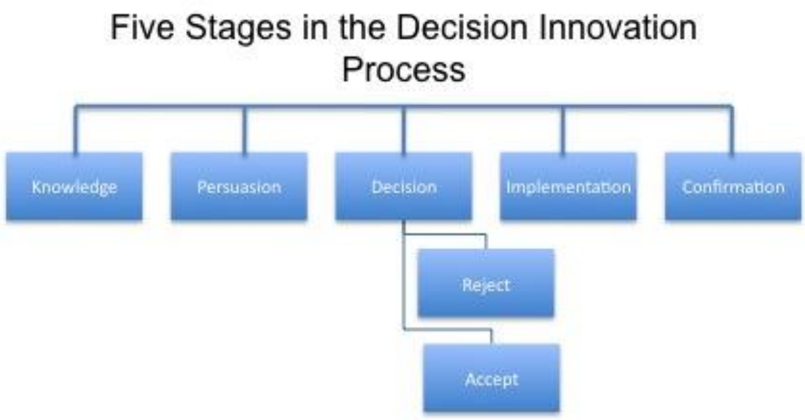


Figure 6.1: Diffusion Innovation Model

Even though Rogers's theory was produced in 1962, it is still workable and valid, and it demonstrates the advancement of knowledge.

The innovation-decision process has been considered in four steps in this research (see figure 6.2). First, the individual receives the knowledge about the technology, second, decides to trust it or reject it, third gets adapted to it and finally implements it in the project.

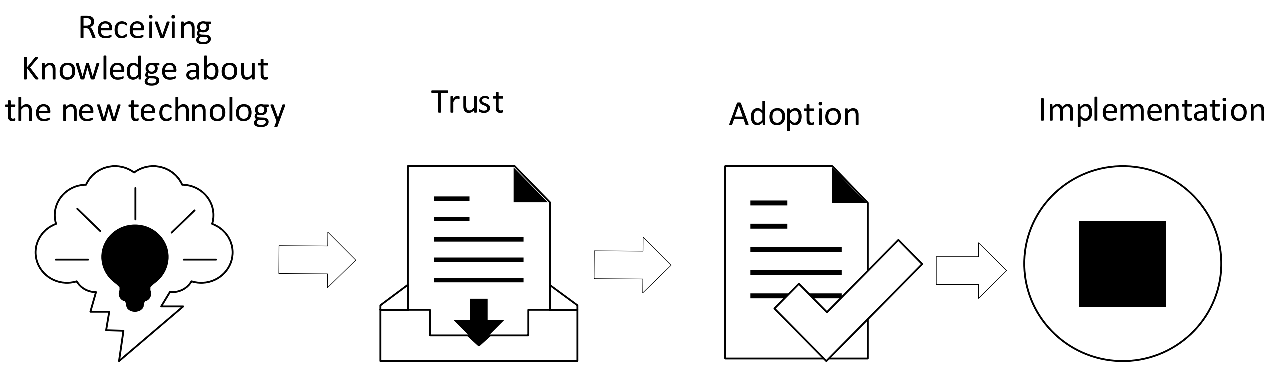


Figure 6.2: Innovation-decision process

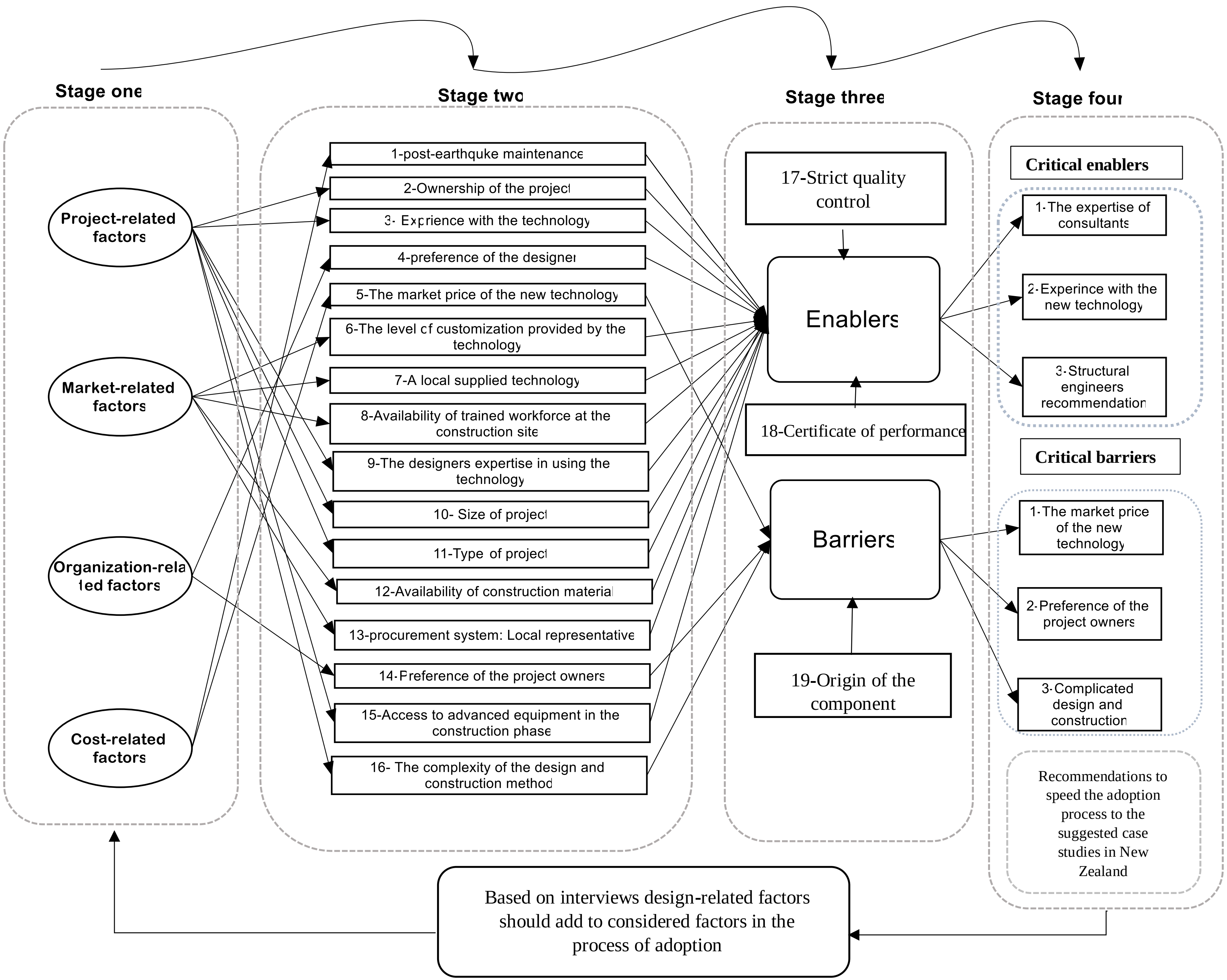
In Chapter 3, we investigated the factors which increase the speed of the adoption process of the new technologies in the New Zealand construction industry In Chapter 2, a literature review has been carried out to explore the factors that cause trust and adoption of the new technologies around the world. These factors were divided into four main groups, cost-related, market-related, organisation-related and project-related. In Chapter three a questionnaire survey was designed around the explored factors from literature and sent to New Zealand construction industry participants to investigate the important factors which cause the adoption of the new seismic-resistant technologies for the New Zealand construction industry. The participants were asked to assess their perception regarding the amount of importance of the factors. Sixteen factors have been chosen as the most important factors by respondents within the New Zealand construction industry.

