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6th NZBERS 2020

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Wajiha Mohsin Shahzad

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Dr Wajiha Mohsin Shahzad, Dr Eziaku Onyeizu Rasheed & A/Prof James Olabode Bamidele Rotimi
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SECTION I

Keynote Speakers

Emeritus Prof. George Baird

Victoria University, Wellington, New Zealand

George Baird is Emeritus Professor of Building Science at the School of Architecture, Victoria University of Wellington, specialising in building environmental science and the assessment of building performance from the point of view of the users. He is a Fellow of the Chartered Institution of Building Services Engineers (UK) and of Engineering New Zealand, and was awarded Life Membership of the Energy Management Association (now Carbon and Energy Professionals) of New Zealand in 2013. He received the NZ Science and Technology Bronze Medal in 1999, the international “Pioneers of the World Renewable Energy Network” Award in 2006 and was appointed a Fellow of the Architectural Science Association at their 50th



Annual Conference in 2016. Dr Baird has authored innumerable conference papers and journal articles over the last half century. Major books include: Energy Performance of Buildings; Building Evaluation Techniques; Architectural Expression of Environmental Control Systems; and most recently Sustainable Buildings in Practice, a worldwide survey of sustainable buildings. Still active in his field, he was an invited speaker at the recent World Sustainable Building Conference in Hong Kong and the Passive and Low Energy Architecture Conference in Edinburgh, and is a member of the editorial boards of several journals in the field of architectural science, including Architectural Science Review, Journal of Building Engineering, Intelligent Buildings International, and Buildings.

For further details see: <http://www.victoria.ac.nz/architecture/staff/george-baird.aspx>

Dr Mehrdad Arashpour

Monash University, Melbourne, Australia

Dr Mehrdad Arashpour is the leader of Infrastructure Engineering and Management Program at Monash University. He is undertaking research on robotics, prefabricated structures and processes, Building Information Modelling (BIM), and automation and optimisation of design, manufacturing and assembly. He is one of 13 worldwide members of the Working Commission on Off-site Construction and Infrastructure Task Group established by the International Council for Building (CIB). Dr. Arashpour holds a Doctor of Philosophy in the Built Environment, Master of Construction Engineering and Management and Bachelor of Civil Engineering degrees.



Professor Vivian Tam

Western Sydney University, Sydney, Australia

Professor Vivian W. Y. Tam is the Associate Dean (International) at School of Computing, Engineering and Mathematics, Western Sydney University, Australia. She was nominated to the College of Expert, Australian Research Council (ARC), Australian Government. She received her Ph.D. in sustainable construction from the Department of Building and Construction at City University of Hong Kong in 2005. Her research interests are in the areas of environmental management in construction and sustainable development. She is currently the Editor of Construction and Building Materials and International Journal of Construction Management. She has published over 3 books, 21 book chapters, 248 referred journal articles and 151 referred conference articles. She has been awarded forty-one research grants (totalled over \$8 million), including two ARC Discovery Projects, one ARC Linkage Project and an ARC Research Hub.



Nick Sterling

Callaghan Innovation, New Zealand

Nick Sterling – Business Innovation Advisor and Construction Sector Lead at Callaghan Innovation. With technology changing at an exponential rate, Nick enables NZ construction businesses to identify and maximise the opportunities that those disruptions bring rather than be disrupted by them. Construction is the only sector in NZ where businesses are folding in boom times. Callaghan Innovation is working in collaboration with industry sector partners, including Massey University, to enable construction businesses in NZ to be more resilient, more productive, more collaborative and do more R&D in environmentally sustainable products and systems with a roadmap to more exports. In his previous roles, Nick has held senior



leadership positions in the ICT sector in NZ and the UK, managing large regional channels, national delivery business units and strategic programmes. He has also supported businesses both as a business growth consultant and as a pro bono Business Mentor, turning around ‘at-risk’ local businesses, with some of his engagements featured as case studies on Business Transformation, published in the NZ Chamber of Commerce ‘Innovate’ magazine. Nick has also supported a NZaid economic development programme in 3 Pacific Islands for 4 years to transform businesses, not-for-profits and charities.

SECTION II

Research Papers

Understanding the Factors Critical to Success of PPPs in New Zealand: Public and Private Sector Standpoint

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ABSTRACT

Funding modern day projects in the face of declining public reserve pools has influenced the scale of infrastructure provision. Public private partnership (PPP) emerged as an effective solution for delivering infrastructure in many countries. However, not all projects have been reported successful. Literature suggests that an understanding of critical success factors (CSFs) is imperative to achieving project goals/successes, hence CSFs for PPPs has generated research interests worldwide. However, there is little to no research in this area in New Zealand. To address this gap, this study established a rank-order of CSFs, which could improve the delivery of future PPP projects in New Zealand. 27 CSFs were identified from the review of literature and presented to PPP practitioners, to capture their perceptions in New Zealand. The questionnaire survey was essentially Likert scaled. Findings revealed that “client’s brief”, “sound economic policy”, “approval and negotiation process”, “project’s technical feasibility” and “competitive procurement process” are five top ranked factors overall. A comparison between the perceptions of public and private sector respondents is also drawn to highlight the difference in opinions of these practitioners. The results of the study can assist stakeholders in policy formulation and investment related decision-making.

Keywords: Public private partnerships, Mean value analysis, Critical success factors, Infrastructure

1 Introduction

Infrastructure demand is on the rise with the ever-growing urban population worldwide (Mcnichol et. al., 2015). Governments are struggling to keep up with such high level of investments in infrastructure. Hence, innovative procurement methods, which involve the private sector, have become a necessity to remedy this situation. One such method is public private partnerships, which helps public sector to achieve its goal of infrastructure provision by tapping into resources of private sector. Moreover, it provides private sector an opportunity to capitalize on its investment. Public private partnership is a popular choice for project delivery and has grown in the recent years with a key reason being the unprecedented lack of economic growth all over the world (Kleimeier & Versteeg, 2010). PPP has been utilized to deliver transport,

telecommunication and energy sector projects for infrastructure expansion in numerous cases (Carnis & Yuliawati, 2013). A key reason behind increasing popularity of PPPs worldwide is the execution of numerous successful projects (Hodge & Greve, 2007). It has been used to achieve value for money with the help of private sector involvement in countries like China, UK, Malaysia and Australia (Chou & Pramudawardhani, 2015). In past, provision, improvement and operation of general infrastructure was achieved using public finances. However, after the rise of PPP more recently, public sector is using private sector’s expertise to provide infrastructure (Iossa & Martimort, 2015; Bwanali & Rwelamila, 2017). Private sector is normally engaged through the use of concession contracts for a pre-determined period of time (Ross & Yan, 2015).

The incentive for application of PPP lies primarily in its

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ability to allocate different risks to the project parties (Sastoque et al., 2016). However, if not managed properly, these risks can result in project failure as well. For this reason, PPP is not considered suitable for projects having high amounts of uncertainty and insecurity of cash flows (Blanc-Brude & Makovsek, 2013). It is rarely used for research and development activities, product launching and other possible risk heavy endeavors. So, projects having manageable risks and well-established operating methodologies are ideal candidates for PPP application (Grimsey & Lewis 2007). These risks can be related to different project stages such as conception, planning, construction and operation.

New Zealand government showed its interest in pursuing PPP option for infrastructure development in 2009. Infrastructure Transaction Unit (ITU) was established to streamline the process for PPP implementation (Liu & Wilkinson, 2011). PPP policy published by the government highlighted its intentions to prefer PPP over traditional methods of delivery provided they deliver value for money (Treasury New Zealand, 2015). National Infrastructure Plan issued in 2010, stressed Government's priorities for infrastructure and its willingness to use PPPs across sectors. Mayoral position paper on PPPs, published in 2013, identified PPPs as a viable procurement strategy in New Zealand (EY, 2013).

Hobsonville schools project was the first project procured through "Design, Build, Finance and Maintain (DBFM)" modality of PPP under a concession contract of 25 years in 2012 (Treasury New Zealand, 2018). Since then, ten new social infrastructure projects, including schools and prisons, have been launched and executed, most of which are in operation stage. Furthermore, two road infrastructure projects are in their construction stage (Treasury New Zealand, 2018).

With the increasing popularity of PPPs internationally, a few numbers of areas related to PPP have been researched upon. A considerable attention has been paid to research domains relevant to relationship management, government regulation and guarantees, procurement and legal issues within PPPs (Osei-Kyei & Chan, 2015). A research trend established by Zhang et al. (2016) by systematically reviewing PPP literature in Chinese and international journals revealed PPP success factors as a promising area for research. Ke et al. (2009) also stressed the importance of this area in his study, which established seven major areas for PPP research. It is evident from such indicators that research interest in

this area will only grow, as PPPs are continuously being applied in other markets around the world.

Al-Saadi & Abdou (2016) suggests that critical success factors are considered vital for successful implementation of PPP projects. Various research methods such as interviews, questionnaires and case studies have been used in the past to investigate these CSFs in numerous countries. However, there is little known about these CSFs in countries such as New Zealand which have just began to adopt PPPs. This study aims to address this gap by investigating the factors critical for success of PPP projects in New Zealand perspective.

2 Literature Review

According to Sehgal & Dubey (2019) CSFs are those particular features and activities of a project, which result in its favorable result when followed in execution of the project. The concept of CSFs has been around since the 1970s (Osei-Kyei & Chan, 2015). Its application in numerous areas such as information systems, business services and manufacturing industry has been observed as a managerial tool (Li et al., 2005). Jefferies (2006) argued that these factors have a positive influence on the outcome of the project if managed periodically.

Since the early 1990s, several researchers have applied this idea of CSFs to formulate and understand PPP policy and guidelines (Zhang et al., 2016). A lot of research has been undertaken to identify CSFs in countries such as UK, Australia, China, Singapore, Malaysia, Nigeria and Ghana (Li et al., 2005; Jefferies et al., 2002; Jefferies, 2006; Qiao et al., 2001; Chan et al., 2010; Hwang et al., 2013; Ismail, 2013; Olusola et al., 2012). A range of areas of PPPs from different sectors consisting of various project models within PPP has been explored in these studies. Some of these sectors for which CSFs have been explored by researchers include transportation, power, telecommunication and housing.

Qiao et al. (2001) identified and analysed 27 CSFs of BOT projects in China against different stages of the project. They argued that "stable political and economic situation" needs to be given importance in the evaluation phase of the project. Moreover, factors such as "technical solutions" for tendering stage, "reasonable risk allocation" for award phase, "competent project team" for construction phase and "management control" for operation phase of the project were identified to be important. Similarly, Zhao et al. (2010) investigated 31 success factors for Chinese PPP power projects that were

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delivered using the “build own transfer (BOT)” mode by reviewing relevant literature and carrying out interview with experts.

A recent study by Yang et al. (2017), followed a similar approach in exploring the CSFs for BOT projects in China. Their findings reveal that “reasonable risk allocation”, “government support and guarantee”, “a strong project consortium” and “project technical feasibility” are top ranked important CSFs for BOT project in China.

On the other hand, despite the unique characteristics of PPP projects several studies have also engaged this concept of CSFs for PPP infrastructure projects in general, without specifying sector or project type (Ismail 2013; Chan et al. 2010).

Li et al. (2005) identified 18 CSFs for PPP/PFI projects in the UK construction industry and examined their relative importance using a questionnaire survey. Mean analysis of these factors found “appropriate risk allocation”, “strong private consortium” and “available financial market” to be the most crucial factors. Similarly, for an Australian sports stadium project, Jefferies et al. (2002) identified and examined 15 CSFs, which was delivered using the “build operate own transfer (BOOT)” mode of PPP. “Technical innovation”, “efficient approval process”, “solid consortium” and “good resource management” were found to be the most significant CSFs. The findings suggest that the negotiation process plays a key role in project success.

Following Li et al. (2005) 18-CSF list, Chan et al. (2010) explored this concept in People’s Republic of China. An empirical questionnaire survey instrument was employed to solicit the views of Chinese PPP experts. They employed factor analysis technique to group these factors into clusters which are, “macroeconomic stability”, “shared responsibility between public and private sectors”, “transparency in procurement”, “stability in political and social atmosphere” and “informed government”. They further concluded that the factor group “stable macroeconomic environment” is very critical due to rapidly changing global financial situation. Ismail (2013) also adopted the same methodology to study these CSFs in Malaysian PPP projects.

Following the New Zealand government’s decision to pursue PPP as a procurement model, Liu and Wilkinson (2011) investigated the barriers and drivers for its adaptation in New Zealand’s perspective. They used semi-structured interviews with PPP experts to investigate these issues. Some of the drivers in their findings are also

the key critical success factors highlighted in a number of international critical success factors studies, namely, better risk allocation and whole of life cost savings.

Asquith et al. (2015) studied the effect of political influence on PPP health sector project in New Zealand. They conducted an exploratory study to identify the critical success factors for partnerships contracts in the health sector. Their findings suggest that clear contractual relationships, commitment and trust play key roles in determining the success of these partnerships. Furthermore, private sector respondents showed their concern about reforms in the political process, which dictates their decisions about entering into these partnerships.

Although several previous studies address CSFs related to PPP in international literature, studies focusing this area in New Zealand’s context remain sparse. Moreover, due to distinctive characteristics of PPP to a country require a study on CSFs specifically for PPP in that country. Hence, this present study fills the gap by investigating the CSFs for implementation of PPP in New Zealand. The factors noted above from the most prominent studies have been extracted into 27 CSFs, as shown in Table 1.

Table 1: List of CSFs identified from literature

Critical Success Factors	References								Total
	1	2	3	4	5	6	7	8	
Appropriate risk allocation	*	*	*	*	*	*	*	*	8
Strong private consortium	*	*	*	*	*	*	*	*	8
Favourable legal framework	*	*		*	*	*	*	*	7
Transparency in procurement	*	*	*	*	*	*		*	7
Political support	*	*	*	*		*	*		6
Strong and committed public authority	*			*	*	*	*	*	6
Risk sharing	*			*	*	*	*		5
Adequate financial market	*		*	*		*	*		5
Stable macroeconomic conditions	*			*		*	*	*	5
Credible cost benefit	*			*		*	*	*	5

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analysis									
Social support	*		*	*		*		*	5
Government guarantees	*		*	*		*		*	5
Commitment and responsibility	*	*		*		*			4
Sound economic policy	*			*		*		*	4
Shared authority	*				*	*		*	4
Sound governance	*		*			*		*	4
Multipurpose project targets	*			*		*		*	4
Competitive procurement	*		*			*			3
Project's technical feasibility	*		*					*	3
Client's brief		*	*						2
Innovation/Project complexity							*		1
Approval and negotiation process		*							1
Environmental impact		*							1
Community support		*							1
Business diversification			*						1
Credit rating of investors		*							1
Availability of suitable financier		*							1

References: 1 = (Li et al., 2005); 2 = (Jefferies, 2006); 3 = (Chan et al., 2010); 4 = (Ismail, 2013); 5 = (Hwang et al., 2013); 6 = (Chou & Pramudawardhani, 2015); 7 = (Al-Saadi & Abdou, 2016); 8 = (Yang et al., 2017)

3 Methodology

This study followed a three-step approach. In the first step, 27 CSFs were identified by reviewing PPP literature. A 5-point Likert scale questionnaire survey was conducted in the second step, which gathered the opinions of PPP practitioners working in New Zealand concerning the importance of the identified factors. In the last step, mean score of factors was used to ranked them which indicated their relevant importance and draw a comparison between the perceptions of public and private sector individuals. The top five factors were selected for discussion.

As stated above, the 27 critical success factors identified

from existing literature (table 1) have received recognition from several researchers. These factors were examined using a five-point Likert scale questionnaire survey. Many other studies have utilized similar kind of scale in the area of construction management (Li et al., 2005; Chan et al., 2010; Ismail, 2013; Yang et al., 2017).

The survey measured the opinions of PPP professionals from public and private sectors in New Zealand regarding CSFs for PPPs. The complete questionnaire comprised two parts. The first part contained questions about the respondents' individual profiles and the second part surveyed the respondent's level of agreement against each of the identified CSFs. Questionnaire was pre-tested with the help of three academic and PPP professionals, before the start of data collection. Their proposed changes were incorporated in the questionnaire to help the respondents understand questions better.

The questionnaire survey was administered through Survey Monkey in July, August and September 2019 among New Zealand practitioners with involvement in PPP projects. Convenience sampling method was adopted to gather responses. Initial set of respondents were approached from an on-going PPP project. Considering the level of experience of these individuals in PPP scene, it was expected that they had connections with other potential respondents also, hence, some of the them were asked to distribute the survey form link to their peers as well.

The data was analysed using mean value analysis (MVA) and based on calculated mean scores, ranking of CSFs was generated. This method has been used by several studies in the past to analyse similar kind of data (Ismail 2013; Hwang et al., 2013). MVA is considered an acceptable method for ranking factors (Chou & Pramudawardhani, 2015). Cronbach's alpha using SPSS was calculated to check the reliability of the data. Cronbach's Alpha value was 0.916 suggesting high reliability of the data.

4 Findings and discussion

A total of 58 responses were received through Survey Monkey. It was anticipated that some respondents might not be familiar with all the success factors identified from literature. To remove any bias from the data obtained from the survey respondents, an additional 'no idea' option for each question was included. Moreover, to safeguard the quality of the data, 12 responses were excluded from the analysis for their incompleteness.

Basic information gathered from the first section of

questionnaire is presented in Table 2. Most of the respondents belong to the private sector. Out of the total 46 valid responses, 32 belong to the private sector and 7 from public sector. About half of the private sector respondents have gained their PPP experience working with the main contractor. Low response rate from public sector is consistent with previous studies in similar area (Chan et al., 2010; Ismail, 2013). Moreover, public private partnership tends to involve more private sector individuals as the public sector’s role is mostly limited to serve as a facilitator in these kind of partnerships. Only 15% of the respondents have PPP work experience of more than 15 years. This could be due to the relatively new nature of PPPs in New Zealand. However, almost half of the respondents have experience of more than 5 years. In addition, 43% of the respondents have also worked on PPP project outside New Zealand.

Table 2: Basic information of survey participants

Item	Type	N	(%)
Public	Central government	5	11
	Local government	2	4
Private	Main contractor	19	42
	Consultant	5	11
Others	Subcontractor	8	17
		7	15
			100
Position	Project Director	4	9
	Construction Manager	3	7
	Project Manger	11	24
	Project Engineer	5	11
	Quantity Surveyor	4	9
	Planning Engineer	3	7
	Others (Supervisor, Contract administrator, Area manager etc.)	16	35
			100
Experience	upto 5 years	24	52
	5-10 years	10	22
	11-15 years	5	11
	Over 15 years	7	15
			100
Country	New Zealand	26	57
	Australia	7	15

	UK	4	9
	Ireland	2	4
	Others	7	15
			100

4.1 Ranking of Critical Success Factors (CSFs)

Mean value analysis of the survey responses for the identified CSFs is used to rank factors in order of their importance. Overall mean scores for these factors range from 3.50 to 4.137 as shown in Table 3. There isn’t much difference in the range of mean values of public and private sector respondents from the overall mean score. The results indicate that all the factors identified are deemed important by the survey respondents. However, 14 out of 27 factors are above the mean score of 4 which are considered more important than others.

The top five important factors based on respondent’s perception are client’s brief, sound economic policy, approval and negotiation process, project’s technical feasibility and competitive procurement process. A brief discussion of some of these factors is provided in the following paragraphs.

Client’s brief, with an overall mean value of 4.137 is the most important CSF in New Zealand’s perspective. A client’s brief helps in clear communication of public sector requirements which play a vital role in the success of PPPs (Cheung et al., 2012). Sound economic policy was rated as the second most important factor for successful implementation of PPPs in New Zealand by the survey participants.

Approval and negotiation process and project’s technical feasibility are both identified as the third most important factor for success of PPP projects in New Zealand. These factors have received considerable attention from PPP practitioners in other countries as well. Li et al. (2005) in his study for PPP CSFs for UK construction industry ranked project’s technical feasibility at sixth position. PPP tend to have a complex approval and negotiation process (Li et al., 2005). Jefferies (2006) identified this factor to be crucial for success in his case study of Australian Super Dome project. He argued that it can help identify key issues to be resolved at the early stage. Project company’s ability to effectively handle the technical aspects play an important role in winning the contract (Chan et al. 2010).

Competitive procurement process is ranked fifth by the participating respondents with an overall mean value of 4.08. Li et al., 2005, identified this factor as the most

important factor in opinion of the public sector respondents.

Surprisingly, the success factor ‘Macroeconomic stability’ has not gotten much attention from the respondents and ranks last in the table above. In Chan et al. (2010) ranking of CSFs it was ranked fourth. Li et al 2005 also emphasized the importance of favourable economic condition for successful execution of PPP projects. New Zealand enjoys a stable economy (OECD, 2019), which is one of the potential reasons for this factor’s low importance in respondents’ point of view.

inventive techniques (Cheung and Chan, 2010). As public sector is considered to be reluctant in adopting to innovation, from their perspective the second rank of this factor is somewhat justified. Strong private consortium have also been identified as the top ranked factor in some previous studies (Li et al., 2005; Chan et al., 2010).

5 Conclusion

PPP has emerged as an innovative way of procuring public infrastructure projects. Private sector expertise and finances are used for provision of a project or service under long term contracts. These long-term contracts and

Table 3: Mean scores and ranking of factors

Critical Success Factors	Mean Score			Rank		
	Overall	Private	Public	Overall	Private	Public
Client's Brief	4.137	4.146	4.182	1	1	12
Sound Economic Policy	4.10	4.102	4.092	2	2	14
Approval and Negotiation Process	4.096	4.097	4.091	3	3	15
Project's Technical Feasibility	4.096	4.073	4.08	3	7	9
Competitive Procurement	4.08	4.077	4.091	5	4	17
Availability of Financier	4.08	4.051	4.182	5	8	11
Strong Public Agency	4.078	4.075	4.091	7	5	18
Realistic Cost-Benefit Analysis	4.076	4.024	4.273	8	10	6
Multi-purpose Objectives	4.04	4.0	4.20	9	11	7
Committed Public and Private Sectors	4.039	4.024	4.10	10	9	13
Good Governance	4.019	4.075	3.818	11	6	23
Innovation/Project Complexity	4.00	3.902	4.364	12	15	2
Appropriate Risk Allocation	4.00	3.90	4.364	12	16	3
Transparent Procurement Process	4.00	3.951	4.181	12	12	10
Favorable Legal Framework	3.98	3.923	4.182	15	14	8
Environmental Impact	3.91	3.925	4.091	16	13	16
Government Guarantees	3.967	3.838	3.81	17	18	22
Risk Sharing	3.923	3.829	4.272	18	19	5
Strong Private Consortium	3.885	3.902	4.40	19	17	1
Shared Authority	3.843	3.732	4.363	20	22	4
Community Support	3.807	3.781	3.91	21	20	20
Political Support	3.788	3.78	3.82	22	21	21
Social Support	3.72	3.70	3.8	23	24	22
Adequate Financial Market	3.714	3.717	3.7	24	23	25
Credit Rating of Investors	3.557	3.43	4	25	27	19
Stable Macroeconomic Conditions	3.54	3.53	3.54	26	25	26
Business Diversification	3.50	3.43	3.4	27	26	27

Innovation and project complexity, and strong private consortium are perceived as top two most important CSF by the public sector participants in this study. Solving complex project issues using innovative methods is one of the strong suits of private sector. It is one of the key reasons for private sector involvement in provision of public infrastructure as public sector often lacks the use of

complex arrangements can cause many issues during this process. Success of the project is dependent on many factors which if managed properly can lead to positive results.

This study examined the relevant critical success factors of PPP in New Zealand and ranked them in order of their importance. The findings show that all factors have a

mean score of 3.50 and above which indicate that they were somewhat significant in PPP practitioners' views. Some of the top ranked factors are client's brief, sound economic policy, approval and negotiation process, project's technical feasibility, competitive procurement process and strong private consortium.

In future, as more responses are collected from public and private sector participants, factor analysis technique will yield useful factor groupings. Moreover, comparison between the perceptions of public and private sector parties can be improved by gathering more responses from public sector to generate some useful insights.

There are some limitation to this study. Firstly, the CSFs are collected from the literature in general and from international PPP experience in other countries, some of which might not reflect a true representation of New Zealand. Secondly, all of the identified CSFs may not apply to all the PPP projects due to their generic nature. A project specific context, such as PPPs in social or road infrastructure, may be investigated in future. Lastly, similar studies can be conducted using a different research instrument such as case study or interviews to highlight the opinions of the practitioners.

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Study on Stakeholders' Responsibilities in Construction and Demolition Waste Management in China, Germany and the Netherlands

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ABSTRACT

Owing to large-scale urbanization and increasing population, an overwhelming amount of construction activities has been resulted in large generation of construction and demolition waste in China. While Chinese government has promoted a great set of policies to address this issue, the existing policies appear to be limited effective. Germany and the Netherlands have the most advanced construction and demolition waste management practices among Europe, as involving in waste recycling and other recovery operations for decades. Participation of stakeholders is critical to the success of construction and demolition waste management, maintaining sustainability of recycling chain. Germany and the Netherlands have developed an integrated recycling cycle with involvement of every stakeholder. However, responsibilities of related stakeholders in the recycling chain are not well demonstrated in China. This paper reviews the existing policies, standards and official documents concerning construction and demolition waste management in China, Germany and the Netherlands, with focus on related stakeholders' responsibilities. Comparative analysis is conducted to compare regulations on stakeholders' responsibilities and analyze unsatisfied performance of construction and demolition waste management in China. The findings demonstrate that incomplete knowledge on stakeholders' responsibilities, and ineffective cooperation between governing bodies would be associated with inadequate practices of the waste management in China. The findings are expected to assist Chinese governing bodies to learn from Germany and the Netherland, and to improve efficiency in construction and demolition waste management by completing stakeholders' responsibilities.

Keywords: Construction and demolition waste; Comparative analysis; China; Stakeholders;

1 Introduction

A large amount of construction and demolition waste is resulted from rapid development in construction industry (Nagapan, Abdul Rahman, & Asmi, 2012). China is the biggest generator of construction and demolition waste around the world, with annual generation of 2.4 billion tonnes in 2015 (Duan, Miller, Liu, & Tam, 2019). The total volume of the waste generated in China is forecasted to be 3.96 billion tonnes by 2020 (China Association of Circular Economy, 2018). Construction industry in Australia generated a total of 19 million construction and demolition waste during the period of 2008 to 2009 (Hyder Consulting, 2011). In 2016, the waste generated by European Union amounted to 912 million tonnes, constituting 34.6% of total waste from economic activities

and household (Eurostat, 2017). Specifically, with 222.8 million tonnes generated in 2016, construction and demolition waste is considered as one of the significant waste streams in Germany (Federal Statistical Office (Germany), 2019). According to the Korea Waste Association (2018), the total volume of construction and demolition waste is estimated to be 196,262 tonnes per day in 2017, comprising 47.3% of the solid waste in South Korea.

The development of global construction industry continues to grow, as construction activities could contribute to growth in economy, creation of wealth and improvement in living quality (Razak Bin Ibrahim, Roy, Ahmed, & Imtiaz, 2010). The large generation of

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construction and demolition waste could be associated with many factors, including large-scale urbanization (Zehai, Yunxiang, & Cong, 2018), rapid population growth, regional planning, and local policies (Duan, Wang, & Huang, 2015). However, without proper management, massive construction and demolition waste has inevitably occupied land resources and destructed habitat (Nagapan et al., 2012), because large amount of the waste is dumped or landfilled in useful lands (Bravo, de Brito, Pontes, & Evangelista, 2015). Considering the negative effects on environment from increasing volume of the waste, effective and proper treatment is in urgent need. It is generally agreed that principles of reduce, reuse and recycle could contribute to a sustainable future (Huang, Wang, Kua, & Geng, 2018). Contribution from waste management is positive and distinctive, compared with traditional treatments, such as landfilling (Huang et al., 2018). Proper management in construction and demolition waste is expected to promote efficient use of resources (Balachandra, Kristle Nathan, & Reddy, 2010), reduction of primary material utilization and avoidance of landfilling (European Commission, 2016).

However, construction and demolition waste management in China is far away from these high-performance countries. China currently produces the largest amount of construction and demolition waste around the world, but the average recovery rate of the waste is only about 5% in 2017 (Huang et al., 2018). Some studies have discussed the most critical factors attributed to inefficient practices of construction and demolition waste management in China, including unachievable targets (China Association of Circular Economy, 2016; Qiufei Wang, Wang, & Li, 2015), limited recycling businesses and facilities (Akhtar & Sarmah, 2018), cheap landfill costs (Huang et al., 2018), uncontrolled dumping (Yuan, 2017), and under-developed market for recycled building materials (China Association of Circular Economy, 2018). Specifically, inadequate regulations on related stakeholders could be one significant factor (Yuan, 2013). Participation of related stakeholders in the success of construction and demolition waste management is critical (Oppong, Chan, & Dansoh, 2017; Yuan, 2017), because participation of stakeholders is expected to maintain the recycling chain and deliver a sustainable environment.

Germany and the Netherlands are advanced in construction and demolition waste management. These

two countries have developed an integrated recycling cycle with involvement of every stakeholder each playing out their roles in maximizing the value of the management (German Federal Government, 1994; Ministry of Infrastructure and Water Management (the Netherlands), 1979). European countries largely correspond to European Union legislations and subjects to Waste Framework Directive, which requires member states to achieve 70% recycling rate of construction and demolition waste before 2020. By 2010, only 6 countries had fulfilled the target, including Germany and the Netherlands (BIO Intelligence Service, 2013). Addition to high recovery rate, generation of construction and demolition waste (exclude soil) in Netherlands and Germany are high (Table), compared with other European countries, such as 3.88 million tonnes produced in Denmark (Deloitte, 2015a), 10 million tonnes in Austria (Eurostat, 2019; Federal Ministry for Sustainability and Tourism (Austria), 2017) and 1 million tonnes in Ireland (Deloitte, 2015c). Previous literatures have conducted analysis on construction and demolition waste management in some developed countries, such as Japan (Amemiya, 2018; Nitivattananon & Borongan, 2007; Sakai et al., 2011; Yolun, 2015), Europe (Galvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl, 2018; Iacoboaea, Aldea, & Petrescu, 2019; Menegaki & Damigos, 2018; Sakai et al., 2011; Tam & Lu, 2016). Singapore (Bai & Sutanto, 2002; Chew, 2010; Nitivattananon & Borongan, 2007) and South Korea (Sakai et al., 2011; Yang, Park, Park, & Seo, 2015). However, previous literatures which evaluate construction and demolition waste management with the focus on stakeholders' responsibility is limited.

Table 1: Generation and recovery rate of construction and demolition waste in China, Germany and the Netherlands.

Countries	Generation	Recovery rate (%)	References
Germany	82.2	88%	(Deloitte, 2015b)
Netherlands	25.71	98%	(Deloitte, 2015d)
China	1930	5%	(China Report, 2019; Huang et al., 2018)

This paper will conduct comparative analysis on construction and demolition waste management practices in China, Germany and the Netherlands, with focus on related stakeholders' responsibilities. Based on the comparison, this paper aims to provide recommendations from experiences of Germany and the Netherlands for Chinese policy makers, in order to formulate a proper

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waste management on related stakeholders. In order to achieve the research objectives, following methodologies are adopted. A thorough review of existing policies, standards and official documents related to stakeholders' responsibility would be conducted. In addition, comparative analysis would be conducted to investigate the performance gap between China and other two countries.

2 Policies on stakeholders' responsibilities in construction and demolition waste management

2.1 China

China is experiencing a rapid economic development, and achieving up to 9.8% annual growth in GDP (J. Wang, HongpingYuan, Kang, & Lu, 2010). With a large amount of construction activities, the construction sector consumes nearly 40% of world consumption of cement and steel (J. Wang et al., 2010). Furthermore, repeated construction and short life spans of buildings in China have been blamed for causing large volumes of construction and demolition waste (Qian Wang, 2010). The average life-span of China's residential buildings is 30 years, which is much shorter than that of developed countries, such as 74 years in United States and a 102-year average lifetime in France (Cai, Wan, Jiang, Wang, & Lin, 2015). Most of construction wastes in China are still directly dumped or landfilled.