In chapter four, the roles the explored factors identified in Chapter 3 play as an enabler or barrier in the process of adoption were identified. Another questionnaire survey was designed and sent to New Zealand construction industry participants in which it was asked of the respondents to label each factor as an enabler or barrier in the process of adoption of the case studies. The survey result data were analysed using the binomial test.

In Chapter 5 the developers and users of seismic resistant technologies were interviewed to investigate the challenges they had faced by implementing these newly introduced seismic technologies in construction projects and the to finalise critical enabler and barrier factors in the process of adoption from their point of view.

The results of this chapter emerged from the literature, surveys analysis and the results of the interviews, which are drawn together and compared. The whole findings of the research are presented in the research framework (see figure 6.3)

Figure 6.3: A research framework



Stage one
Stage two
Stage three
Stage four
Project-related factors
Market-related factors
Organization-related factors
Cost-related factors
1-post-earthquke maintenance
2-Ownership of the project
3- Exprience with the technology
4-preference of the designer
5-The market price of the new technology
6-The level of customization provided by the technology
7-A local supplied technology
8-Availability of trained workforce at the construction site
9-The designers expertise in using the technology
10- Size of project
11-Type of project
12-Availability of construction material
13-procurement system: Local representative
14-Preference of the project owners
15-Access to advanced equipment in the construction phase
16- The complexity of the design and construction method
17-Strict quality control
Enablers
18-Certificate of performance
Barriers
19-Origin of the component
Critical enablers
1-The expertise of consultants
2-Experince with the new technology
3-Structural engineers recommendation
Critical barriers
1-The market price of the new technology
2-Preference of the project owners
3-Complicated design and construction
Recommendations to speed the adoption process to the suggested case studies in New Zealand
Based on interviews design-related factors should add to considered factors in the process of adoption

The lessons we can learn and the recommendations are discussed below.

6.2.1 Finalised list of critical enablers and barriers

6.2.1.1 Enablers

In the previous chapter, the developers and the users of seismic resistant technologies chose the essential enabler and barrier factors influencing the process of adoption of these technologies. The final list of factors and the ways to reinforce enablers and to overcome barriers are discussed next:

The expertise of consultants in using the new technology

In order to adopt new ways of doing things and using new technologies, the sector needs to understand the need for the change and to have the skills to adopt [20]. If these skills are not present, new ways and new technologies can not be adopted. Having the expertise of consultants in using the new technologies was indicated as being one of the key enablers of adoption of the new seismic technologies in New Zealand's construction industry. Barbosa [21] noted that construction firms and workers need to continuously reskill and retrain to use the latest equipment and digital tools. This is particularly applicable given the fast pace of technological innovation experienced both within and outside the building and construction industry. Reskilling and continuous training can be achievable by holding workshops, seminars to introducing new technologies and attending annual conferences to get updated regarding new methods and new technologies. And finally by presenting case studies of the real-life projects that adopted new technologies and the advantages they reached after this adoption related to the cost-saving and time-saving.

- **Experience with the new technologies**

It is hard to justify the cost of investment and taking on the risk of implementing new technologies. This scepticism creates a loop where most firms avoid being the first-adopters, and then no one wants to step up to be the first [156]. Poor communication inside and outside of the companies cause the low-speed in the process of adoption of the new technologies, by preventing the transfer of experience of using the technology properly [95]. Solving this issue, by providing a high level of communication about the advances that new technology brings to construction users who had experience in using of new technology, will result in better and faster adoption processes [95].

Internal communication channels should be developed to keep the workforce up to date with the advantages of the new technologies inside the industries. So, the advantages of the new technologies over their predecessors will be recognised, and they will be motivated to narrow the gap [95]. Also, contractors with previous experience of using new technologies or new methods in their projects would adapt easier and faster to using the new technologies in their project [127].

- **Structural engineer's recommendation**

The end-users' ideas regarding the new technologies may encourage the process of acceptance of these new technologies [125]. In our research, structural engineers are the end-users which have to be convinced about the advantages of the new seismic technology. Because structural engineers decide about using new technologies in the design of the buildings, they are the critical characters in this procedure [81]. This factor was chosen to be one of the most significant factors in the list of enablers. The recommendations for the developers of the seismic technologies to reinforce this factor would be as below:

First, structural engineers should be technically convinced related to the advantages of new seismic-resistant technology.

Second, they should be satisfied with the cost of new technology. This can be achieved by comparing the cost of the new technology to the overall value of the building and how much the post-earthquake maintenance cost will decrease by using new seismic technology.

Third, holding technical presentations for structural engineers about how to design, model and implement new technology in a new project would be helpful.

And finally, providing design-ready packs of the new seismic technologies for structural engineers will increase the speed of design, which make new technology more acceptable for structural engineers.

6.2.1.2 Barriers

- Cost of the new technology

As has been discussed above, most of the time, new technologies have a higher cost compared to the traditional ones. This factor has been chosen as the most critical barrier in the process of adoption of the new technologies. To convince clients to accept this higher cost:

First, the cost of new technology should be considered in the overall cost of the whole project.

Second, it should be explained to the clients how much benefit will be achieved by using new seismic technology in construction projects such as:

- Providing life-safety
- Post-earthquake maintenance cost will decrease substantially
- These types of new seismic-resistant technologies can be damage-free, and some are capable of restoring the building to its original position.

By considering the above suggestions for clients, the cost of the new seismic technologies would be less of a barrier in the future in the process of adoption of the new seismic technologies.

- The client resistance to change in user level

Resistance to change was selected as another significant barrier in the process of adoption of the new technologies. The recommendations to solve this issue in the process of adoption are as follows:

If clients become more familiar with the benefits of the new technologies, they will be more likely to be convinced to adopt the new technologies and the observed resistance to change may be reduced. The steps for this are as below:

1- *Explaining goal and expectations positively*: before introducing new technology or a new method to a company, clear goals and expectations should be set, desired outcomes and timeline for progressing well should be written down. Then this should be communicated with the employees of the organisation. If they can not see the whole picture, they can not react appropriately[157].

2- *Identify the issue*: Resistance to change behaviour by the organisation's employees may be the result of issues such as not understanding the new technology or being afraid of asking questions regarding new technology. Addressing these issues will help to create a model for the process of adoption in the company [157].

3- *Regular training*: Some basic training would help employees to learn how to use the new technology properly. While young employees may have the basic skills, the older employees may not be comfortable about using the new technology. Considering regular training schedules, in-depth training and conducting consistent check-in with both data and in-person meetings with employees will help to understand the details of the new technology properly [157].

4- *Smaller steps to implement changes:* Changes should be introduced little by little; it is achievable when the employees are permitted to first understand the new technology or new method, and learn how they operate before starting to use it. If the introduction level to implementation level of new technology happens little by little, then it will be more enjoyable for employees [157][158].

5- *Motivate it:* When the employees are stubborn and resistant to change, they should be motivated regarding using new technology. For example, if a new digital device is introduced to the company, they might be given a chance to take it home and use it after hours. To make them excited and motivated, tell them if they learn how to work with it properly, then they can keep it as an encouragement [157][158].

6- *Teaching is the best form of learning:* sometimes the best way of learning a new thing is when people teach it to others. For example, if a new technology is introduced into a school, old teachers can be asked to train new teachers on how to use new technology [158]. The same way works for big company employees who are asked to teach their colleagues how to use new technologies, and they would learn better to deal with new technologies.