The idea of recycling is not new in China, but construction and demolition waste has not been utilized efficiently. While some Chinese cities have achieved higher recovery rates than the average value, such as 20% in Shanghai and 16% in Shenzhen (Ghisellini, Ji, Liu, & Ulgiati, 2018), these numbers are much smaller than that of developed countries. From 2015, the Chinese Government promoted environmental production as a priority policy (China Concrete and Cement-based Products Association, 2018). A set of policies regarding environmental protection have been introduced, restricting the mining of origin materials to create markets for recycled building materials. Consequently, the restriction of mining will cause the price of natural construction materials in several areas to increase (China Cement Association, 2018). Construction industries might turn to recycled products to replace origin materials.

In recent years, the Chinese government spent a great

effort to encourage construction and demolition waste management. Issue of Plan for Comprehensive Utilization of Solid Waste (2011), Green building plan (2015), Circular Development Plan (2017) and Notice of Experimental programs on Construction Waste Management (2018) aims to reduce the waste from designing, extend recycling scale and promote development of recycling technology. While documents related stakeholders' responsibilities were issued by governing bodies, such as National guideline, regulations for construction waste management in cities (1996) and Responsibility of the construction waste recycling department (2010), regulations on related stakeholders are insufficient. Chinese policy makers emphasize burden on governmental departments and ignored responsibilities of related parties, such as collectors, transporters and recyclers. However, the cooperation between governmental departments are not efficient (Huang et al., 2018). The duties of departments overlap and are unclear (Qiufei Wang et al., 2015). China needs to seek an efficient regulation on stakeholders, to trigger involvement of all related stakeholders and to overcome overlapping of responsibilities and functions among different governmental departments (Zhang, Tan, & Gersberg, 2010).

The Chinese existing policies on construction and demolition waste management related to stakeholders' responsibilities are listed in Table 2.

Table 2: Policies related to stakeholders' responsibilities in Chinese construction and demolition waste management.

Ref	Laws enacted	Year	References
C-1	National guideline, regulations for construction waste management in cities	1996	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 1996)
C-2	Regulations on urban construction waste management	2005	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2005)
C-3	Responsibility of the construction waste recycling department	2010	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2010)
C-4	Green building plan	2013	(General Office of the State Council of the People's Republic of China, 2013)

2.2 Germany

A set of European standards controls construction and demolition waste management, binding all member states in the European Union (Sáez, Merino, & Porrás-Amores, 2011). The main policy driver for the management in Europe could be Waste Framework Directive. The broad estimation of the average construction waste recycling rate in Europe is around 46% (BIO Intelligence Service, 2013), as recycling rates vary greatly across the European countries for geographical, cultural and political reasons. However, some European countries have already recycled all suitable construction and demolition waste, and fulfilled the target (European Aggregates Association, 2012).

Germany has the most advanced construction and demolition waste management practices among Europe (Deloitte, 2015b). High quantities of construction and demolition production were reported in this country (BIO Intelligence Service, 2013), with 82.2 million tonnes in 2016 (exclude soil) (Federal Statistical Office (Germany), 2019). Germany has been involved in conserving natural resources through recycling and other recovery operations for decades. At present, waste recovery rate in Germany is one of the highest in the world, with up to 88% (Kuehlen, Thompson, & Schultmann, 2014), while the number was 17% in 1994 (Merino, Gracia, & Azevedo, 2010).

The introduction of Acts for promoting closed substance cycle waste management and ensuring environmentally compatible waste disposal (1994) turns the waste management into resource management, as recycled aggregate could be used for concrete production in the structural engineering sector (Jeffrey, 2011; Weil, Jeske, & Schebek, 2006). This act was further developed based on the European Union Waste Framework Directive in 2010. Basic obligations on related stakeholders to avoid waste production are strengthened in closed-substance cycle waste management. For instance, waste producers are required to pursue high-quality and appropriate recovery methods, accordance with its types and natures. In addition, waste disposal should be compatible with the public interests, and take place within the country. The federal government is responsible to ensure safe recovery, including placing restrictions on certain waste, mandating requirements of separation, transport and storage of waste, and supervising the performance of waste

producers. The federal government is in charge of delivering licenses for collectors and transporters and responding to questions from related parties. Existing policies on stakeholders' responsibilities in German construction and demolition waste management are listed in Table .

Table 3: Policies related to stakeholders' responsibilities in German construction and demolition waste management.

Ref	Laws enacted	Year	References
D-1	Act for promoting closed substance cycle waste management and ensuing environmentally compatible waste disposal	1994	(German Federal Government, 1994)
D-2	Waste catalogue ordinance	2001	(Federal Ministry of Justice (Germany), 2011)
D-3	Ordinance simplifying landfill law	2009	(German Federal Government, 2009)
D-4	Ordinance on the management of municipal solid waste and certain construction and demolition waste	2017	(Federal Ministry of Justice (Germany), 2017)

2.3 Netherlands

Requirements in the Waste Framework Directive were implemented to the Netherlands, with at least a 70% recovery rate of construction and demolition waste requirement to be satisfied before 2020. However, the Netherlands has already surpassed the requirement, with 100% of construction and demolition waste recovered in 2016 (Eurostat, 2019). In addition, construction and demolition waste management in the Netherlands is presented to be effective, integrated and matured (Brantwood Consulting, 2016), with a high recovery rate maintained for decades.

The 12 provinces of the Netherlands are responsible to adapt national policies made by ministers into a regional context, including regional policies and plans (European Union, 2018). Ministers, provinces and municipalities have powers to grant exemptions from certain prohibitions. For example, if there are temporarily no other processing options for certain wastes which the landfill ban is applied to, the government would grant exemptions from the ban. Quarterly reports from waste collectors and waste processing companies are obtained,

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in order to monitor disposal (BIO Intelligence Service, 2013). The Netherlands enacts strict regulation on related stakeholders. Waste could only be processed by companies who are authorized. Any collectors, transporters, recyclers and operators of landfills must register in the National and international road transport organization and then be included in the official list.

Information on the existing policies related to stakeholders' responsibilities in the Netherlands (Table 4) have been sourced from the Ministry of Infrastructure and Water Management, Royal Netherlands Standardization Institute and Netherlands Enterprise Agency.

Table 4: Policies related to stakeholders' responsibilities in construction and demolition waste management in the Netherlands.

Ref	Laws enacted	Year	References
N-1	Environmental protection act	1979	(Ministry of Infrastructure and Water Management (the Netherlands), 1979)
N-2	National waste plan 3 (LPA3)	2017	(Ministry of infrastructure and Water Management (the Netherlands), 2017)
N-3	Registration of waste transporters, collectors, dealers and brokers	2019	(Netherlands Enterprise Agency, 2017)
N-4	Landfill in the Netherlands	2019	(Ministry of Infrastructure and Water Management (the Netherlands), 2019)

3 Comparison on policies

3.1 Incomplete knowledge on stakeholders' responsibilities

Participation of other related stakeholders is critical in the recycling of construction and demolition waste (Yuan, 2017). However, general responsibility of various relevant stakeholders involved in construction and demolition waste recycling activities is not well defined in China (Table). Although contractors' responsibilities to formulate plans on waste disposal are specified in C-1 (S-8), straightforward procedures for how to recycle are not involved in legal grounds. Contractors' full responsibility for waste produced is strengthened in all the countries. However, recycling is still not considered as the first choice for contractors to dispose waste, due to low landfill charging fee (Huang et al., 2018). Responsibilities of other related parties, such as collectors, transporters, recyclers

and operators of landfill sites are not demonstrated.

Flow charts for the processing waste among related stakeholders in Germany and the Netherlands are demonstrated in Figure 1. The two countries have concerned all the related stakeholders in the recycling chain, including contactors, collectors and recyclers. Depart from duty on waste disposal, waste reduction from design (S-7) and waste deliver to an authorized company (S-11) is an important part of the contractors' responsibility. Specifically, in Germany, legal regulations require contractors to take into account the efficiency of demolition of materials and technology selection in a building design (S-7) and undertake construction work in a safe and environmental manner. The concept of product responsibility is introduced in Germany, for which the suppliers of building materials should use recycled building materials or recoverable waste (S-24), consider waste generation during production as well as subsequent use and recycling (S-23). Consumers are encouraged to protect, maintain and extend lifespan of buildings in Germany (S-25). Registration of collectors (S-14), transporters (S-26) and recyclers (S-17) are mandatory in the recycling process. In the Netherland, collectors, transporters and recyclers must register with the National and international road transport organization and be included in the national list. In order to be able to register, related stakeholders must demonstrate liability to present a good conduct. Moreover, in Germany (S-20), visual inspection and assessment on construction and demolition waste is necessary to control and assure the quality of waste for recycling and determine if the waste is capable of being recycled or otherwise sent landfilled. Figure 2 demonstrated related stakeholders' responsibilities in China. However, there is a lack of an intermediate link in the recycling chain, between waste generation and use of recycled materials. Recycling is not considered as a prior waste treatment. Therefore, duties of related parties are not completed and represented in Chinese regulations on construction and demolition waste management.

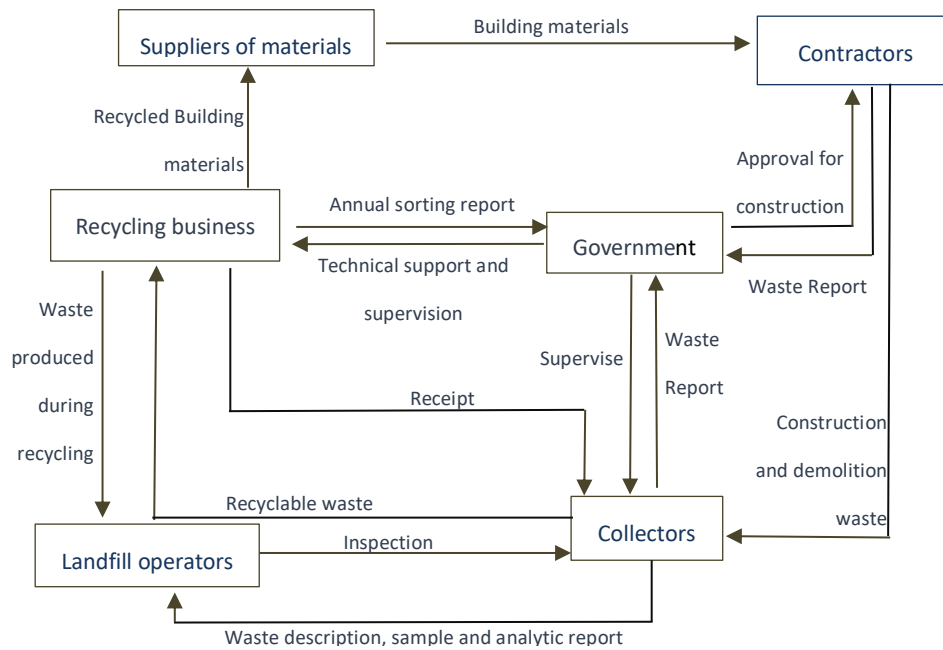


Figure 1: Responsibilities of related stakeholders in Germany and the Netherlands

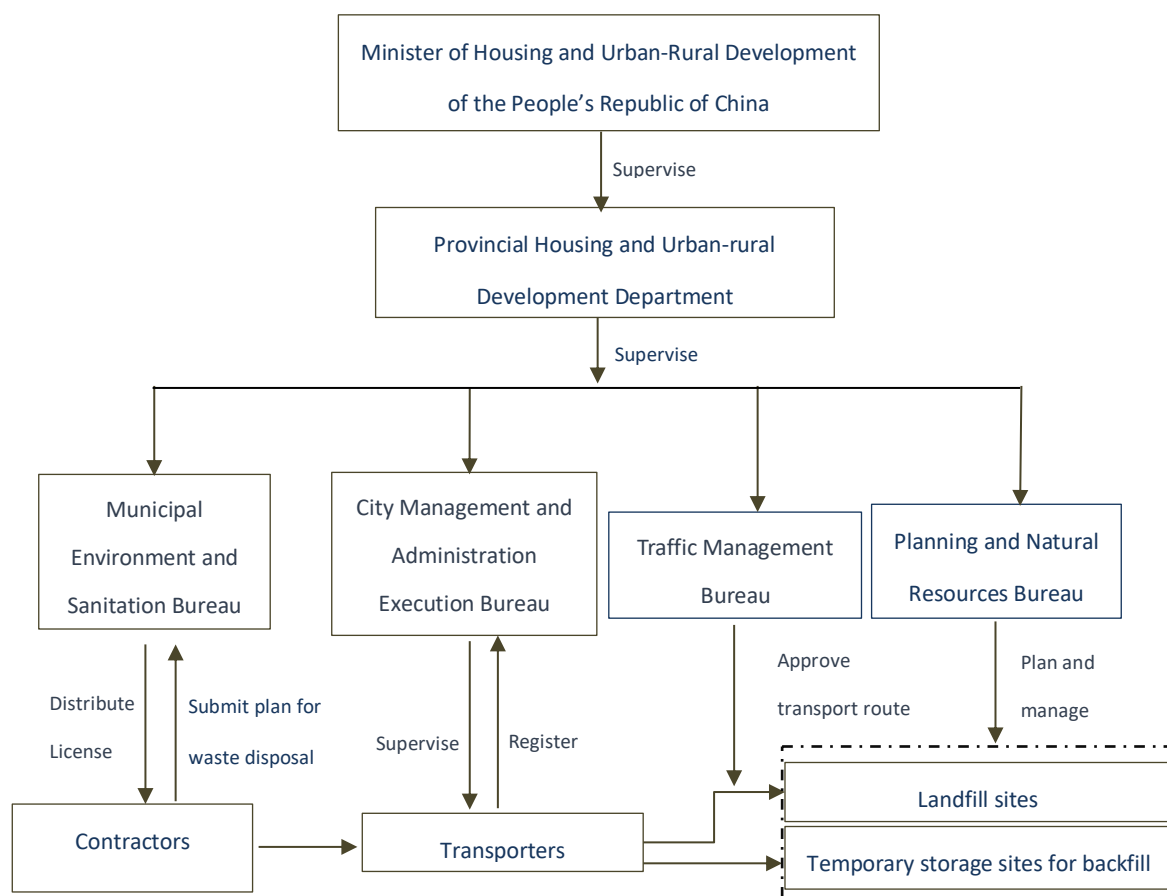


Figure 2: Responsibilities of related stakeholders in China

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3.2 Ineffective cooperation between governing bodies

Responsibilities on different levels of governments are determined in C-1 and C-8 (S-1, S-4, S-5). Similar to other Germany and the Netherlands, Chinese central government makes important decisions on behalf of the country and is given the responsibility of drafting national waste management plans with greatest priority. A national plan would further form the basis of legislation. Provinces are responsible to translate these basic policies into regional contexts, and municipalities take actions for proper waste management that are compatible with these regulations. Besides, technical assistance from central governments to lower governments is provided in Germany and the Netherlands (Figure 1), to effectively turn waste into resources and additionally ensure a safe operation. Although some regulations are adopted in China, the practices of construction and demolition waste management vary across the regions. Some Chinese cities have achieved higher recycling rate than the average value, such as Shanghai with 20% recycling rate and Shenzhen with 16% (Ghisellini et al., 2018). As indicated by Figure 2, governing bodies of 3 levels help to implement construction and demolition waste management in China, with focus on four departments of municipal levels involved in the present construction and demolition waste disposal. Construction and demolition waste management at the city level is within responsibility of Municipal Environment and Sanitation Bureau (Huang et al., 2018). The Traffic Management Bureau is in charge of planning waste transporting route, while management of transporters is under supervision of the Administration Execution Bureau. The Planning and Natural Resources Bureau formulate plans and management on landfill sites and temporary storage sites (Figure 2). However, whether efficient culture of cooperation among departments could be achieved still remains unseen (Huang et al., 2018). According to Table , China could enrich responsibilities on governments of different levels from experiences of Germany and the Netherlands. The central government in Germany and Netherlands implemented recycling into culture, and defines requirement for waste facilities to standardize recycling process.

Table 5: Comparison on stakeholders' responsibility.