On the other hand, resistance is not always about the change itself but can be about the introduction of the change. Lack of information and guidance in the form of introduction may cause this behaviour. To deal with this problem, adding the reasons for change, providing complete instructions and learning related to new technology or new method would be useful [158][157].

- Complicated design and construction

One of the disadvantages of using new technologies in designing construction is the increased level of complexity in the process [50]. Implementing new technologies and new methods needs more complicated designs, which requires more updated and recent software. However, the most common technological barriers indicated are the lack of technology related to the software resources and insufficient technical knowledge of the team [159]. To overcome these issues, the construction companies should have a regular schedule to get up to date in regard to the software packages and employees should be trained on how to use and work with these software packages. Describing the technology benefits both for business and to each employee would be helpful so that the training will not look like a compliance issue [160]. Another way is to prepare a design ready pack of new technologies and new products which can help designers in the complicated design of projects [136].

Based on our findings in this research, the recommendations are grouped into four main categories. The categories are users, policy and regulations, product, design and construction-related recommendation; these are discussed next.

6.2.2 Users related recommendations

This section addresses the problems identified at the user level in the process of adoption of the new technologies and how to overcome these issues.

6.2.2.1 Overcoming resistance to change behaviour in organisational level

In section 6.2.1.3, resistance to change behaviour has been discussed as an issue at the user level, and in the next section this behaviour is examined at the organisation level and the recommendations to overcome this behaviour offered.

Hymes [70] explained that change, specifically about new technologies, is a stressful procedure for any society. And also, resistance is the best-known attitude towards change [70]. To overcome this issue, resistance to change should be framed in a positive manner by considering changes as the opportunities for improvements and encouragement of people to work at higher levels which prepares them better for change in organisations [70]. Organisational learning may be another affirmative result of the resistance process that shows resistance to change is not always negative [70]. Another issue about resistance is that it is not always being related to the exact change, but in many cases the resistance comes from the way that change has been introduced [161]. Sometimes, timing is one of the biggest challenges in relation to the change; it means the time and the method in which the change has been delivered is the problem, not the changing act itself. Accordingly, to overcome the issues mentioned above, improving organisation performance and positively re-evaluate those behaviours to encourage adoption of the new technologies would be practical. Some specific strategies to overcome resistance to change behaviour are discussed below.

1- Effectively engage employee and structure the team to maximise the potential

After explaining the change to employees, the weakness and strength of each team member in relation to change can be identified. The ways to help employees improve personal weaknesses should be explored while using their power. Always their voice must be heard and their feedback must be responded to correctly. Pertinent questions must be shared with the employees such as if the change is working or the ways to make the change easier. All these help employees to understand that their concerns and ideas are listened to [162]. Another important thing for the leader of the organisation to recognise is that every employee has a unique character which makes them respond differently, so their behaviour in relation to change should not be compared.

2- Implementing change step by step

The change should not happen in one step. First the organisation should be prepared for the change, second, it should be introduced to the employees, third a plan made for managing change and, finally, precise observation on the process of transition to assure that all is going as planned [162].

3- Showing passion and persuasion

Leaders of a company should talk about the change passionately and be an example of the belief in the future vision. If employees observe leaders are passionate behaviour in relation to the change, then they will adapt to the change easier and faster. Being an energised leader who always persuades employees toward accepting change, explaining the future vision of the company with similes, will help employees in the process of adoption of the change [162].

4- effective communication and remaining supportive during the change process

The best way of communication about the change between employer and employees is to tell them exactly what is going on. Different means of communication can be used such as email, company intranet or face-to-face meetings to make sure that employees receive the message of change. Visions, goals and expectation must be explained in several ways of communicating. During all these communications, it is necessary for a leader to stay positive toward the employees, because they find change unsettling. Successful leaders make culture in a company where change becomes everyone's duty [162].

In summary, resistance to change is a psychological reaction. For managing this behaviour first, the reasons that cause resistance to change should be explored. Then the strategic approaches and tactics should be implemented to reduce resistance to change in the organisation’s employees.

6.2.2.2 Having education and skill levels

As discussed in Chapter 3, lack of training about the new product and unskilled labourers decreases the speed of the adoption process. To overcome this issue, the first respondents of this sector should understand the reason for the change. As Erdogan [15] observed, most of the time, construction companies consider change only at the project level (such as design process), but not at the organisational level (such as adopting new ways of doing things) because of the difficulty introduced by geography, size and nature of projects. This will lead to a misunderstanding of the reason for the change. Second, participants in this sector should have the skills to adopt new methods. The skills should be presented to the participants in the construction industry to make way of adoption easier and simpler for them. This presentation of skills could be by providing seminars, workshops, and publishing journal papers.

6.2.2.3 Supporting by the large-scale construction companies

Large-scale construction companies, as the leading players in the construction industry, have a vital role in the process of adoption of the new technologies. These companies can make this process more straightforward by providing and transferring detailed technical expertise to assist small and medium-sized corporations to gain information about the design and installation of novel devices. Moreover, the manufacturers of the devices or the local representatives also can play a coordination role in facilitating technical assistance by providing technical or in-kind support to launch a series of training initiatives [163].

6.2.3 Policy and regulations related recommendations

This section addresses the problems identified about the lack of regulations and policies in the adoption process to new technologies and the solutions to solve these issues.

6.2.3.1 The importance of government role

It has been identified that a lack of government support related to investment or policy on technology will lead to a decrease in the speed of adoption [155]. As discussed in Chapter 3, the New Zealand government sets the regulation for the level of design between 1 and 5 according to the importance of the building. This level of importance corresponds to the life safety provided by the building and post-earthquake functionality of the building [88], so the new seismic technologies that offer these characteristics may be more easily adopted. Government has several policy tools that can encourage the development and implementation of the new technologies in construction fields [164]. Some examples are as below:

- Government funding
- Tax incentives
- Forming cooperative relationships between universities and the private sector.

Based on BRANZ study report [20], easing regulatory processes and reducing the time taken with this processes was chosen as the single significant change that may result in greater adoption of new methods. Every corner of the construction industry has been touched by the purchasing power of the government, while the regulatory powers of the government can mandate using new technologies by setting new standards.

This research suggests the following recommendations for governments to accelerate the adoption process of the new technologies:

1- From the beginning, a government can define a direction for use and adoption of the new technologies for public sector projects to show the priority of developing more efficient construction industry by extensive use of new technologies. To approach the goal of time and cost reduction of public sector projects, one road can be considering a digital construction strategy to motivate using of the new tools. For example, some regulations can be set for using pre-fabricated components that are enabled by digital collaboration tools such as BIM, which result in a reduction in instances of reworks and order changes.
2- Governments can use their tendering process for motivating construction companies to use new technologies and new methods in their projects. For example, public grants can be allocated to the companies which are going to use new technologies in their design and execution parts of their projects. International competition and prizes which reward adoption of the new technologies in construction field also can provide additional financial supports for first technology adopter companies that recognised the importance of using new technologies in decreasing the cost of construction. Other examples would be, the UK construction project authority estimated that about $780 billion would be invested between 2017 and 2027 in the public and private sector; regarding this, they guarantee "to use its purchasing power to drive adoption of modern methods of construction." [165].
3- Governments can reduce the risks and barriers of the adoption process to new technologies. For example, procurement regulations have a direct emphasis on the contractors' past performance for future source selection. However, contractors who wish to operate with new technologies often do not have much experience compared to the traditional solution, which may cause a major disadvantage in the process of adoption. The solution for this issue can be the rethinking of guidelines for making a contribution in accepting new technologies and allowing them time to

demonstrate a new foothold to increase adoption. Accompanying governments can cover some of the contractors' risks regarding using new technology. For example, if the new technology failed to deliver projected savings, the government can provide a refund for the contractors.

6.2.3.2 Regulations and standards in New Zealand

The Building Code is a key building control mechanism in New Zealand. All code-compliant buildings should meet the conditions indicated by the building standards.

Most of the current earthquake design codes use the life-safety philosophy of design. It means for the code-compliance buildings the life-safety is maintained, while the social and economic impacts of the post-earthquake damage are ignored. The building code mostly covers how the building performs rather than defining how the building should be designed and constructed. Therefore, incorporating a "Functional Recovery" philosophy of design into the codes could significantly aid the uptake and trust of the new technologies. As discussed, currently, New Zealand standards and many other international standards are based on the 'life-safety' criteria that do not consider business downtime and the value of the building. With the Functional Recovery implemented in the design codes, the building owners are more encouraged to employ seismic-proofing technologies. These technologies would assist the clients in achieving the standard requirements with minimal effort and at minimum cost. The specific standards in New Zealand that this change is proposed for are NZS 1170, NZS 3404 and NZS 3606. The equivalent international standards that can be considered for the proposal are ASCE-7 in the US, NBCC in Canada and Euro code 8 in Europe.

6.2.4 Product related recommendations

In this part, the problems related to introducing new technologies, the process of adoption of them and the ways to overcome these issues will be explained.

6.2.4.1 Cost

For applying the change in any type of industry, time and cost should be invested, specifically for the New Zealand construction industry sector, which has a strong competitive nature [20]. One of the essential factors in adopting new technologies is to minimising cost for the industry. For solving this issue first for encouraging the construction industry to spend their time and funds to adopt new technologies or a new technique has a satisfactory impact. The best way to encourage others to adopt new products is to show how those new products are advantageous for them; maybe it costs a little bit more but clearly will deliver many benefits in the future [20]. It should be emphasised to customers that the cost of the new technology should be considered in the overall cost of the project. For example, it should be clearly explained for the clients that, with the use of new technology, the amount of damage after the earthquake will be greatly reduced, which will reduce the cost of the entire project.

Another solution to reduce the impacts of the cost of new technology is to reduce taxes. For example, in New Zealand businesses would benefit from tax breaks worth at least $80 million over five years from 2019, to encourage them to spend more on research and innovation [166]. By this, when companies spend $10,000 or less on finding new innovations, such spending would be tax-deductible.

6.2.4.2 Ability to customise the product

Customisation refers to the ability of the producer company that can add or subtract extra features to the product based on customer demand which causes customer satisfaction [105]. Availability of good resources in the developer company is another reason that causes delivery of quality products [95]. When a new product or a new technology can be manufactured in any size and can be implemented in any part of the building, it has the priority to be chosen by the customer [105]. When all these advantages are present in a product, the chance of accepting this new product and its adoption will increase [105]. The recommendation for technology developers and manufacturing companies is to consider designing new technologies giving the advantages of flexibility in production and implementation. Flexibility in production means that the new technology can be produced in any size and any cost, and flexibility in implementation means it can be implemented in any part of the building or can be modified based on the soil requirement or location of the buildings.

Bischof [167] explained some guidelines to provide flexible products which are useful for suppliers to consider:

- Try to define different types of interfaces
- Use standard machine parts in production
- Try to place replacement parts and individual custom parts at the outside of the product
- A parametric design would be preferable
- Having differential design is more useful compared to integral design. It subdivides the product into elements.
- Try to install software solutions instead of hardware solutions
- Try to increase the number of elements in the product, so they can be changed and replaced easily
- The internal connections between product parts should be minimised
- It is better to not have internal dependency between product parts, so if one part does not work correctly, it can be easily replaced.
- Aim to have additional functions and configurations from the beginning.

By using mentioned guidelines, suppliers can provide products with flexibility in design, production and implementation.

6.2.5 Design and construction-related recommendations

Design and construction-related problems about the construction projects, new products and the solutions to fix these problems will be reviewed in the next section.

6.2.5.1 Project design

In the last decade, the construction industry has invested more and more in new technology, advanced technology, computer-based technology, and also has adopted new processes and products to survive and to stay competitive [155]. One example of these new technologies is seismic technologies. However, one of the biggest challenges during the process of adoption of seismic technologies is the lack of information regarding new seismic technology. This lack of information as has been mentioned by interviewees in Chapter 5 cause many issues in the design process of buildings for construction industry people, especially structural engineers, so the design-related factors should be considered in the process of adoption. To overcome this issue, first, the ultimate solution can be to inform the structural engineers about the advantages of the new seismic technologies and make them familiar with the design tools that support incorporating these new products into their design [99]. These can be achieved through technical presentations, workshops and conference/journal publications [99]. Second, a design-ready pack of technology can significantly reduce the designers' efforts to meet codes and regulations and can promote trust and adoption levels [55]. And finally, a more straightforward configuration associated with a simpler seismic design makes it more achievable for the designers without using design-ready elements [168].

6.2.5.2 Method of construction

Construction work is mostly limited to the labour-intensive type of works until now [119] that cause the slow process of construction. To overcome this issue, the anticipation of mechanisation and intelligent automation in new markets is considered as a practical way. It is believed that the pace of work can be increased while reducing the required man-hours [119]. As identified by BRANZ [20], there is often pressure on time and cost because of the competitive nature of the construction industry, where contracts may be won or lost based on time and cost. For example, the work that could be done by three people for three days now can be done in two days by two people that cause saving in the amount of time and cost. Thus, mechanisation and intelligent automation can reduce the labour cost, the overall time of the project and ultimately, the overall cost [119].

6.2.5.3 Product design

Technology capability is as important as another functional capability in organisations, particularly as a competitive weapon. Technology capability can be used as a strategic tool for developing products and processes, expanding market share, and increasing profitability provided that technology is well integrated with the functional capability of the company [169].

New technology has certain distinctive features which, it is claimed, allow of a good deal of choice in relation to how it is used. These features include its flexibility and scalability [170].

There are many factors driving companies to adopt technology, both internally and externally. The external factors include 1) global competition; 2) increasing customer demand for quality products; 3) The changing economic conditions that cannot be predicted; 4) higher market pressure; 5) environmental sustainability; 6) The degree of competition in the local market, and 7) media coverage. Internal factors include: 1) implementing technology strategy; 2) increasing material costs of production; 3) increasing operational costs; 4) increasing business costs;5) obsolescent plants and equipment; 6) increasing labour cost; 7) decreasing profits; 8) decreasing quality of products, and 9) high labour turnover [155]. A new seismic technology which has the advantages of flexibility and scalability will encourage the companies to adopt faster to the new technology [155]. By having flexible and scalable technology, number one, two of external factors and number one of internal factors will meet, and as a result, the process of adoption of these kinds of seismic technologies will be increased. The guideline for suppliers for having scalable and flexible product has been discussed in 6.2.4.2 part of this chapter**.**

6.3 Conclusion

In the first part of this chapter, the summary of our findings in this research, the finalised list of enablers and barriers in the process of adoption of the new technologies were discussed. Then the suggestions and recommendations to reinforce the enablers and overcoming the barriers were considered.