Stakeholders' responsibilities		Ref	China	Germany	The Netherlands
Central government / Federal government / Minister	National guidance on waste management	S-1	C-1, C-3	D-1	N-1
	Promote related technology	S-2		D-1	
	Defines requirement for waste facility	S-3		D-1	
Prefectural government / States/ Provinces	Proper waste management in administrative area	S-4	C-1	D-1	N-1
Municipalities	Take actions for proper management	S-5	C-1, C-3	D-1	
	Follow national policies	S-6	C-1	D-1	
Main contractors / waste producer / waste holders	Reduce waste from design	S-7		D-1, D-3, D-4,	
	Make and submit construction, recycling and disposal plan	S-8	C-1, C-2, C-4		N-1
	Use recoverable or recycled building materials	S-9		D-1	
	Manage waste for whole life cycle	S-10	C-4	D-1, D-3	N-1
	Deliver waste to authorized disposal companies	S-11		D-1	N-3
	Separate collection	S-12		D-1, D-2, D-4	N-1, N-2
	Report information of waste	S-13		D-1, D-4	N-1
	Registered	S-14			N-1, N-3
Waste collectors	Proper demolition	S-15		D-1, D-4	

	work				
	Records on waste	S-16		D-1	
Recycling businesses	Registered	S-17			N-1, N-3
	Proper, safe and high-quality recycling	S-18		D-4	
	Records on waste	S-19		D-1	N-1
Operators of landfill site	Acceptance inspection on waste	S-20		D-3	
	Arrange the organizations of landfill sites	S-21		D-3	
	Records of waste	S-22		D-3	N-4
Suppliers of materials	Products designed for reducing waste	S-23		D-1	
	Use recycled products	S-24		D-1	
Consumers	Proper maintenance	S-25		D-1	
Transporters	Registered	S-26			N-1, N-3
	Record data on waste	S-27		D-1	N-1, N-3

4 Recommendations

China should consider strategies in Germany and the Netherlands and pursue a proper construction and demolition waste management, which involves all key stakeholders.

A national standard and legislation on construction and demolition waste should be released to establish an integrated recycling chain, in order to fulfil the blanks of recycling in the recycling chain. Waste generators should be required to be responsible for the full life cycle of the waste and take technology and material selection into account. Besides, a construction and disposal plan should be formulated by contractors and approved by governing bodies in administrative areas. Contents of responsibilities of collectors, transporters and recyclers could be fulfilled to ensure their operations in accordance with the guidelines. In order to better improve management efficiency, every stakeholder in the supply chain should be required to keep waste records. Waste generators should be required to submit information of waste description (such as waste class, appearance, amount and following

treatment). Transporters should check the waste class and record drop-off location. Recyclers and operators of landfill sites should carry visual inspection on waste and evaluate whether the waste could be lawfully accepted. In addition, Chinese government could move beyond voluntary use of recycled products and impose obligatory recycling content in building materials, increasing percentage of recycled building materials in market shares.

However, not all the strategies would be suitable to be applied to China. Evaluation on advantages and disadvantages should be adopted through actual practices.

5 Conclusion

This paper compared existing policies, standards and official documents concerning stakeholders' responsibilities in construction and demolition waste management in China, Germany and Netherlands. Comparative analysis was conducted to compare regulations on stakeholders' responsibilities in these three countries and analyze unsatisfied performance of construction and demolition waste management in China. The findings demonstrate that incomplete knowledge on stakeholders' responsibilities, and ineffective cooperation between governing bodies would be associated with inadequacy definition of stakeholder's responsibilities in Chinese construction and demolition waste management. By understanding these challenges, this study could further help China to develop proper policies to enhance the waste management.

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Information Technology Applications in Construction Organizations: A Systematic Review

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ABSTRACT

The construction industry has traditionally lagged other industries in technology adoption. However, in recent years, driven by the pressure to improve productivity, reduce costs, improve safety and increase sustainability, there is growing momentum to introduce new technologies into the construction sector. A large amount of research has been devoted to the technology application in different industries. However, few scholars have attempted to summarize and review the depth and breadth of these studies, especially in the Information Technology applications and its effect on Construction Organizations. This paper fills this gap via a systematic and quantitative review in the construction information technology field. Based on that, the main aim of this study is to investigate the state-of-the-art and trends of information technology in collaborative working in construction. To achieve this aim, a manual review as well as the systematic analysis method, relevant literature was reviewed; and classified from high impact sources to construct the knowledge map and comprehensive framework for Information Technology in Construction. Accordingly, the boundary of information technology applications in construction organizations can be defined as construction productivity, construction IT, construction technology, IT impact on construction, construction organizations, and tools assisting in construction organization. Based on the trend, knowledge gaps and future research directions were found out and discussed. This study contributes to the existing construction information technology knowledge by presenting a comprehensive knowledge framework. Furthermore, these findings can provide the researchers and practitioners with an in-depth understanding for the sustainable governance of construction information technology.

Keywords: Construction productivity, Construction IT, Construction technology, IT impact on construction, Construction organizations

1 INTRODUCTION

The construction industry has traditionally lagged other industries in technology adoption (Negahban et al., 2012). However, in recent years, driven by the pressure to improve productivity, reduce costs, improve safety and increase sustainability, there is growing momentum to introduce new technologies into the construction industry

(Oliveira et al., 2011). Lee, Yu and Jeong (2013) predict that we are moving towards a “machine-dominated” construction sector (Lee et al., 2013). However, it is well known that the construction industry is hesitant in adopting advanced technology (Peansupap et al., 2005; Pekerikli et al., 2004; Perkinson et al., 2006). Lu et al. (2014) brought forward two main reasons for the reluctance to utilize innovative technologies: uncertainty

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in using new technologies and lack of information regarding technologies and corresponding benefits. With the development of various technologies, more and more researchers have realized that technology could be an effective solution to the issue of the construction process (Lu et al., 2014).

Implementing the information technologies in construction industry organizations create enormous opportunities for improving communication and work productivity to enhance the effectiveness of construction processes and for creating business innovation (Peansupap et al., 2005). Both technological and managerial advancements of the information technology application in the construction industry organizations have been significant (Ahmad, 2000; Perkinson et al., 2006; Sanders et al., 2002). Distinctive features of the construction industry make the task of managing construction projects particularly appropriate for applications of information technology tools (Jung et al., 2011).

This study provides a general and a systematic review of information technology application in the construction organizations based on mainstream studies performed during 2000–2019 in select journals.

The overall aim of this review is to investigate the state-of-the-art and trends of information technology in collaborative working in construction. Based on the overall aim, the objectives of this is to understand the holistic research status and evolutionary trend from the perspective of published journal articles, document co-citation, and keyword co-occurrence. To achieve these research goals, we employ the systematic analysis method, which is used to map the visualization review of a specific knowledge area. This paper provides valuable guidance and in-depth understanding for researchers, practitioner and policymakers to promote information technology implementation in construction organizations.

2 RESEARCH METHODOLOGY

2.1 Data Collection

Both the Web of Science core database and Scopus selected as the data source for this paper; because of their comprehensive collection of construction and management databases (Valderrama-Zurián et al., 2015). Data extracted from the WoS Core collection database and Scopus between November and December 2019. In order to conduct a comprehensive analysis, the following steps

have been followed. In the first stage, we go through several highly-cited publications on the topic of information technology applications in construction organizations to identify the related key terms. Then, a combination of most frequently appearing search terms about construction information technology have been selected after reviewing preliminary papers.

Papers containing information technology, applications in construction organizations, digital technologies and information systems search terms in their titles, abstracts or keywords were selected. The final search terms included “TS = (“construction organizations *” OR “information technology *” OR “construction and information technology *” OR “construction IT” OR “construction&IT”) AND TS = (“information technology” OR “IT applications” OR “technology applications” OR “innovation”)”. The language of the publications was limited to English and document type was limited to articles; the time span was set to 2000–2019. As a result, 512 bibliographic records were retrieved.

The boundary of information technology applications in construction organizations has been defined as technology applications, construction productivity, construction IT, construction technology, information technology (IT) impact on construction, construction organizations, performance measurement, and tools assisting in construction organization (Oliveira et al., 2011; Perkinson et al., 2006). Based on this boundary, a manual review of paper titles and abstracts was conducted to exclude articles concerning technology application in construction, such as computer-aided design, building information modelling, and tools software and communication networks. After manual review, a total of 376 papers were selected. Figure 1 displayed the time-trend analysis of 376 information technology applications in construction organisations studies. The number of publications relating to IT in construction increased significantly from 2009 to 2019. This is because of the impact of the information technology application in construction considered after 2009, and many researchers started to compare the impact of using technologies in other industries with the construction industry.

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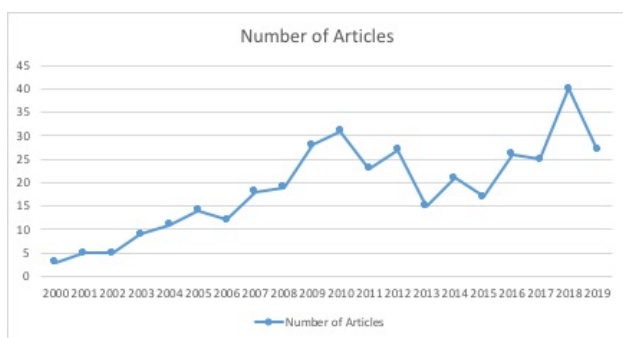


Figure 1: Number of studies on IT in construction from 2000 through 2019

2.2 Systematic literature review

Information technology application in construction literature focuses on multiple disciplines; however, little attention is paid to characterizing the whole field through manual and systematic review.

Manual analysis tends to be subjective and limited in terms of the number of publications being reviewed, as well as the relationship between publications cannot be analysed (Surulinathi et al., 2013). A systematic review is essential for analyzing the knowledge domain for a particular subject with a large number of articles (Kaliyaperumal, 2015). It should be noted that the review and analysis process can be performed quantitatively, but the presentation of results can have qualitative characteristics.

Different software has been developed in recent years, such as BibExcel, Ucinet, SCIMAT, VOSviewer, and CiteSpace which can assist the systematic review.

The general framework for this analysis require researchers to combine software output information with manual interpretation. Furthermore, the depth and quality of the interpretation are subjected to the researchers' experience, knowledge, and academic background.

CiteSpace, automated systematic analysis software for mapping and visualizing the intellectual structure of a scientific knowledge domain has been selected for the systematic review in this study.

3 RESEARCH RESULTS

more than 75% of the identified articles have been extracted from 12 top journals and databases in the field.

Table 1 presents the performance of these most productive journals that have published at least four articles on information technology application in construction from 2000 to 2019. The ratio of articles in the top 12 productive journals in addition to journal impact are also shown in Table 1.

Moreover, the top five journals account for 79% of these articles which probably means that these five journals are the most famous and important publications on construction management and technology. Automation in construction published the highest quantity of articles with 18.1%, much higher than the second and third journals, Journal Of Construction Engineering And Management 13.6%, and Journal Of Computing In Civil Engineering 12.5%.

Table 1 The performance of top 12 journals from 2009 to 2019.

Impact factor: Journal Impact Factor (Clarivate Analytics) in 2018.

No.	Journal Name	% of the related articles	Journal Impact Factor
1	Automation In Construction	18.1%	4.032
2	Journal Of Construction Engineering And Management	13.6%	3.711
3	Journal Of Computing In Civil Engineering	12.5%	1.798
4	Journal Of Management In Engineering	8.8%	2.282
5	Journal Of Civil Engineering And Management	7.4%	1.66
6	Aebmr Advances In Economics Business And Management Research	4.5%	0.428
7	Communications In Computer And Information Science	3.7%	1.996
8	Advanced Engineering Informatics	2.4%	3.358
9	Advanced Materials Research	1.6%	1.95
10	Communications In Computer And Information Science	1.6%	4.616
11	Advances In Education Research	1.1%	1.163
12	ACSR Advances In Computer Science Research	1.1%	4.41

The following high-frequent keywords "BIM" (frequency = 56), "impact" (53), "ICT" (49), "case study" (47), "management" (36), "use" (25), and "adoption" (19) represent the hot topics in construction management and information technology research, corresponding to the followed categories: (a) Building information modelling in construction, (b) The impact of technology on construction, (c) Information and communication technology in construction, (d) Case study on implementation of technology in construction, (e) Construction Management, (f) The use of IT in

construction, and (g) IT adoption in construction. As a widely accepted strategy for IT in construction impact, adoption, management, and use are jointly included the categories. The topic of building information modelling in construction has attracted the most research efforts. The category of the impact of technology on construction also received considerable interest from researchers because of its significant and benefit in terms of calculating construction productivity and management assessment. In this paper, cluster labels are generated, which selects the top-ranked words occurring in each cluster and labels. Four clusters are identified based on research keywords, such as BIM, analysis, construction enterprise, application, case study, impact, building information modelling, and challenge as presented on the left side of Figure 2.

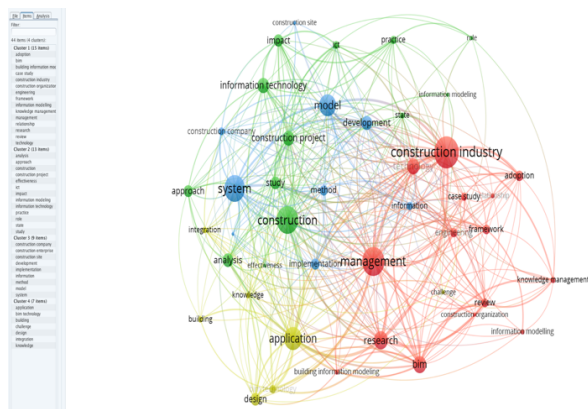


Figure 2: Grouping of Construction Information Technology research: 2009–2019

4 Conclusion

This study systematically reviewed publications related to IT in the construction industry from 2000 to 2019 by using the systematic analysis method. A total of 376 papers were selected for co-citation analysis, keyword co-occurrence, cluster analysis, and burst detection, in order to investigate the state-of-the-art and trends of information technology in collaborative working in construction. Automation in Construction, Journal of Management in Engineering, Advanced Engineering Informatics, and Journal of Intelligent & Robotic Systems were identified as the four major journals associated with research on the IT application in the construction industry. By measuring the high-frequent co-occurrence keywords, the major research topics in this area include “Building

information modelling in construction”, “The impact of technology on construction”, “Information and communication technology in construction”, “Case study on implementation of technology in construction”, “Construction Management”, “The use of IT in construction”, and “IT adoption in construction”.

These findings can help researchers and practitioners quickly understand the current researches related to IT applications in the construction industry. In particular, knowledge domains and evolutionary trend can offer clear and in-deep cognition of construction IT researches.

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Computerising the New Zealand Building Code for Automated Compliance Audit

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ABSTRACT

One key ingredient in the automated compliance audit process is the availability of a computable form of normative requirements (e.g. codes and standards), which are usually written in natural language intended for human interpretation and not readily processable by machines. The predominantly ‘Blackbox’ approach of hardcoding these computable normative rules into a compliance audit system has been reported to be problematic and costly to maintain in response to frequent regulatory changes. The current research sets out to investigate to what extent normative texts can be represented as computable rules for automated compliance audit as well as to ease maintenance in response to changes in the source documents. A set of priority compliance documents supporting the New Zealand Building Code has been selected as the subject for a case study. This paper describes the digitisation and quality assurance process, the knowledge extraction experience, and challenges identified during the study. Furthermore, the paper explores how the legal knowledge captured by the digitised rules can be used effectively in an automated compliance audit environment. The findings from the study suggest that a semi-automated digitisation process is feasible and up to 80% of prescriptive text can be translated and encoded into the open standard *LegalRuleML*. However, only approximately 50% of these can be used directly in an automated compliance audit environment without any human intervention. The lessons learnt from the study can be used towards improving the digitisation process. Ultimately, this could in turn help to improve the natural language source text in subsequent revisions of the codes.