The recommendations are divided into four subgroups. First, users-related recommendations discuss the reasons for resistance to change behaviour, the impacts of the support of large-scale companies, education and skill levels. Second, policy and regulation related recommendations that explore the role of the government, regulations and standards. Third product-related recommendations, which release suggestions related to the cost and ability to be customised of the new seismic technologies. And finally, design and construction-related recommendation in relation to design methods, construction methods, flexibility and scalability in designs methods in different cultures and countries were considered.

CHAPTER 7

Conclusions

7.1 Research overview

This research identified and discussed the factors that impact the adoption of new seismic-resistant technologies in the New Zealand construction industry. The topic is important for building national earthquake resilience. Seismic-resistant technologies can play a significant role in the process. From this perspective, the major contribution of this research is that it identified critical enablers and barriers to the adoption of specific seismic-resistant technologies and offered recommendations regarding users, products, policies and regulations. The results are of importance for policy-makers and decision-makers in New Zealand.

This research first explored the factors that cause trust and adoption of the new technologies globally. The comprehensive literature review explored forty factors. At phase two, these forty factors were specified for the New Zealand construction sector for the process of adoption by designing and releasing a survey.

Four recent seismic-resistant technologies were considered as case studies. Sixteen factors were identified as the most important and effective factors in the process of adoption of the case study in this phase.

At the next phase, the roles that the sixteen explored factors play as an enabler or barrier play in the adoption process were found. Three more factors were added by respondents to the survey as the missing factors from the list presented. Fourteen factors were chosen as enabler factors, and five factors were chosen as barrier factors.

This research examined the developers and users point of views in relation to the enabler and barrier factors, and the challenges they faced in relation to cost, market, organisation and project. Finally, recommendations and suggestions to improve the low rate of the adoption process were offered.

In this chapter, the results from the literature review, content analysis and interviews are drawn together and synthesised according to the research objectives. This chapter is dedicated to classifying the significant findings of this study.

The discussions initially identify the links between the findings and how they led to the accomplishment of research objectives.

7.2 objective development

To achieve research objectives as it has been shown in the research framework in the previous chapter (see figure 6.3), this study involved four stages.

7.2.1 Stage one: *Identifying the factors facilitating the adoption of new technologies*

At stage one, the factors that allow new technologies to be trusted and adopted into the building industry was covered. At this stage of this thesis, the factors that cause trust and adoption of the new technologies globally around the world were explored. Forty factors were found. This was initially done through a comprehensive literature review. The explored factors from the literature review were categorised to project, market, cost and organisation-related factors.

The four more recent and favourable of seismic-resistant technologies in the New Zealand construction field were considered as the case studies of this research.

7.2.2 Stage two: *Finding the decision factors for adopting the case studies in the New Zealand construction industry*

At stage two, essential factors that speed up the adoption process of new technologies into the New Zealand construction industry were identified. This stage consists of two parts. At the first part, a questionnaire survey was designed by using the forty factors discovered in stage one, a web link generated in Survey Monkey and released to construction experts in New Zealand. The respondents were requested to assess their perception of the relative importance of the factors for the adoption process to the case study. Sixteen factors have been chosen as the most significant factors for the process of adoption.

At the second part, the reasons for the importance of the selected factors were discussed.

7.2.3 Stage three: *Identifying the enablers and barriers of the process of adoption for the case studies in the New Zealand construction industry*

At stage three, the barriers and enablers of the adoption process for new technologies by the New Zealand construction industry were determined. A second survey was designed at this stage to find the role of the factors identified in stage two as an enabler or barrier. A web link was generated on the Survey Monkey website and released to the construction experts in New Zealand. In the survey, first the case study was explained, and then the respondents were requested to rank the factors in the enablers or barriers groups. At the end of the survey, the respondents added any enabler or barrier factors which were missing from the survey. The collected data was analysed by using a binomial test. Fourteen factors were chosen as the enablers, and five factors were selected as barriers. The reasons for being chosen as an enabler or barrier were also discussed. And finally, the ways to reinforce enablers and fix the barriers were explained.

7.2.4 Stage four: *Exploring the finalised list of enablers, barriers and making recommendations for the process of adoption of the new technologies in New Zealand*

At this stage, assessing the significance of the enablers and barriers factors from the perspective of the users and developers of the new technologies and recommendations about approaches to enhance the rate of the adoption process of the new technologies by the New Zealand construction industry were covered. A series of interviews were arranged with developers and users of the case studies in New Zealand. At these interviews, firstly the challenges they faced in relation to cost, project, organisation and market by implementing the case studies in their projects, were revealed. Second, the impacts of enabler and barrier factors in the process of adoption of these technologies were discussed. And finally, the top three critical enabler and barrier factors from their point of view were identified. The top critical enablers elected by respondents were the expertise of consultants, experience with the new technology and structural engineers' recommendations. The top critical barriers chosen by the respondents were the market price (cost) of the new technology, preference of the project owners and complicated design and construction. Based on interviews, it was suggested by the respondents to add design-related factors to the factors which should be considered in the process of adoption of the considered case studies.

At this stage, suggestions and recommendations that speed up the process of adoption of the new technologies in the New Zealand context were discussed. Ultimately,

As a part of stage four, three factors of *the expertise of consultants in using new technology, experience with the new technology and structural engineer's recommendation* were identified as the top enablers in the adoption process.

The interviews suggested by holding workshops, seminars and annual conferences, new technologies can be introduced to consultants. And also, workers in construction firms can be continuously reskilled and trained about the latest technologies in the market. Structural engineers should be convinced about the advantages and cost of new seismic technologies.

As another part of stage four, three factors of *the market price (cost) of the new technology, the client resistance to change and complicated design and construction* were elected as the top barriers of adoption of the new seismic technologies in New Zealand.

To address the top critical barriers in the future, the interviews demonstrated that:

First, clients should be more familiar with the pros of new technologies, reasons for the change to reducing the resistance to change behaviour. Second, It should be explained to the customers that the higher cost of the new technology should be considered in the overall cost of the project, and they should be convinced about the benefits that can be achieved by these new types of technologies.

In dealing with the complicated design of new technologies in new projects, more recent software and more modern design methods should be introduced into the construction companies, and personnel should be trained in working with them. Table 7.1 gives a summary of the main findings in this research.

Table 7.1: Main findings from research

Chapter	Main finding (s)	Objective
Chapter 2	Forty factors explored from the literature review that causes trust and adoption of the new technologies globally. Factors were categorised into four subgroups: Project-related, Market-related, Cost related and organisation-related.	Objective 1
Chapter 3	Sixteen factors have been chosen in survey one as the deciding factors for adopting the case study in the New Zealand construction industry. Evaluate the reasons for the importance of the identified factors.	Objective 2
Chapter 4	Between sixteen factors, 12 factors chosen as enablers and four factors chosen as barriers. Two factors of strict quality control and certificate of performance were added to enablers, and one factor of the origin of the component was added to barriers list as missed factors by respondents. And finally, fourteen factors ranked as enablers, and five factors chose as barriers of the process of adoption of the case studies in the New Zealand construction industry in survey two. Explore the reasons for the role that enabler and barrier factors play in the process of adoption of the case studies.	Objective 3
Chapter 5	The significance of the enablers and barriers factors from the users and developers of the case studies point of view were explored. The study finalised the top critical enabler and barrier factors for adopting to the case studies in the New Zealand construction industry.	Objective 4
Chapter 6	The research user-related, policy and regulations, product-related, design and construction-related recommendations and suggestions to improve the adoption process to new technologies in the New Zealand construction sector were explained.	Objective 5

7.3 Research Contributions

This thesis has different contributions in theoretical and practical nature. Different methodologies such as surveys, interviews and case studies were used in this research to have conclusions based on collected data. The research contributions cover problems ranging from decision making to execution and technical problems in construction projects. These contributions are categorised into four groups. The categories included the users, policy and regulations, products, design and construction-related groups.