Keywords: Normative, Computable rules, Automated compliance audit, Building information modelling, Legalruleml

1 Introduction

1.1 Background and Motivation

The compliance audit process in the built environment has conventionally been a manual process, which is costly, error-prone and inefficient. One key obstacle in automating this process has been the inability for machines to process normative requirements currently conveyed in natural language intended for human interpretation. Over the past 40 years, there have been numerous approaches to sharing normative requirements for automated compliance audit processes (Dimyadi &

Amor, 2013). A common solution has been to represent normative requirements as rules that are hard coded into a compliance audit system. This “Blackbox” approach creates a snapshot of the normative requirements in the form of static rules that may not necessarily reflect the latest amendment of the source provisions. This approach lacks the transparency to allow independent verification of the correctness of the representation and has been reported as problematic and costly to maintain. Previous research has shown that representing normative requirements in an open standard computable form is one solution towards enabling a “digital twin” of the source

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document that maintains the same status of the source provisions (Dimyadi & Amor, 2017; Dimyadi, Governatori, & Amor, 2017). This provides a guarantee that the computable rules always reflect the latest amendments. Regardless of the representation approach, however, the first step towards computerising any legal text is the knowledge extraction process and the formalisation of that knowledge into computable rules. Fully automated knowledge extraction from natural language is still an active research topic despite extensive research over the years (Voorhees, 1999; Zhang & El-Gohary, 2013). At the other end of the scale, manual knowledge extraction by a domain expert remains a reliable approach, albeit laborious and costly. In between, there have also been numerous semi-automated approaches suggested by researchers (Dragoni et al., 2016; Kiyavitskaya, Zeni, & Breaux, 2007; Strahonja, 2006; Wyner & Peters, 2011). The current research sets out to investigate to what extent natural language normative requirements, such as those conveyed by regulations or a building code, can be computerised to support automated compliance audit processing of a given building design.

1.2 Open Standard Legal Knowledge Model (LKM)

Emerging open legal knowledge interchange standards *LegalDocML* (LDML) and *LegalRuleML* (LRML) (OASIS, 2015, 2016) have recently drawn some attention among researchers in the Architectural, Engineering, Construction (AEC) domain (Dimyadi et al., 2017; McGibbney & Kumar, 2013) as a potential de-facto standard for representing normative requirements in the domain. LDML is a standardisation of *Akoma Ntoso* (Cervone et al., 2016), a former UN project for e-Parliament services in the Pan-African context, which has been designed to represent the structure and literal content of a legal document. LRML (Athanasopoulos et al., 2013) has been developed on top of the open standard RuleML (Boley, Paschke, & Shafiq, 2010) with formal features specific to norm modelling, and is intended to represent the semantic or logical content of a legal document. Together, LDML and LRML constitute LKM in the context of this research as they are complementary standards that are close coupled by means of isomorphism, in which each rule in LRML is linked to its legal source provision by a unique key in LDML.

1.3 New Zealand Building Code (NZBC)

The New Zealand Building Code (NZBC) is part of the

Building Regulations made under and in accordance with the primary legislation for the AEC domain in New Zealand, the Building Act 2004. The NZBC is a performance-based code, which specifies how a building is required to perform in its intended use but does not define how this performance is to be achieved. In order to provide practical information on how the requirements can be met, the NZBC is supported by a set of documents that are either Acceptable Solutions, which set out technical specifications for construction systems, materials or methods; or Verification Methods, based on industry-established calculation methods, laboratory tests or in-situ tests for building components or systems. These documents provide prescriptive approaches to meeting the performance requirements of the NZBC, and designs that demonstrate compliance with them must be accepted by the building consent authority (BCA).

The NZBC is divided into clauses, each with associated acceptable solutions and verification methods, that relate to particular technical aspects of building design and construction, including stability (B series documents), protection from fire (C series documents), access (D series documents), moisture (E series documents), safety (F series documents), services and facilities (G series documents), and energy efficiency (H series documents).

2 The Computerisation Process

2.1 General Process

In the context of this research, computerisation pertains to the process of digitising a legal document by capturing its structure and literal content as well as the semantics of its normative texts by translating and formalising them into a set of computable rules, which are then encoded into an open standard format. It also extends to the process of enabling access to the computable rules by a specific application, such as in an automated compliance audit environment.



Figure 1: The Digitisation Process

As depicted in Figure 1, the digitisation process starts with document preparation where the structure and literal content of each document is captured. This is followed by the knowledge extraction step where the intent and semantics of the normative text are formalised into rules.

The rules are then encoded into the open standard LRML format, which is then made available for access and query by any software system that supports the LRML standard. To provide a white-box solution to automated compliance audit, the LRML version of the NZBC must be owned and maintained by the official government body or a certified third-party responsible for the upkeep of the paper-based source documents. The intention is for the digital version to be updated at the same time and alongside the source documents in response to any amendment. Any system can then request an authentication from the remote repository hosting the documents to access the digital content on demand.

A guidelines document was written at the outset to set out the standard and conventions to be used for each step of the digitisation process. A number of software tools (written in Python and Swift programming languages) were also developed to automate and manage some of the tasks involved in the process.

2.2 Document Preparation

New Zealand legislation, regulations including NZBC Acceptable Solutions and Verification Methods, and some normative standards are published online as PDF documents. The first step in the document preparation process is using a software tool (such as the Adobe Acrobat) to extract the content of a PDF document into plain text, which is then formatted into an intermediate XML data structure (Figure 2) that will enable mapping to the LDML schema. The main objective of this initial step is to ensure the structure of the document is captured as accurately as possible.

```
<section key="9.0" title="Disposal to Soak Pit">
  <paragraph key="9.0.1">
    <p>1 Where the collected surface water is to be discharged to
    without causing damage or nuisance to neighbouring property,
    <commentary title="COMMENTARY:">Means of demonstrating the suite
    surface water to a soak pit may also require a resource mana
  </paragraph>
  <paragraph key="9.0.2">
    <p>2 Field testing of soakage shall be carried out as follows
    <ol>
      <li key="9.0.2.a">Bore test holes of 100 mm to 150 mm dia
      hole then this depth shall be taken as the depth of the s
      <li key="9.0.2.b">Fill the hole with water and maintain it
      a short time).</li>
      <li key="9.0.2.c">Fill the hole with water to within 750
      greater than 30 minutes, until the hole is almost empty,
      <li key="9.0.2.d">Plot the drop in water level against t
      curve. If there is a marked decrease in soakage rate as t
      average can be adopted.</li>
    </ol>
  </paragraph>
  <paragraph key="9.0.3">
    <p>3 The soak pit shall be designed utilising soakage and str
    overflowing. The rainfall intensity used in the design of the
    occurring annually. Either local rainfall intensity curves or
```

Figure 2: Structural and Literal Content of Document

One of the software tools developed can be used to take this intermediate XML representation of the document as

input and to generate a spreadsheet proforma with pre-populated text paragraphs and their corresponding rule IDs. This process also splits complex paragraphs into more manageable sentences to facilitate knowledge extraction by the domain expert. Rules are related by their rule IDs and can therefore be automatically grouped together at the end of the digitisation process.

The pre-populated proforma prepared for each document is then distributed to the domain expert team for the knowledge extraction exercise.

2.3 Knowledge Extraction

The knowledge extraction exercise involved manually capturing the logic (condition expressions and conclusions) inherent in individual normative text paragraphs and sentences and identifying atoms, their relationships, and logical operators. The outcome was highly dependent on the level of expertise and experience of individual domain experts undertaking the work.

Apart from text paragraphs, NZBC Acceptable Solutions and Verification Methods also contain many tables, graphs, and illustrated provisions, as well as explicit and implicit mathematical expressions. Some of these forms of normative requirements, particularly illustrations, are often not easily formalised into rules (see Section 4 for some discussions on the challenges). Tabulated provisions, however, can be encoded into LRML semi-automatically in most cases by means of pre-populated and proforma-based specifications.

Atoms (entities, attributes, and relationships) and logical operators extracted from each sentence were entered into their respective places on the Knowledge Capture Profoma (Figure 3) along with logical expressions and deontic operators (obligation, prohibition, permission) to form one or more logical statements for each rule. Atoms and operators were also added to a centralised LKM data dictionary, which had been developed to align with the buildingSMART Data Dictionary (bsDD), formerly known as the International Framework for Dictionaries (IFD) (ISO, 2007). Additional parameters such as mathematical functions and intermediate variables were introduced into each rule as necessary to convey the intent of the provision and to facilitate computability of the rule.

As mentioned above, tabulated and some illustrated provisions can be generated into LRML rules semi-automatically through a machine-readable table schema proforma (Figure 4), which incorporated input and output components and other conditional parameters specification.

RuleId	if	then	deontic	neg	fun	rel	var	operator	val
1.3.2	if			(
				not		activity	building	is	household u
						riskGroup	building	equal	SH1
)					
				and	count	step	accessRoute	equal	1
				and		purpose	step	is	threshold we
						height	step	greaterThan	20 mm
	then	prohibitio	n						
1.4	if						building	has	buvo:access
	then	obligation				heightClearance	accessRoute	complyWith	table
				and		key	table	equal	t1.1
				and		heightClearance	accessRoute	complyWith	figure

Figure 3: Knowledge Capture Proforma

table	6.1		
input	1 and 2		
output	3 and 4		
	1	2	3
stair.type	stair.pitch	stair.riserHeigh	stair.treadDepth
equal	lessThanEqual	t lessThanEqual	lessThanEqual
service	47 deg	220 mm	220 mm
minorPrivate	47 deg	220 mm	220 mm
secondaryPrivate	41 deg	200 mm	250 mm

Figure 4: Table Schema Proforma

2.4 Validation, Formalisation and Encoding

Each completed knowledge capture proforma was subject to quality assurance peer-review by another member of the team. The main objective is to review that the logical content of each sentence has been captured correctly and in accordance with the guidelines. More importantly, this step also ensures that the standard and conventions as specified in the guidelines are followed consistently throughout the process.

Once the knowledge capture proforma has passed the peer-review process, it is then subject to validation by the LKM Data Processor, which is a dedicated software application developed independently for managing LKM. The LKM Data Processor also takes prepopulated table schema proformas related to a document and generate the corresponding LRML rules.

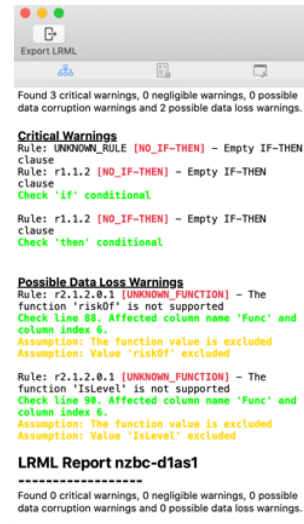


Figure 5: Validation Check Warnings

The data processing by the LKM Data Processor involves checking the content of the proforma for unknown or unidentified atoms or operators, incorrect logical expressions and syntax. A list of warnings is given as part of the validation (Figure 5).

The validation process may be repeated until all the errors and warnings are corrected or attended to on the source proformas. At the end of the validation process, the LKM Data Processor would encode the content of the proformas into valid LRML rule statements (Figure 6) as well as grouping related rules together by their rule IDs into associations.

```

LRML Header  LRML Associations  LRML Statements  LRML Table Rules
<lrml:Statements>
<lrml:PrescriptiveStatement key="NZ_nzbc-d1as1#2.6_r1.1.1.a">
  <ruleml:Rule key="NZ_nzbc-d1as1#2.6_r1.1.1.a">
    <ruleml:if>
      <ruleml:And>
        <ruleml:Expr>
          <ruleml:Fun iri="lovo:has"/>
          <ruleml:Atom>
            <ruleml:Var iri="buvo:building"/>
          </ruleml:Atom>
          <ruleml:Data xsi:type="xs:string">entrance</ruleml:Data>
        </ruleml:Expr>
        <ruleml:Expr>
          <ruleml:Fun iri="lovo:is"/>
          <ruleml:Atom>
            <ruleml:Var iri="buvo:entrance"/>
          </ruleml:Atom>
          <ruleml:Data xsi:type="xs:string">principal</ruleml:Data>
        </ruleml:Expr>
        <ruleml:Expr>
          <ruleml:Fun iri="lovo:is"/>
          <ruleml:Atom>
            <ruleml:Var iri="buvo:accessibleRoute"/>
          </ruleml:Atom>
          <ruleml:Data xsi:type="xs:string">practical</ruleml:Data>
        </ruleml:Expr>
      </ruleml:And>
    </ruleml:if>
  </ruleml:Rule>
</lrml:PrescriptiveStatement>

```

Figure 6: LRML Rule Statements

part of the formalisation process include identifying and processing the correct data types and units of measurement in the atoms, which would support the computability of the rules in the application environment.

The LKM Data Processor can also extract relevant metadata from the LDML file to construct a valid header for the LRML file.

Additionally, the LKM Data Processor supports two-way interoperability between LRML and the source proformas. The tool can also be used to manage LKM versioning and temporal characteristics of the LRML rules.

3 Case Study

3.1 Scope

The focus for this case study was on the prescriptive step-by-step normative requirements and processes stipulated by the Acceptable Solutions, and 20 of them from clauses B, C, E, and G of the NZBC were selected for digitisation. In addition, two Verification Methods related to G clause of the NZBC were also included, as their content was considered essential in the priority consenting environment where an automated compliance audit process will take place.

3.2 Resources and Roles

A team of six experts was involved in digitisation, mainly dedicated to the document preparation and knowledge extraction process. Members of the team brought expertise in a variety of domains, including knowledge engineering and computational logic, data science, fire engineering, architectural design, construction management, and software engineering. They were assigned different roles throughout the process, such as document preparation, analysis, formalisation and translation, review and verification, and software development.

4 Experience and Challenges

4.1 Document Preparation Experience

Most of the documents selected for digitisation had a similar hierarchical structure. However, there were some variations in the hierarchy and naming convention between some documents that caused issues when generating the knowledge capture proforma using the software tool. This was handled by scanning all of the documents and incorporated all document structure variations into a schema specification (Figure 7).

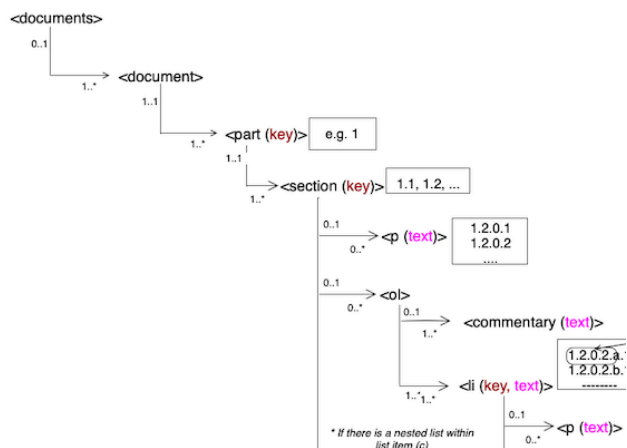


Figure 7: Document Schema for Knowledge Capture Proforma

Apart from variations in the structure of the source documents, there were also variations introduced as part of the initial document preparation from PDF to plain text and manual formatting into XML. This had to be managed iteratively by correcting any errors and eliminating unexpected elements discovered by the software tool.

4.2 Knowledge Extraction Experience

Starting the knowledge extraction process through an expert-driven process brought its own challenges. Members of the team brought different levels of expertise and experience and came from different background. The diversity of expertise and background coupled with the subjective nature of natural language interpretation resulted in many different ways knowledge could be extracted from a text. Two divergent approaches were taken to address this issue. To explore the extent of the variation, several of the Acceptable Standards were given to multiple people to translate, and the resulting translations were compared and shared amongst the team. Preferred translations were identified and disseminated as templates for specific types of text. In other cases, each Acceptable Standard was given to a different individual to translate so that a single approach

could be used throughout a text. In practice, an amalgam of both approaches was used on most documents, with members of the team collaborating to address gaps or determine appropriate methodologies.

A related issue was the standardisation of atoms and logical operators. The framework used for these was based on the glossaries provided in the NZBC and the bsDD, but there were many necessary terms and expressions that were not included in either. This was addressed iteratively through the use of an interim centralised data dictionary that was developed over the course of the process. Each Acceptable Solution brought its own definition of terms that was straightforward enough to negotiate, but one challenge was the use of similar operators that held different relationships within different contexts. For example, a structural member required to be *under* another has a different relationship to a drain that is *under* a building, despite the use of the same expression. The dictionaries of vocabulary were developed iteratively with agreed expressions and more efficient methodologies of defining expressions being disseminated to the team. Completed translations were reviewed and updated as better approaches were developed.