In the user-related category:

- Improving organisation performance and positively re-evaluate the resistance to change behaviour to encourage adoption of the new technologies were strategies recommended to overcome resistance to change behaviour as the primary attitude towards the change
- Having education and skilled level impacts on the process of adoption was explained.
- The positive impacts of the support of large-scale construction companies on small and medium-sized companies to assist them by transferring the details of technical expertise, information about the design and installation of new technologies were revealed.

In the policy and regulations-related category:

- The importance of governments' role by setting regulations in using new technologies which provides life safety advantage in supporting the adoption process of these technologies in New Zealand was discussed.
- The impacts of regulations and standards by incorporating a "Functional Recovery" philosophy of design into the building code of New Zealand, which improve the process of adoption of the new technologies, were revealed.

In the Product-related category

- The impacts of the higher cost of the new technologies on the adoption process were investigated. It was revealed that if clients became convinced about the benefits of new technologies or new methods, the higher cost of the new technologies would be more acceptable for them.
- The ability to customise the product, which refers to the flexibility in design and implementation of the new technologies, and the impacts of these characteristics on the adoption process, was discussed.

In the design and construction-related category:

- Solving the project design issues, such as lack of information regarding the new technology and lack of designing tools, by preparing design ready packs for designers, informing structural engineers about the pros of new technologies and finally providing more straightforward configuration with simpler designs.
- Method of construction concerns, such as the limitation of construction works that should be done by hand and the pressure on time and cost in construction projects, were discussed. The solutions recommended by this research were adding mechanisation and intelligent automation into the market to overcome.
- Recommendations related to the product design methods, such as designing flexible and scalable technologies for developers of the technologies

7.4 Research limitations

A discussion of possible limitations for this research has been included in the following:

An important limitation was the scope of research. The study was based in New Zealand and focused on a small industry under the specific cultural influence. There were no specific data available to compare the process of adoption of the new technologies, especially the mentioned case studies in different construction cultures.

Notwithstanding, in all statistical tests, the minimum sample and response rate requirement were met; the small size of the New Zealand construction industry restricted the number of respondents for different analysis. Arranging the interviews with the industry experts was a time-consuming procedure. Many of them were not responsive even after the initial email confirmation.

Some of the explored enabler and barrier factors were neutral and multifaceted in nature, and understanding the role that they played in this research for the case studies as an enabler or barrier made some confusion for respondents.

7.5 Recommendations for future research

Research is always limited in terms of scale, scope and boundaries. The findings of this research can be considered as a preliminary but relevant starting point that will prompt further interest and investigation into the adoption process for different kinds of new technologies and new methods in different cultures and countries.

Reviews should go beyond of early stages of the adoption process, and further research could focus on exploring factors that speed up the implementation and confirmation process of new technologies in construction projects. In addition, it would be worth exploring the barrier and enabler factors for the implementation process of new technologies.

These new technologies have only been available in the market for a few years, so another research should be done to explore the market reaction to newly introduced technologies in the long run. Some effects are not directly caused by new technologies themselves, but the changes can happen to people's behaviour. And generally, these indirect effects are not considered. Future research would be on assessing the impacts of new technologies on the market. This research can be localised for a specific market like New Zealand, and it can explore both the direct and indirect impacts.

CHAPTER 8

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Appendices

Appendix 1: Ethics Approval and Documentation

Appendix 2: Questionnaire survey one

Appendix 3: Questionnaire survey two

Appendix 4: Interview questions

Appendix 1

Ethics Approval and Documentation

Research Office

Post–Award Support Services

20 Symonds Street Auckland, New Zealand

Telephone: 6493737599 ext.: 88166, Facsimile: 6493737462

The University of Auckland, Faculty of Engineering

UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE (UAHPEC)

16-Jul-2018

MEMORANDUM TO:

Prof Suzanne Wilkinson

Civil and Environmental Eng

Re: Application for Ethics Approval (Our Ref. 021049): Approved with comment

The Committee considered your application for ethics approval for your study entitled

Innovation in Construction.

Ethics approval was given for a period of three years with the following comment(s):

1. All PIS

Please increase the font size of the contact details. Font size 8 is not easily read.

The expiry date for this approval is 16-Jul-2021.

If the project changes significantly, you are required to resubmit a new application to UAHPEC for further consideration.

If you have obtained funding other than from UniServices, send a copy of this approval letter to the Activations team in the Research Office, at ro-awards@auckland.ac.nz. For UniServices contracts, send a copy of the approval letter to the Contract Manager, UniServices.

The Chair and the members of UAHPEC would be happy to discuss general matters relating to ethics approvals if you wish to do so. Contact should be made through the UAHPEC Ethics Administrators at ro-ethics@auckland.ac.nz in the first instance.

Please quote Protocol number **021049** on all communication with the UAHPEC regarding this application

UAHPEC Administrators

University of Auckland Human Participants Ethics Committee

c.c. Head of Department /School, Civil and Environmental Engineering

Mrs Shermineh Zarinkamar

Prof Pierre Quenneville

Dr Johnson Adafin

Tabinda Chowdhury

Mr Hossein Sadeghzadeh Fasaghandis

Additional information:

1. Do not forget to fill in the 'approval wording' on the Participant Information Sheets, Consent Forms and/or advertisements, giving the dates of approval and the reference number. This needs to be completed before you use them or send them out to your participants.

2. At the end of three years, or if the study is completed before the expiry, you are requested to advise the Committee of its completion.

3. Should you require an extension or need to make any changes to the project, please complete the online Amendment Request form associated with this approval number giving full details along with revised documentation. If requested before the current approval expires, an extension may be granted for a further three years, after which time you must submit a new application.

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Faculty of Engineering

20 Symonds Street Auckland, New Zealand

Telephone: 6493737599 ext.: 88166, Facsimile: 6493737462

The University of Auckland, Faculty of Engineering

Consent Form (CF) for research participants

Title of the project: Developing pathways for innovative product uptake

Name of researcher: Shermineh Zarinkamar

Degree: PhD in Civil Engineering

Department: Civil and Environmental Engineering

Research supervisor: Professor Suzanne Wilkinson

I agree to voluntarily take part in this research study undertaken by Shermineh Zarinkamar.

I have read the Participant Information Sheet (PIS) and understood the nature of the research and why the participants have been invited. I have had the opportunity to ask questions and have also had them answered to my satisfaction.

- I confirm that I hold the appropriate authority to provide consent for the following statements.
- I permit the employees of my organisation to take part in the research.

- I permit the employees of my organisation to provide information related to my organisation to support this research. I understand that any such information will be treated confidentially and any reported information will appear in a general form.
- I confirm that the employees' participation in this research will not, in any way, affect their employment in my organisation.
- I understand that the participating employees will not be provided with the opportunity to review the recording of the interview.
- I understand that the employee will retain the right to keep their response transcripts confidential from other members of my organisation and me.
- I know that the data will be transcribed by the researcher himself without the assistance of any third party.
- I understand that the data will be kept for six years, after which they will be destroyed.
- I understand that the data provided by the participants will be stored securely within the university premises, and only the researcher and supervisor can have access to it.
- I understand that the participating employees will have the rights to review a draft of the final report related to the information they have provided to ensure that the information reported satisfies my organisation's confidentiality requirements.
- I understand the estimated time duration of the interview/ survey questionnaire, as stated in the PIS.
- I agree/do not agree for the interview to be audio-recorded.
- I understand that I may choose to have the recorder turned off at any time during the interview.

- I understand that the participating employees are free to withdraw their participation in this research at any time without giving any reasons.
- I understand that the participating employees are able to withdraw the data provided by them up to one month after undertaking the interviews.
- I understand that although, data provided by the participants will be reported, and it will be done in a way that does not identify the source either by name, innuendo or inference.
- I understand that I will be offered a copy of the final research report.

Name: ………………………….. Signature: …………………………

Date: ………………… Company/Organisation: ……………………..

Correspondence Address: ………………………………………….

………………………………………………………………………………

Telephone: ………………………. Mobile Telephone: ……………………

Fax: ……………………………… E-mail: ………………………………..

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 16-July-2018 FOR (36) MONTHS REFERENCE NUMBER 021049.

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Faculty of Engineering

20 Symonds Street Auckland, New Zealand

Telephone: 6493737599 ext.: 88166, Facsimile: 6493737462

The University of Auckland, Faculty of Engineering

Participant Information Sheet (PIS)

Title of Project: Developing pathways for innovative product

Name of researcher: Shermineh Zarinkamar

Degree: PhD in Civil Engineering

Department: Civil and Environmental Engineering

Research supervisor: Professor Suzanne Wilkinson, Professor Pierre Quenneville

Purpose of this Participant Information Sheet

You are invited to participate in the above-captioned research currently undertaken for a PhD study at the University of Auckland. The objective of this project is to identify the factors which cause the trust to new technologies such as seismic-resistant technologies in the construction industry in New Zealand.

Project Description

This Doctoral research is undertaken by Shermineh Zarinkamar of the Department of Civil and Environmental Engineering, the University of Auckland, New Zealand. The current research endeavours to identify which factors are influencing the uptake of innovative seismic-proofing products into the NZ building industry.

New Zealand's location on the Ring of Fire implies its vulnerability to earthquake hazard. Earthquakes have caused significant damages to the built environment of the country and heavily disturbed its economy. Recently, innovative seismic-proofing products are making their way to the construction industry, which offers a significant damage reduction in the structural and non-structural elements of buildings. They provide a possibility of immediate occupancy after the seismic event. However, the process of adaption to these new technologies is slow in new Zealand construction industry.

This research explored the factors that speed up the adaptation process to new technologies, especially seismic-resistant technologies in New Zealand.

Data Collection

This study aims to explore the factors which cause the trust to new technologies such as seismic-resistant technologies into the NZ building industry. Therefore a mix of qualitative and quantitative methods will be used to provide measures of analysis and validation for this study.

Participation

Participants will be invited to attend in interviews based on their experience in the New Zealand construction industry. for each participant, the time of interview would last approximately 20 to 30 minutes.

Your endorsement will be extended to the employees who are invited to participate in this research, but they will still retain their right to decide whether or not to participate. Furthermore, participants will retain the right to keep their response transcripts (interview) restricted from access/review by other members in your organisation (including yourself).

All the information and data collected will remain confidential and will not be disclosed to any other party except the research team. No names will be mentioned in the final thesis and any other publications produced. In this regard, to ensure that nobody will be identifiable such as the case or project's date, place, and title will not be disclosed to anyone. Any other third party named or identified in the data collection process will remain anonymous and will not be mentioned in any reports or publication. The employer is the only person who will know you have participated in the interviews.

The researcher will notify you of the results and conclusions drawn from the collected data as well as any publications produced including information gathered from you based on your request.

Funding

The current research is being funded by the University of Auckland's Postgraduate Research Student Support Accounts (PRESS).

Queries

If you have any inquiries regarding your participation in the research project, please contact:

Researcher: Shermineh Zarinkamar

Mobile: +64 226274859

Email: szar830@aucklanduni.ac.nz

Supervisors: Prof. Suzanne Wilkinson

Phone: +64 9 3737599 ext. 88184

Email: s.wilkinson@massey.ac.nz

Prof. Pierre Quenneville

+64 9 9237920

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Head of the department: Jason Ingham

Mobile phone: +64 9 9237803

Email: j.ingham@auckland.ac.nz

For any queries regarding ethical concerns, you may contact:

The Chair, the University of Auckland Human Participants Ethics Committee

Telephone: 09 373 7599 ext. 83711.

Postal Address: The University of Auckland, Office of the Vice-Chancellor, Private Bag 92019, Auckland 1142.

Appendix 2

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

ENGINEERING
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Auckland 1142
New Zealand

16 July 2018

LETTER ACCOMPANYING QUESTIONNAIRE

Dear Respondent,

A SURVEY OF INNOVATION IN CONSTRUCTION

This is to invite you to a PhD research we are currently undertaking at the University of Auckland, New Zealand on ***Innovation in Construction*** and to request your assistance in completing the attached questionnaire as a basis for the research. This survey is based on your experience as a ***Construction Industry Practitioner*** on ***The Value of Innovation in NZ Construction Industry*** generally.

The aim of this research is to develop a practical tool for improving innovation and productivity performance in the NZ construction industry.

Survey Design

- ***There are 9 questions in all: Estimated time to complete them is 15 minutes***

- ***Questions 1-5 outline the subject and profile the respondents (quick to complete)***
- ***Questions 6-9 ask respondents to rate pre-identified factors from No impact to extreme impact (low to high) for one measurable attribute (level of significance) in the question so you can easily identify the subtle change in question/answer requirements (allow 10 minutes to complete).***

If you have any inquiries on the survey, please do not hesitate to contact **Prof Suzanne Wilkinson** (Tel: 02118 122 54 and E-Mail: s.wilkinson@massey.ac.nz) at the address below. Your response to this questionnaire would be helpful to our research. We look forward to your comments and appreciate it if we could get further feedback about this research from you.

Yours faithfully,

"Signed"

Dept. of Civil & Environmental Engineering,

The University of Auckland,

Auckland 1142.

New Zealand.

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 16 JULY 2018 FOR (18) MONTHS REFERENCE NUMBER 021049.

Please answer the following questions based on your current job.

Section A:

A short questionnaire for judgment of the construction industry participants towards their working relationship with using this new technology RSFJ (Resilient Slip Friction Joint)

1. What is your role in the construction industry?

- o Client
- o Contractor
- o Consultant
- o Other (please specify)

2. How many years of experience do you have in the construction industry?

- o 0-5 years
- o 5-10 years
- o 10-20 years
- o More than 20 years

3. Under which sector have you performed the majority of your professional career?

- o Public
- o Private

4. What type of construction have you been involved mostly?

- o Building and residential
- o Industrial
- o Commercial
- o Other types (please specify)

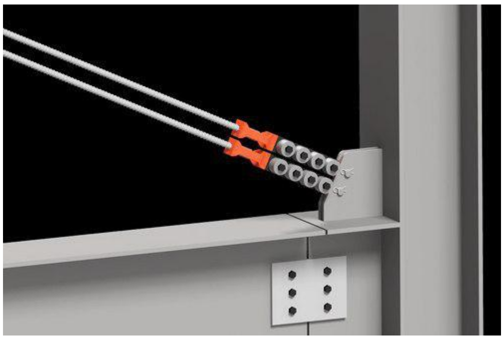
5. What is your profession in the construction industry?