The complexity of many of the statements within the Acceptable Solutions caused many challenges. Clauses can include multiple sub-clauses, be cross referenced to other clauses, refer to illustrations or tables, refer to external documents such as standards or other Acceptable Solutions or Verification Methods, or involve multiple factors or relationships within one clause. Resolving some of these complex clauses became a multi-level problem, with questions of how complex statements should be allowed to get in the translation process, and how many statements to combine with combinations of AND and OR in order to define a rule. Although an early principle was to keep rules as simple as possible, in some cases it became cumbersome to divide complex clauses into individual rules, and so more convoluted combinations of AND and OR became necessary, which may impact on the computability of the rule in an application.

Computations introduced another situation where rules often became complex. The options in cases where a computation was introduced in an Acceptable Solution or Verification Method are to either encode the calculation process directly into a rule, or to define a function that fulfils the calculation, and refer to the function in the rule. The former was generally preferred, but there were

exceptions and hence it was addressed on a case by case basis. Where a calculation is initially used it has tended to be represented as a rule, wherever possible. However, when it is repeated throughout a document it becomes for efficient to define the function separately. This allows a function to be defined once and used across different Acceptable Solutions and Verification Methods and requires subsequent review of previously digitised documents to follow a standard process.

Spatial and temporal computations and other more complex analyses often require external support such as third-party simulation or other tools. Other situations require human judgement or analysis and cannot be completely encoded into rules. All of these situations are accepted in this approach, with the computable aspects identified and coded for automated compliance checking, but additional resources such as tools or human expertise can be called on where needed.

4.3 Challenges

Despite the prescriptive intent of the Acceptable Solutions, some of the language used is imprecise and relies on human judgement. While this is a necessary element in many situations, ambiguity is introduced when specifications or minimum standards are stated but include the caveat “where practicable”, for example.

Challenges that arose were not all a result of the process of translation from natural language to a digital structure. The systematic process of breaking down the many rules highlighted a number of ambiguities or contradictions within the Acceptable Solutions themselves. In some cases, requirements to meet an Acceptable Solution for one clause of the NZBC contradicted requirements of an Acceptable Solution for another. Other issues included cross-references to out-of-date or inappropriate standards documents, incorrect or inconsistent terminology, and unclear or ambiguous writing within the documents.

5 Discussions and Conclusion

A case study to digitise a set of compliance documents from the New Zealand Building Code has been presented. The entire process and challenges experienced by the team undertaking the project have been described.

The entire digitisation project took 6 months to encode 10,729 rules. This represents approximately 80% of all normative text contained in the selected Acceptable Solutions and Verification Methods documents.

Some of the LRML rules produced as part of this study

have been tested in a prototype workflow-model-driven automated compliance audit system in conjunction with a given building model. The findings from preliminary tests suggest that only half of the rules can be used without supplementary human input. The main reason was the inadequate level of details available in the building model used in the test. Another case study has been scheduled to investigate to what extent additional information will be needed to assist the automated compliance audit using these rules.

Future work includes combining spatial and temporal operations with LRML to extend its capabilities in resolving geometry-related and geometry-dependent operations.

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Improvement of Off-Site Construction performance in construction waste reduction using Building Information Modelling

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ABSTRACT

New Zealand population has increased significantly in recent years. Urbanization has resulted in substantial environmental problems such as a considerable rise in waste generation. Half of the New Zealand waste consists of construction and demolition waste and a considerable amount of it dumped in landfills. Construction waste disposal to landfill has many adverse impacts on the environment. Among Various methods for waste reduction using off-site construction (OSC) and Innovative technologies such as Building Information Modelling (BIM) are widely used and popular. This paper aims to indicate the potentials of BIM implementation in OSC for improving waste reduction in construction projects. The results are summed up to reveal the clear perception of BIM in OSC consists of benefits and barriers of this integrated method as well as future research needs on the joint use of BIM and OSC.

Introduction

Excess and damaged materials generated during construction, demolition, and renovation processes are known as construction and demolition (C&D) waste (Roche & Hegarty, 2006). One of the largest waste streams around the globe is C&D waste which makes up about 30-40% of all produced waste (Akhtar & Sarmah, 2018; Jin, Li, Zhou, Wanatowski, & Piroozfar, 2017; Zhao, Leefink, & Rotter, 2010). It made up 36% of the total solid waste generated in the European Union in 2016 (924 million tons) and about 67% (534 million tons) in the United States (Ruiz, Ramón, & Domingo, 2019). This proportion in china is around 30–40% (2.36 billion tons) (Zheng et al., 2017). In New Zealand, about 50% of generated waste originates from C&D activities (Building-Research-Association-of-New-Zealand, 2014).

Disposal of C&D waste to landfills extensively contributes to water, air and soil pollution; as anaerobic digestion processes of waste release CO₂ and methane gas. Moreover, this issue incurs high pressure on landfill's capacities (W. Lu, Webster, Chen, Zhang, & Chen, 2017). According to Auckland Council, C&D waste currently and

in the future is one of the most common sorts of waste disposing to landfill. Therefore, it should be considered as one of the priorities to decrease the disposal of waste to landfill (Auckland council, 2017).

Construction waste management and minimization (CWMM) attempts to explore and minimize waste from the construction industry to decrease its contribution to environmental pollution (Shen, Tam, Tam, & Drew, 2004). Sequences of CWMM include the 5Rs, respectively reduce, reuse, recycle, recover and residual management (H. Liu, Sydora, Altaf, Han, & Al-Husseini, 2019). Although reuse, recycle and recovery sequences have attracted a lot of interest, they mostly lead to inefficient waste management and a significant amount of waste use for landfilling or dump without environmental maintenance plans (Esa, Halog, & Rigamonti, 2017; Suárez, Roca, & Gasso, 2016). For instance, the average recovery rate of C&D waste is about 20-30% all over the world (World-Economic-Forum, 2016). This rate reaches 46% in European Union (Ruiz et al., 2019) while China has less than 5 % recovery rate (Huang et al., 2018). The last sequence of CWMM-residual management requires various societal efforts as well (Won & Cheng, 2017). The

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waste reduction sequence eliminates waste disposal and reduces the cost of waste sorting and transporting (W. Lu & Yuan, 2011). Therefore, it had been regarded as the most advantageous technique in waste management.

Waste is generated within the various stages of a construction project, especially in the actual construction phase (Chileshe, Rameezdeen, & Hosseini, 2016; H. Li, Chen, Yong, & Kong, 2005). It has been indicated that making wrong decisions and improper actions during the design, the design changes and inadequate communication among participants are the cause of significant amount of rework and waste generation (Ajayi et al., 2017; Alwi, Hampson, & Mohamed, 2002; Z. Liu, Osmani, Demian, & Baldwin, 2015; Osmani, 2013). Ajayi et al. (2017) proposed that accurate design process with complete information and detailed drawings minimize rework and consequently reduce waste generation. The development of communication among parties significantly reduce construction waste generation and improve the design process as well (Ajayi & Oyedele, 2018; Al-Hajj & Hamani, 2011; Ikau, Tawie, & Joseph, 2013). To tackle material waste issues in construction projects, several methodologies have been employed to reduce the amount of material waste generated during construction activities.

The Off-site construction method (OSC) and building information modelling (BIM) have been increasingly used to reduce material waste (H. Liu et al., 2019). OSC and BIM bring substantial benefits for project participants in many respects including high-quality design, development of data exchanges, material waste reduction and lead to the product with a higher quality (Yin, Liu, Chen, & Al-Hussein, 2019). OSC has been considered as a promising method to address the construction waste generation issue (L Jaillon, Poon, & Chiang, 2009; Medibodi, Kew, & Haroglu, 2014). BIM also has been regarded to reduce waste, time and cost in architecture, engineering and construction (AEC) industry (Ahankoob, Khoshnava, Rostami, & Preece, 2012; Cheng, Won, & Das, 2015; Z. Liu, Osmani, Demian, & Baldwin, 2011; Rajendran & Gomez, 2012). The integration of OSC and BIM is suggested to provide more improvement in construction projects (Yin et al., 2019). This study examines how the integration of BIM and OSC contributes to construction waste reduction. Then, it reveals the advantages and challenges of BIM implementation in OSC. Finally, it suggests the future research needs of BIM in OSC.

Methodology

To gain an overall understanding of OSC and BIM potentials in construction waste reduction a systematic literature review is conducted (Ajayi et al., 2017; Babaeianjelodar, Yiu, & Wilkinson, 2016; Jelodar, Yiu, & Wilkinson, 2015). Articles from various journal papers and conferences have been reviewed through Google Scholar and Scopus databases. The keywords for the article search contained: "construction waste management" or "construction and demolition waste" or "construction waste reduction" or "construction waste minimization" or "off-site construction" or "off-site construction and waste reduction" or "prefabrication" and "construction waste" or "prefabricated building" and "construction waste" "Building information modelling" or "BIM" and "construction waste" or "BIM" and "construction waste reduction". Besides, some government reports were used to acknowledge the research need and provide more information. Then the identified articles were narrowed according to their relevance to this study. The abstracts of primarily selected papers were examined to eliminate irrelevant ones. Furthermore, a deeper investigation was carried out to provide a knowledge domain in terms of using BIM in OSC. Similar to the previous stage, another literature search was conducted using "Building information modelling" and "off-site construction", "prefabrication" and "BIM", "prefabricated buildings" and "BIM" as keywords. A screening process was carried out by categorizing papers focusing construction waste reduction which provides a clear insight of potentials and barriers of the jointly BIM and OSC method for construction waste reduction.

Potential of OSC method for waste reduction

New Zealand's population has grown rapidly, and it is projected to reach 5.7 million by 2038 (Brunsdon, 2019). Population growth has resulted in a strong need for more houses. OSC method has drawn extensive attention in order to respond to the Shortage of 71,766 new houses across New Zealand (Kennerley, 2019). Implementing the OSC methods in New Zealand provide a better opportunity to improve environmental sustainability than conventional construction methods (Building-Research-Association-of-New-Zealand, 2013). OSC implies an approach that produces building elements in a climate-controlled manufacturing factory using advanced

machinery in order to prefabricate building elements efficiently (H. Liu, Holmwood, Sydora, Singh, & Al-Hussein, 2017). Then the complete or semi-complete prefabricated products are transported into the construction site. Ultimately, components are assembled and installed to the construction buildings (V. W. Tam, Tam, Zeng, & Ng, 2007). There are four different degrees of OSC: (1) component manufacturing and sub-assembly such as structural components; (2) none-volumetric preassembly that does not enclose usable space; (3) volumetric pre-assembly include usable spaces; and (4) complete modular buildings (Jin, Hong, & Zuo, 2019). A few different and exchangeable terms have been utilized for OSC in the construction industry. These terms consist of modularization, prefabricated construction and industrialized buildings (Mao, Shen, Pan, & Ye, 2013). For consistency purposes, the term "OSC" is utilized in this literature review. The benefits of using OSC compared with conventional method of construction consist of improvement of safety and project quality (Kamali & Hewage, 2016), reduction of material waste, labor and construction time (L Jaillon et al., 2009; V. W. Tam et al., 2007), development of structural reliability and significant environmental benefits (Cao, Li, Zhu, & Zhang, 2015; Hosseini et al., 2018). The ability of OSC in waste minimization is enhanced by using more prefabricated elements in buildings (Arashpour et al., 2017). C. Tam, Tam, Chan, and Ng (2005) claimed that construction waste reduced 35 to 100% using OSC. Lara Jaillon and Poon (2009) achieved 56% construction waste reduction, 20% construction time reduction and high quality of process control using the OSC method. V. W. Tam, Tam, Chan, and Ng (2006) investigated the efficiency of OSC methods in construction waste reduction by measuring the wastage level of several construction trades in two groups of projects including the conventional (in situ) method and the OSC adopted method. Material waste reduction in concreting, rebar fixing, tiling, and plastering were reported respectively 73.51%, 76.88%, 58.33%, and 100% in a group which adopted the OSC method. They considered "poor workmanship" as the main cause for waste generation in the conventional construction method which greatly can be avoided by adopting OSC.

Potential of BIM-based method for waste reduction

BIM has been recognized as an effective tool in reducing

construction waste (Ahankoob et al., 2012; Cheng et al., 2015; Z. Liu et al., 2011; Rajendran & Gomez, 2012). BIM integrates and manages information during the entire construction project in order to achieve an efficient coordination among stakeholders (Mostafa, Kim, Tam, & Rahnamayiezekavat, 2018). Adaptation of BIM as a technological tool serves benefits for the construction industry in several areas, consists of the enhancement of design quality (W. Lu et al., 2017), communication among stakeholders (Fischer & Kunz, 2004), maintaining information to lessen discontinuity (H. Li, Lu, & Huang, 2009), advancement of on-site waste management (Hewage & Porwal, 2011) and enhancement in clash detection (Z. Liu et al., 2015). Won, Cheng, and Lee (2016) indicated that design review and clash detection capabilities of BIM reduce on-site construction waste by 15%. Z. Liu et al. (2015) revealed that the reduction of construction waste through the design stage leads to 33% of total waste reduction in construction projects.

BIM-based decision-making workflow results in High-quality design which reduces design errors, unexpected changes and reworks during the project's lifecycle (Young Jr, Jones, Bernstein, & Gudgel, 2009). Won et al. (2016) implied that limited studies have quantified the amount of waste reduction using BIM-based methodology in the construction projects. In this respect, they examined two projects in South Korea to quantify the amount of prevented construction waste using BIM-based design validation. The study was conducted during preconstruction and construction stages. The cases included a residential building and a sports complex. The rate of prevented construction waste was reported by 15.2% and 4.3% respectively. The different percentages for these two cases were attributed to the different complexity of the projects and rework that caused by client's design changes (Won et al., 2016). Porwal and Hewage (2011) also suggested a BIM-based model to reduce waste of reinforcement in reinforced concrete, BIM implementation improved communication among different design groups for applying crucial changes in design stage targeting rebar waste minimization.

OSC improvement using BIM

Although OSC brings many advantages to the construction industry, its implementation represents new challenges during the design process. Development of precise and well-organized building models is required to improve the

planning of productions and fulfill the manufacturing requirements (Alwisy, Al-Hussein, & Al-Jibouri, 2012; Arashpour, Wakefield, Abbasi, Arashpour, & Hosseini, 2018).

BIM and OSC are increasingly regarded from the angel of the product planning and process. From the product planning perspective, BIM is widely known for its parametric design capability (Sacks, Eastman, & Lee, 2004). Parametric design capability provides a flexible design for OSC, it includes defining a broad range of variants, dividing building models into elements with various sizes and exploring different alternatives (Arif, Goulding, & Rahimian, 2012; Goulding, Pour Rahimian, Arif, & Sharp, 2015). For instance, BIM using parametric design can easily adopt design changes for standard building components, which are needed for OSC (N. Lu & Korman, 2010; Ramaji & Memari, 2016). Banihashemi, Tabadkani, and Hosseini (2018) employed the parametric design capability of BIM in the OSC to effectively reduce the waste generation in the constriction stage by adaptation of waste reduction policies during the design process. Alwisy et al. (2012) proposed a BIM-based method to automate the design and drafting processes of wood-frame walls in prefabricated buildings. Chen et al. (2018) suggested a BIM aided platform to enhance the effectiveness of resource management and minimize human errors in OSC.

These potentials of BIM reduce material waste of OSC projects efficiently (Singh, Sawhney, & Borrmann, 2015, 2019).

H. Liu et al. (2019) introduced a hybrid BIM-based algorithm to reduce material waste of sheathing during roof sheathing installation in OSC. They concluded that BIM and OSC jointly can reduce material waste effectively. As construction practitioners can identify different construction plans ahead of time using virtual and computational potentials of BIM, while OSC provides efficient conducting of construction activities in a standardized and high controlled environment. Nevertheless, the proposed method is unable to eliminate material waste completely (H. Liu et al., 2019).

Based on the innate feature of OSC, its processes engage more parties compared to the traditional method. As manufacturers bring about further participants and the whole process of OSC varies from the traditional method. Thus, efficient communication tools are crucial to decrease discontinuity among participants and improve their communications during the fragmented process of

OSC (C. Z. Li et al., 2016; Yin et al., 2019). Effective design coordination and clash detection in OSC method were achieved in a study by N. Lu and Korman (2010), all Mechanical, Electrical, and plumbing (MPE) coordination were carried out using a BIM-based platform and 258 conflicts were detected and eliminated within the design stage. BIM adaption in OSC with the aim of efficient information exchange, efficient coordination among stakeholders, and decision making on changes bring managerial advantages of BIM as well (Alwisy et al., 2012; Mohsen, Knytl, Abdulaal, Olearczyk, & Al-Hussein, 2008). It leads to the reduction of delays and reworks and more accurate planning which can reduce material waste (Wu, 2017).