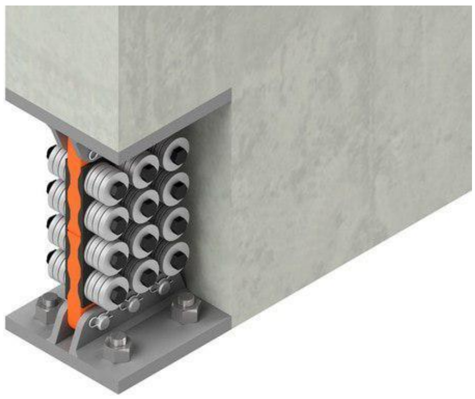
- o Architect
- o Structural engineer
- o Planner
- o Quantity surveyor
- o Project manager
- o Other (please specify)

The questionnaire is about choices made for new product or technology introduction to the NZ market.

Section B:

The Resilient Slip Friction Joint (RSFJ) is an innovative structural invention that combines the two most important characteristics of seismic protection – energy damping and self-centring – into one device. When these joints are installed into buildings, they work to strengthen the buildings against earthquakes and bring them back to their original positions.





6. How much would the following factors influence your choice of RSFJ?

5= Most influence **0= Least influence**

			0	1	2	3	4	5
This section should be completed from **an organisational** point of view	From the Stakeholder's perspective	Deciding as a developer						
		Deciding as an Architect						
		Deciding as a structural Enginieer						
		Deciding as a contractor						
	From the occupant's perspective	Deciding as an owner						
		Deciding as a Tenant						
	Deciding as a project owner when the requirements of the project are changed on the way							
	As a construction expert when the client is resistant to adopt new technology							
	Other(please specify)	………………………						

7. How much would the following factors influence your choice of RSFJ?

5= Most influence **0= Least influence**

			0	1	2	3	4	5
This section should be completed from the **Project characteristics** perspectives	Location of the project	Urban						
		Rural						
	Project type	Government						
		Private						
	The scale of the project	Large						
		Small						
	The Complexity of design and construction	Normal						
		Complicated						
	Type of the construction	Residential						
		Industrial						
		Commercial						
		Other types						
	Site access	Easy accessibility						
		Hard accessibility						
	Lack of experience with the new technology							
	Method of construction	Using conventional construction equipment						
		Using more advanced equipments						
	The level of expertise of consultants in using RSFJ							
	Other(please specify)	....						

8. How much would the following factors influence your choice of RSFJ?

5= Most influence **0= Least influence**

			0	1	2	3	4	5
This section should be completed from **Cost related** perspective	Post earthquake maintenance cost decreases because the system is damage avoidance							
	Cost of the new technology is higher compared to the conventional (not self-center/high damage) technologies							
	The cost of the project can be misestimated owing to lack of information about RSFJ							
	The project is targeted to reduce costs as much as possible							
	Type and quality of cost planning data							
	Other(please specify)	…………………………						

9. How much would the following factors influence your choice of RSFJ?

5= Most influence **0= Least influence**

			0	1	2	3	4	5
This section should be completed from **Market related** perspective	Procurement system	Local representitive						
		Overseas representitives						
	Product availability	Of the shelf products						
		Customized products						
	Inflation							
	Availability of construction material							
	Avalability of labour							
	Flactuating in in labour prices							
	Flactuating in material prices							
	Being a made-in New Zealand technology							
	Other(please specify)	....						

Thank you for completing this survey

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Appendix 3

ENGINEERING
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

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1. Barrier or Enabler

Trust to technology is defined as "a belief that the technology has the attributes necessary to perform as expected in a given situation" and adoption of the technology represents to the time that the client starts to use of the technology. The factors which can influence trust and adoption in new construction technologies and methods in New Zealand were identified in a previous survey. This survey is seeking to describe the type of impact of each factor. Do the following factors enable the uptake of new technology, or are they a barrier to new technology?

Answer each section for the specific technology.

The Resilient Slip Friction Joint (RSFJ) is an innovative structural invention that combines the two most important characteristics of seismic protection – energy damping and self-centring – into one device. When these joints are installed into buildings, they work to strengthen the buildings against earthquakes and bring them back to their original positions.

1. Governmental projects

☐ Enabler

☐ Barrier

2. Large scale project

☐ Enabler

☐ Barrier

3. Commercial construction projects

☐ Enabler

☐ Barrier

4. The industrial construction projects

☐ Enabler

☐ Barrier

5. Using more advanced equipment in the method of construction

☐ Enabler

☐ Barrier

6. Lack of time to complete a project.

☐ Enabler

☐ Barrier

7. The client

☐ Enabler

☐ Barrier

8. Post-earthquake maintenance cost

☐ Enabler

☐ Barrier

9. Cost of new technology

☐ Enabler

☐ Barrier

10. Ability to customized products

☐ Enabler

☐ Barrier

11. A New Zealand supplied technology

☐ Enabler

☐ Barrier

12. Availability of labour

☐ Enabler

☐ Barrier

13. Availability of construction material

☐ Enabler

☐ Barrier

14. Local suitability of the technology

☐ Enabler

☐ Barrier

15. The expertise of consultants in using new technology

☐ Enabler

☐ Barrier

16. Experience with the new technology

☐ Enabler

☐ Barrier

17. Structural engineer's recommendations

☐ Enabler

☐ Barrier

18. Origin of the component (for example made in China)

☐ Enabler

☐ Barrier

19. Strict quality control (every product is checked in the laboratory)

☐ Enabler

☐ Barrier

20. Certificate of performance

☐ Enabler

☐ Barrier

21. Complicated design and construction

☐ Enabler

☐ Barrier

22. Please add any factor that you considered has been missed from the survey as enabler or barrier factor in technology adoption?

Appendix 4

ENGINEERING
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Structure and schedule of the interview

The interviews will be conducted in two groups:

It includes five open-ended questions and two closed questions.

First section: open-ended interview questions (around 30 minutes)

The open-ended interview in the first question lets respondents give a comprehensive answer about the pros and cons of each technology. First, it was asked from the respondents

1*-Please explain the characteristics of this technology (press-lam, lead damper, SHJ and RSFJ)*

In the next four questions, the respondents explained the challenges they had to encounter regarding cost, market, project and organization by using new seismic-resistant technology in their construction project. The questions are as below:

2*- What challenges have you faced in relation to cost?*

3*-What challenges have you faced in relation to market?*

4*- What challenges have you faced in relation to the project?*

5*-What challenges have you faced in relation to the organization?*

Second section: Closed interview questions (20 to 30 minutes)

Two closed questions were asked from respondents to obtain more specific answers. Question 6 was asked from developers and users about the three top finalised enabler and barrier factors in the adoption of the seismic-resistant technologies.

***6**-Present table of barriers and enablers factors and ask them to rank the significance and tell which one of them do you consider as the three critical barriers and three critical enablers?*

Enablers	**Barriers**
1-Access to advanced equipment in the construction method	1-Preference of the client (resistance to change)
2-Ownership of the project	2-Complicated design and construction
3-Type of project	3-Origin of the component(place of the manufacturer)
4-Ability to customize products	4-Cost of the new technology
5-A local supplied technology	5-Lack of time to complete a project
6-Trained personnel	
7-Structural engineer's recommendation	
8-Post-earthquake maintenance cost	
9-Experience with the new technology	
10-Availability of labor and construction material	
11-Size of the project	
12-The expertise of consultants in using new technology	
13-Strict quality control	
14-Certificate of performance	

The seventh question was asked from developers of the case studies only, about the changes in relation to the cost of insurance in resilient buildings:

***7**- How do insurance companies value your new technology or describe how the insurance process has worked for your new technology? (process and problems)*