The emergence of BIM provides new opportunities to further leverage the proficiency of the OSC method in construction projects. BIM digitally represents a constructed facility and provides line of "integration" which is essential for the delivery of components in OSC method (Chen, Lu, Peng, Rowlinson, & Huang, 2015; Eastman, Teicholz, Sacks, & Liston, 2011). Despite the recognized advantageous, the adaptation of BIM in OSC is still slow (Mostafa et al., 2018).

N. Lu and Korman (2010) and Elmualim and Gilder (2014) recognized the difficulty in adaptation to the BIM process as a significant barrier. Difficulty in reengineering the existing process substantially limits the BIM implementing (Yan & Demian, 2008). BIM implementation in OSC provides working cooperatively on a single integrated BIM model, while stakeholders have negative attitudes toward working cooperatively (Arayici, Egbu, & Coates, 2012). Stakeholders also worry about time and cost required for the training of BIM implementation (Eadie, Odeyinka, Browne, McKeown, & Yohanis, 2014). The resistance of stakeholders to changes constraint BIM implementation in OSC because its implementation inevitably changes the delivery of projects. Stakeholders are willing to the conventional paper-based procedure in comparison with the adaptation of new technologies (Tan, Chen, Xue, & Lu, 2019). Inadequate external motivation for BIM implementation has been regarded as an important barrier as well (D. Cao et al., 2015). Mostafa et al. (2018) proposed the Australian government supports to overcome these barriers in Australia. N. Lu and Korman (2010) recommended that construction professionals should spend adequate time and man-hours for educating of main stakeholders to integrate BIM technology into their project's platform.

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The jointly BIM and OSC method maximize the potentials of each method in terms of construction waste reduction and it could be achieved by developed coordination among stakeholders.

Conclusion

This study conducted a review on the potentials of BIM, OSC, and BIM in OSC especially in terms of construction waste reduction to indicate the benefits and barriers of jointly implementing BIM and OSC method. The findings indicated that although the inherent of OSC provides significant benefits, there are some challenges in the implementation process. The integration of BIM and OSC can address the challenges. It enhances the benefits of each method. The adaptation of BIM in OSC decreases reworks, develops effective coordination among stakeholders, provides accurate and flexible design and high-quality control of projects. Additionally, facilitates clash detection and making decisions on design changes at the earlier stage. These potentials of integrated BIM in OSC address waste generation issues during construction activities. The advantages and challenges of using BIM in OSC have been indicated by several studies. The agreement is that BIM is an advantageous tool in the OSC method (Hammad & Akbarnezhad, 2017). However, some barriers impede the benefits of BIM in OSC. Partly the problem could be associated with the fact that digital and IT tools such as BIM and its derivative are not strategically aligned with the business goals and objectives of the construction project and the wider industry behind it. This is also indicated in a study by Eliwa, Jelodar, and Poshdar (2018) in exploring the strategic alignment model of IT applications in construction.

Future studies could be conducted to examine the effectiveness of BIM implementation in OSC method in New Zealand targeting construction waste reduction. Furthermore, these studies should be considered from the perspective of clients and stakeholders. Those findings could be an advantageous foundation for the future development of the OSC in New Zealand.

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Lean Philosophy and BIM for Productivity in New Zealand Construction

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ABSTRACT

Construction industry is behind most industries in terms of quality productivity. In general, the construction process is carried out in different stages, for the overall construction process to be successful, continuity between these stages must be achieved. Construction industry becomes more innovative, competitive and complex, more participants are involved in projects and thus, more integrated collaboration is needed especially during the design phase of the construction life cycle process. To generate information, make decisions and to improve the process of delivering facility in respect to the benefits for integrate BIM and Lean construction for productivity in construction project in New Zealand. The qualitative research approach was used in this research, pre-study showed and concluded that this would be the most effective way to carry out this research as it's about investigating an idea in a different way through theoretical approach. The study explores benefits to integrate Building Information Modelling (BIM), Lean construction, and sustainability principles for productivity in construction projects in the New Zealand construction industry. BIM use allows for better co-ordination between parties both internal and external contractors and trades, it plan well, reduce rework, reduce waste in construction, improve communication and collaborate environment. The study activates the management knowledge on how to minimize inefficiencies and enhance value delivered during design, build and operation

Keywords: BIM, Construction industry, Lean construction, Productivity, Sustainable principles

1. Introduction

Construction industry is behind most industries in terms of quality and productivity. In general, the construction process is carried out in stages. For the overall construction process to be successful, continuity between these stages must be achieved. This has been the major setback of construction productivity improvement for decades now. Waste is generated between the continuing activities by the unpredicted release of work and the arrival of resources (Hardin & McCool, 2015).

Although the construction industry globally is not highly productive however, the industry is one of the largest in the world economy. Consequently, its productivity has grown an average of just 1% per year over the last 20

years; on the other hand, and in comparison, the manufacturing industry has increased productivity by 3.6% per year during the same time period (Barbosa *et al.*, 2017). Currently, New Zealand building and construction industry needs to significantly increase its productivity to meet the expected demand for residential and non-residential construction.

BIM has been described as a game-changing methods and cultural process for the construction sector. A few countries globally are starting to realize the opportunities it brings and are now investing in developing their own capability (Mordueet *al.*,2015). Building Information Modelling (BIM) as a digital representation of a building geometric and non-geometric data, used as a reliable,

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shared knowledge resource to make decisions on a facility throughout its lifecycle (Meyer & Thumell, 2016).

Ingle & Waghmare, (2015) define Lean construction as a combination of operational research and practical development in design and construction with an approval of lean manufacturing principles to the successive design and construction process. Aziz & Hafez. (2013) revealed in their study, Lean construction as a way to design production system which reduces material waste, time and effort in order to produce a reliable amount of value, in addition Lean construction is also a production management philosophy which seems to suit sustainability principles in terms of waste minimisation, resource optimisation, continuous improvement resource, end user satisfaction and so forth (Rahman *et.al.*, 2013). While sustainable construction has been acknowledged as a driver for societal transformation (Rahman, *et.al.*, 2013).

The use of Building Information Modelling (BIM) is spreading rapidly through the global design and construction industry, and architects, engineers, constructors and owners in Australia and New Zealand are no exception (Mehran D, 2016). Australian and New Zealand are among the world's leading regions for Building Information Modelling (BIM), with firms planning to deepen their involvement. In order to accelerate this adoption, there is need to be able to define BIM benefits clearly and help educate owners about its value (Smith, P, 2013).

According to the United States BIM Standard; Building Information Model is a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle (National BIM Standard-United States, 2010). Therefore, construction industry had started the study on how to implement and integrate BIM, Lean construction and BIM with sustainable principles for better management in projects execution (Bolpagni *et.al.*, 2017).

More so, in recent decades the construction industry had accepted great need to improve its productivity, quality and incorporate new technologies to the industry due to increased foreign competition. According to the survey

conducted by Government Statistical Service in 1998 in United Kingdom (UK), the construction industry produces over 70 million tons of waste, which is about four times the rate of household waste produced by every person in the UK every week (Keys *et.al.*, 2000). A relatively new tool that is increasingly getting popular is BIM, which has been playing a major role in reducing construction waste. BIM involves representing a design as objects that carry their geometry, relations and attributes (Ahankoob *et.al.*, 2012).

Ahmad Latiffi *et al.* (2013) stated that BIM is more involved on design construction projects, for it helps to overcome construction problems in terms of delay, clash of design and construction cost overrun. Ahmad Latiffi *et.al* (2013) added construction players need awareness and knowledge of literature findings on implementation of BIM in safety management aspect and the potential of BIM. Therefore, this scenario demonstrated some avenue of achieving benefits of BIM usage when applied properly.

1.1 Integrated BIM and Lean construction principles

BIM involves representing a design as objects which carries its geometry, spatial relationships, quantities, properties of building elements, cost estimates, material inventories and project schedule. BIM is involved on design in construction projects which helps overcome construction problems in eliminating delay, clash of design and construction cost overrun while, Lean construction deals with managing and improving the construction process to profitably deliver what the customer needs. These reflect the entire life cycle of the project and not only the stage during which construction take place. Lean construction as a philosophy of achievements can be used to pursue several different approaches (Ahankoob *et.al.* (2012); Forbes & Ahmed, (2010); Ahmad Latiffi *et.al.* (2013). Therefore, construction industry had accepted the study to implement and integrate BIM, Lean construction with sustainable principles for better management in projects execution.

2. Knowledge gap

Delay in construction process is one of the factors that contributes towards hindering the quality of the finished facility in construction projects (Hussin *et.al.*, 2013). Smart Market Report (McGraw-Hill, 2010) clearly showed globally how the construction industry is experiencing a modification in the form of BIM, and with the ability of

BIM to reduce rework and increase project value, governments around the world are taking points on the usage of BIM

It is important to improve quality of materials management in order to overcome these problems by adhering to specification regarding Bill of Quantities (BOQ), International Organization for Standardization (ISO) and Construction Industrial Development Board (CIDB) Scott & Marshall, (2009). Therefore, to overcome these irregularities in construction projects, there is need to obey the objectives of the National Housing Policy (NHP). Scott & Marshall, (2009) suggested to construction players in the construction industry, New Zealand to strictly obey and observe the aims and goals of NHP. The study itemized benefits in the application of BIM, Lean construction principles for productivity in construction projects.

Numerous problems occurred in sustainable projects, these problems include delay, dirty construction sites, difficult and dangerous site conditions, poor quality of work and occurrences of accidents on construction sites such as the collapse of buildings (Sundarai. H, 2006). Bernama (2009) shows such problems caused negative impact to construction industry, these are signs of weaknesses to construction industry, which can occur to any construction industry if right measures are observed. Though, these problems could be resolved with ICT solutions. The use of ICT in construction projects helps to manage projects in creative and effective ways (Sebastian R, 2011). Sundarai H, (2006) further stated that ICT motivate the introduction of BIM as a tool to manage construction projects effectively.

BIM application usage can overcome problems in construction projects, and its application remains in its beginning stage (Jabatan K. R., (2013). Therefore, construction players need to be aware of the benefits involved using BIM as it helps to improve implementation of construction processes. It also noted that BIM is still new in most of the construction industry. BIM is perceived as a high-class technology to be adopted, but it has been proven to provide solutions to the above-mentioned construction problems.

According to Baines *et al.* (2006) Lean Construction was introduced based on the following basic principles

- focusing only on the products/items which add value to the customer and ignore anything which does not have any value for customer
- consider production as a continuous flow and not as an isolated phase
- make product as good as possible, reliable flow in the production line, decentralized decision making and distributed information
- deliver a product with specific customer specification with nothing in inventory

Therefore, the preparation for sustainable construction has not succeeded yet as expected because of the discipline division over the entire project life cycle. As a result, it is expected an "Integrated approach" is imperative to eliminate the current limitations for delivering sustainable projects (Jelodar *et.al.*, 2013; Rahman, A. *et.al.*, 2013), further stated BIM, and Lean Construction have the prospective to achieve sustainable goals in a highly integrated method. Therefore, BIM has protected different sustainability issues such as energy efficiency, optimum resource consumption, process commencement in an integrated method through partnership with different stakeholders. According to Koskela *et. al.* (2010) Lean Construction, BIM and sustainable construction play the role of production, representation and requirement of a creation. It shows the approaches and interactions within Lean construction, BIM and sustainable construction to each other, which can be an opportunity to change the model of the AEC industry for better (Likita and Jelodar, 2019). Therefore, the study has three approaches to be used to theoretically show case the benefits of using BIM in construction project. Figure 1 shows an illustration for integrated framework using BIM, Lean construction and sustainable construction (Rahman *et. al.*, 2013).

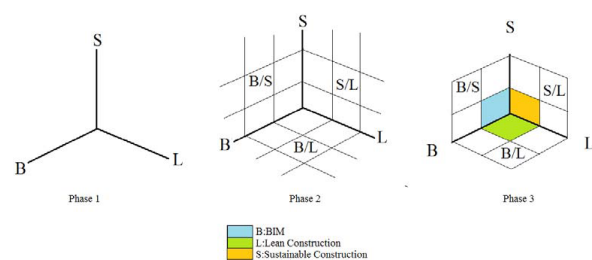


Figure 1 Integrated framework of BIM, Lean Construction; Adopted from (Rahman *et.al.*,2013)

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To generate information, make decisions and to improve the process of delivering facility in respect to the benefits for integrate BIM and Lean construction for productivity in construction project in the New Zealand construction industry

3. Methodology

Pre-study carried out on the study is the literature review of relevant articles to examine the possibility of writing thesis on this field and to get useful research papers for future researches in this field of study; as many prior studies have adopted this approach (Jelodar *et.al.*, 2014, Eliwa *et.al.*, 2018). To achieve aim and objective of the study, one hundred (100) pool of articles of previous studies were considered initially and explored using keywords; such as BIM, Lean construction, construction industry, sustainable construction and lean thinking. After a thorough investigation of articles; twenty seven (27) relevant articles and research work, with the theme of BIM, lean construction and sustainable principles in construction industry locally and globally were identified to be relevant to the goal of this; these articles were considered carefully in order to outline the pool of possible benefit in integrating BIM, lean construction for productivity in construction projects. Findings were discussed and compared, the qualitative research approach used for the study, after the pre-study, it was concluded to be the most effective way to carry out the research as it's about investigating an idea in a different way.

4. Findings

The study explores benefits to integrate Building Information Modelling (BIM), Lean construction, and sustainability principles for productivity in construction projects in the New Zealand construction industry. BIM use allows for better co-ordination between parties both internal and external contractors and trades, it plan well, reduce rework, waste, better communication and collaboration environment. It as well creates better understanding of complicated design (Wang, *et.al.*, 2013). BIM use also improved efficiency from take-off through to construction, when done properly and efficiently it works well and limits the issues on site, less risk, better engineering outcomes (Liu, *et.al.*, 2017). Lean

construction, BIM and sustainable construction play the role of production, representation and requirement of a creation. It as well shown the approaches and interactions within Lean construction, BIM and sustainable construction have to each other, which can be an opportunity to change the model of the AEC industry for better.

Therefore, innovation in the industry is the key to increasing productivity. However, productivity within the industry is needed so that innovation can deliver on demand (PWC, 2016).

Therefore, New Zealand construction industry need to accept the fact that all major construction management research organizations in New Zealand such as BRANZ, and other relevant bodies, currently has development plans in pipelines, including potential re-developments of the Christchurch City, it seems the perfect time required to take BIM-based research initiative in collaboration to construction industry in NZ is ready. A co-operative BIM research programme is hence needed towards construction industry in New Zealand, in order to move forward to the next level (Miller *et.al.*, 2013).

- It improves efficiency
- It plays role of production
- Requirement of a creation
- It eliminates current limitations for delivering sustainable projects
- It reduces rework
- It plans well
- Better communication and collaboration environment
- It creates better understanding of completed design
- Improve quality of material management etc.

It shows the approaches and interactions within Lean construction, BIM and sustainable construction (Koskela *et.al.* 2010)

5. Research significance

The construction industry globally is not highly productive, the industry is one of the largest in the world economy. Currently, New Zealand building and

construction industry needs to significantly increase its productivity to meet the expected demand for residential and non-residential construction.

Previous study related to this field clearly showed globally how the construction industry is experiencing a modification in the form of BIM, and with the ability of BIM to reduce rework and increase project value, governments around the world are taking points on the usage of BIM, and Lean construction principles for productivity in construction project, it saves a lot of designer's time, each view is coordinated through built-in intelligence of the model. It allows for better co-ordination between parties both internal teams and external contractors

MBIE, (2016); revealed the need for improvement in the New Zealand construction industry, is been documented in a variety of reports. Series of research within the New Zealand context showed motivation to increase productivity to meet future demand for construction, the reports needs improvements in specific areas of practice across the industry, for instance.

- regulation
- collaboration
- contracting
- design and engineering
- procurement and supply-site management, and
- on-site execution.

More, so other studies show a considerable work on benefits of BIM for construction processes and the expectation for BIM implementation in the construction industry is very huge, it revealed lack of BIM-focused on research, specifically to the construction market in New Zealand.

Proved indicates just few research papers are available describing possible ways to integrate BIM and Lean in the design phase. An added research is required in order to integrate the lean construction philosophy with BIM.

Therefore, BIM, and Lean construction are commonly helpful and co-operative.

The study explores benefits for integrated approach at theoretical level which links BIM, and Lean construction principles in order to promote productivity in construction projects using BIM, and Lean construction principles.

6. Conclusion

There are benefits achieved in application to integrate BIM, Lean construction principles for productivity in construction project and construction industry, according to previous study on this field and literature reviewed. BIM and Lean construction principles is a platform to share knowledge and communication between project participants, it is made of intelligent building components which includes data attributes and parametric rules for each object. It also provides consistent and coordinated views and representations of digital model including reliable data for each view.

Finally, BIM, Lean construction principles for productivity in construction project saves a lot of designer's time, each view is coordinated through built-in intelligence of the model. It allows for better co-ordination between parties both internal teams and external contractors. Design co-ordination improved and being able to demonstrate spatial areas and beneficial for decision making.

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Addressing Resource Shortages using International Joint Ventures in New Zealand: A Case Study

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ABSTRACT

The construction industry in New Zealand is facing acute shortages in key resources. Shortage of skilled labour, designers, engineers and other building practitioners, is well known and has impeded performance on ongoing and pipeline projects. The current study seeks possible solutions to help mitigate the risks associated with resource shortages and relief pressures on the NZ construction industry. No previous studies had investigated the role of international construction joint ventures in New Zealand nor is there any study on the impact of international construction joint ventures on resource acquisition. The study establishes the most demanding local resources and those which foreign construction firms could bring into the local market through International construction joint venture (ICJV) strategies. Primary data was collected through the administration of an online questionnaire survey to a representative sample of contractors and developers. The data obtained is analyzed using simple descriptive methods for ease of understanding. The result of the survey is anticipated will identify the most demanding resources and the potential constraints of resource acquisition through ICJV.

Keywords: Construction, International joint venture, Limitations, New Zealand, Resource shortage

1 Introduction

The New Zealand (NZ) construction industry is beset with a range of constraints and many issues that may impede ongoing and pipeline projects. These include access to skilled labour, building materials and funding (Vaughan, 2016). The deficiency of skills is not only in the trades but also in professional consultancy services including designers, engineers and other specialists (Steeman, 2018).

It is reported that labour shortages is highest in the Auckland region where according to the National Construction Pipeline Report in 2018, has a number of construction activities lined up in the next few years. The demand for all types of construction remain strong in the region and is forecasted to grow about 41% of the total national construction. The forecast is sustained year-on-year until the end of the forecast period of 2023, reaching approximately \$17 billion and 26% of total increase compared to 3rd quarter 2017 (MBIE, 2018).

While, the National Construction Pipeline Report

examined the volume of ongoing and future construction activities, the Reserve Bank outlines their concern about the fragmented nature of the NZ construction industry (Vaughan, 2016). The common perception is that big main contractors such as Fletcher Construction and Hawkins shall have their own directly employed tradesmen. However, the reality is that projects are operated with 30 to 50 subtrades, meaning that main contractors would need to co-ordinate and manage all these subcontractors (Steeman, 2018). At the Great Construction Debate held by the Property Council (2018) recently, Chris Haines from RLB pointed out it is the fact that the industry was made up by small and median size players, that it has been challenging to get training done and difficult for small contractors or subcontractors to employ a substantial number of staff because their workloads are unpredictable. Phil Eaton, managing director of Greenstone Group suggested resources were stretched, and contractors only had time to focus on delivering projects rather than investing in training programmes (Steeman, 2018).

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Furthermore, Harris (2019) reports that builders and subcontractors are very concerned about number of big construction companies failing in the middle of a booming building market. Arrow International placed itself in voluntary administration in Feb 2019 (Harris, 2019), Ebert Construction went into receivership in July 2018 (Gibson), Orange-H Group was placed in receivership by shareholders in May 2018 (Howard, 2018) and Mainzeal collapsed in 2013 (Gaynor, 2013). The collapse and failure of these sizeable contractors create nervousness to the financial sector and inevitably constraining some contractors' ability to enter into new contracts. Vaughan (2016) suggests that in such situations of funding challenges, projects may be delayed or cancelled.

Due to the above-mentioned market conditions and challenges, the industry is now struggling to achieve complex and large-scale construction works, coupled with lack of innovation. It was reported by Hartley (2018) that Pete Hodgson the chairman from Southern Partnership Group stated that no current main contractors in NZ could undertake the Dunedin Hospital Project. Pete stated that the project would expect to take 7 to 10 years to complete. Nevertheless, over the period about a decade, there could be great changes to the market and the industry including inflations, policies, regulations and government. This will lead to many unforeseeable risks over the time span of the project period. Construction industry specialist Jim French believed a joint venture of NZ company could be an option to undertake the main contracting role. There are indications that some Chinese and European companies are showing interest in undertaking joint venture on the Dunedin project (Hartley, 2018).

The central bank and prudential regulator of banks made the points in its 3rd quarter 2017 Monetary Policies Statement (MPS) suggesting the entry of international construction firms into the NZ market could help the construction industry defeat some of the funding challenges, and injecting the required resources and new technologies into the construction market (Vaughan, 2016). In light of all of these, there seems to be no easy solution nor short-term solution for addressing existing industry shortcomings. Although government and local authorities have intervened in the market through new and updated policies including introducing new regulations. Such policy initiatives are useful as the market cannot be expected to fix itself (Oliver, 2018).

2 Research Aims and Significance

Historically, the construction sector has experienced a cycle of boom and bust which had great impact on the national economy and employment. Currently, the NZ building and construction industry is experiencing its longest and strongest period of strength and it is anticipated to continue until 2023 at least. Nevertheless, the industry is also experiencing multiple challenges which constrain the sustainable growth of the economy and place industry participants at great risk (BDO, 2019). With all the difficulties and challenges facing the current market, industry insiders have been and are continuously seeking resolutions to these issues. The most frequently mentioned solution is the entry of "external" resources into the market by the way of introducing international construction firms into the NZ market. These could become a catalyst, to inject additional resources and new technologies, which may resolve current issues in the short and medium term.

Therefore the aim of this study is to identify the most demanding resources that foreign construction firms could bring into the local market through International construction joint venture (ICJV) strategy. The study also identifies the constraints of utilising overseas resources in order to help mitigate resource shortages that exists in the current market. This study focuses on three main research questions:

- What are the most demanding resources in the local market?
- What is the potential constraints/limitations in acquiring the identified resources?
- Could ICJVs help overcome some of the existing resource challenges in the local market?

The significance of this study is to in determining the most demanding resources from contractors, developers and consultants' point of view, to investigate the resource shortage issues from local practitioners' point of view and to identify the potential constraints and limitations of acquiring different types of resources. So that, existing and pipeline projects could consider these factors, then existing policies and project management plans and strategies could be adopted and improved to overcome these challenges. Also, this study could provide a basis for future ICJV studies carried out in New Zealand.

3 Literature Review

Resource shortages, fragmented nature of the construction industry, and funding shortage issues have been highlighted by a large number of reports and news articles over the past five years including but not limited to the recent BDO (2019) construction survey report, 'National construction pipeline report 2018' and the Reserve Bank 'Monetary policy statement 2017'. It is very clear that these issues in the NZ construction sector are already overwhelming, and interestingly ICJV strategy has been frequently mentioned by industry insiders and specialists. There are very few ICJV related studies in NZ

could obtain cheaper materials and or capable subcontractors (Ping Ho, Lin, Wu, & Chu, 2009).

Furthermore, Sung-Lin and Min-Ren (2011) argued that through the coalition of ICJV strategy, contractors can also share technologies and managerial resources to obtain new contract by breaking through the tender thresholds (prequalification requirement). Interestingly, this coincides with Jim French's suggestion that a joint venture of international and NZ companies could be an option to undertake the main contracting role for the Dunedin Hospital Project (Hartley, 2018). The thresholds for the Dunedin project was set to be no single NZ main contractor could undertake the job considering the scale

Table1: Potential demanding resources from overseas partners

1	Access to overseas supply chain - access to cheaper building materials & equipment.
2	Access to skilled labour & specialists (Carpenters, Joiner, Stopper, Tilers & Plumbers etc.)
3	Access to specialised overseas subcontractors (Design and build contractors, e.g. façade.
4	Acquiring design support services (detail design and coordination services)
5	Access to technical support (Material & equipment certification and testing)
6	Transfer of Technology (e.g. virtual design simulation and construction)
7	Acquiring procurement support services (Preparation of multi trade SoQ to enhance procurement process)
8	Transfer of project execution knowledge & experiences (Tunnelling, Deep foundation, Highrise structural, 5-Star hotel fitout)
9	Acquiring Project Management resources (Experienced project managers, site managers, site engineers, etc.)
10	Access to additional funding resources

construction industry that cover the resource acquisition issues. Resources sharing, transferring and pooling in ICJVs have been identified in previous studies outside of New Zealand, as one of the primary motivations of joint ventures in the construction sector (Razzaq, Thaheem, Maqsoom, & Gabriel, 2018). ICJVs allow partner organisations to access additional and new resources including new markets, capacity, staff, supply chain, technology, funding and finance (Terjesen, 2004). Through ICJV strategy, greater resources of expertise and knowledge could be made available (Norwood & Mansfield, 1999). Furthermore ICJV could assist by transferring advanced building technology, project management to the local partner as well as giving access to skilled labour resources (Luo, Gale, and He 2001); Panibratov (2016).

Also, it was pointed out that difficulties in finding and keeping skilled labour could be distributed to foreign partners by the way of transferring employees from foreign country to the host country where there is labour shortage issues exist (Bon-Gang Hwang, Xianbo Zhao, & Eileen Wei Yan Chin, 2017). ICJVs are gaining popularity because the procurement advantages through ICJV also

and complexity of the project. Resource sharing and cross-training and learnings from partners through ICJVs are considered one of the major sources that could lead to competitive advantage, different firms should consider the characteristics of their specific resource advantages and strengths to pursue different emerging strategies (Ping Ho et al., 2009). Due to the unique nature of construction projects, the level and types of resources available to the contractor are different (Khatab & Soyland, 1996) across different regions and nations. This study attempts to analyse the most demanding resources and its constraints, if projects were to be executed using ICJV strategy. The study establishes the potential demanding resources (see **Table 1**) through the review of literature relevant to international project execution.

Risks and constraints associated with ICJVs were similarly identified from previous studies to assist the evaluation of the potential constraints and limitations in acquisition of overseas resources. There are 25 risks in ICJVs in East Asia region, identified by Li and Tiong (1999); 58 ICJVs risks investigated by Shen, Wu, and Ng (2001) in mainland China; while Ozorhon et al. (2008) suggested it was difficult to manage ICJVs due to the different cultural

backgrounds between partners; Zhang and Zou (2007) investigated 17 risks in Sino-foreign construction JV project via fuzzy analytical hierarchy process approach. However McIntosh and McCabe (2003) identified 64 risk factors, probably the highest number of recent studies. Risks and constraints associated with overseas resource acquisition through ICJV strategy have been categorised (see table 2) but other non-resource related risks have been excluded from **Table 2** for clearer understanding. Some risks have been added by the researchers based on their industry experience in the local NZ construction market.

Table 2: Risks and constraints with resources acquisition

1	Quality control risk – Shen (2001); McIntosh (2003)
2	Warrantee risk
3	Import restrictions – Li & Tiong (1999); Zhang (2007)
4	Lead time risk – McIntosh (2003)
5	Delivery risk – McIntosh (2003)
6	Compliance risk (Building Code) – McIntosh (2003)
7	Currency fluctuation risk – Li & Tiong (1999); Shen (2001)
8	Language barriers – Li & Tiong (1999); Zhang (2007)
9	Culture barriers – Li & Tiong (1999); Shen (2001)
10	Differences in rules and regulations – Shen (2001)
11	Differences in construction methodology – McIntosh (2003)
12	Comply with local laws & regulations – Li & Tiong (1999)
13	Availability of labour – Shen (2001); McIntosh (2003)
14	Differences in design practices – McIntosh (2003)
15	Time differences
16	Buildability issues – Zhang (2007)
17	Incompliance with local practice – McIntosh (2003)
18	Restrictions from building authorities
19	Incompliance with Building Code
20	Restrictions of Money Transfer Policy – Li & Tiong (1999)
21	Intellectual Property Rights – McIntosh (2003)

4 Method

First, literature review relating to the theme of this study was carried out. The review was focused on the resource sharing, transferring, and pooling in ICJV from previous studies outside of New Zealand, as there is no previous ICJV studies found in New Zealand. 10 types of potential demanding resources were identified through literature review. Also, potential risks and constraints of resources acquisition through ICJV were listed out. Secondly, a

quantitative research method was carried out through the administration of an online questionnaire survey for data collection. The third step in the study approach was data analysis. This was undertaken to identify the most demanding resources and potential risks and constraints in relation to resources acquisition through ICJV strategy. Finally, a detailed case study was carried out in conjunction with the survey result analysis to further justify the findings and analyse the practicability of acquiring overseas resources through ICJV strategy.

Primarily, data was collected from local (NZ) construction practitioners through the administration of an online questionnaire survey. The survey focused on a representative sample of contractors, developers and consultants. A respondent-driven sampling method so-called snowball method was used to ensure adequate responses can be collected. A few industry professionals were contacted directly and asked to help recruit other participants through calls and e-mails. This method is commonly used to locate rare population or target participants that are anticipated to be very hard to reach (Zhipeng Cui, Junying Liu, Bo Xia, & Yaxiao Cheng, 2019). Also, a non-profit professional organisation - New Zealand Chinese Building Industry Association (NZCBIA) was approached to get additional support. The NZCBIA represents a wide range of businesses and professionals in the building industry in New Zealand as well as the Kiwi business and professionals that have close working relationship with the Chinese building industry as well as the local NZ industry.

The online survey questionnaire was developed by using "Google Form" which is free and easily accessible. The online survey was posted via social media 'LinkedIn,' and 'WeChat'. Email invitations attached with questionnaire links were sent to the identified construction professionals to get more survey responses. The survey period is anticipated to take about one month to complete from October to November 2019. The online survey contains 30 questions in total and anticipated to take about 15-20 minutes to complete. The questionnaire consists of three major sections. The first part (section 1) is the general information section which aims to collect information about respondent's profiles including the discipline or field of work, years of local working experience, any involvement in ICJV project/s and finally the respondent's job title. Feedbacks collected in this section allows the researcher to filter data and enables the delivery of a more accurate survey result. The second

part (Section 2) of the survey covered specific survey data regarding the demanding level of each identified potential resource which could be acquired from the foreign JV partner/s by using '5-point Likert' scale and followed by 'checkbox' of associated risks and constraints. For each question, there is an option to select "others" to allow the provision of gathering additional comments, which is designed to collect additional views for the risks and constraints from the participants that maybe addition to options other than those been listed.

The target participants are New Zealand based contractors, developers and consultants as these groups are deemed to be the key stakeholders of any type of project delivery. And they would most likely to be directly involved in ICJV types of project. Also, these target groups are assumed to be most appropriate to participate in the survey with less potential biases. For instance, local suppliers are likely to respond against sourcing of cheaper overseas materials through ICJV, local subcontractors would potentially be reluctant to partner with overseas subcontractors. Undoubtedly, overseas resources would bring potential competition to the local market which local subcontractors and suppliers would potentially act against to protect their own interest. Hence, contractors, developers and consultants are the most appropriate target participants in this research study.

5 Case Study – Application of survey results to an ICJV project

5.1 Case description

The case study project is an international hotel project, consisting of basement offices and ancillary spaces with parking. There are around 200 suites in total with a gross floor area of about 30,000m².

The case study project is one of the most challenging projects in New Zealand. The overall development has taken more than 4 years and is still ongoing. This is mainly due to its large-scale nature and complexity. Moreover, there are other factors such as lack of local project experience, poor design management, resource shortage and deficient project management.

The developer is an overseas international company that has no local project development experiences. The project management firm that was hired back in 2015, was rather a small project company at the point of time with limited large-scale project experience. The pre-construction stage involves many consultants from overseas, this added

difficulty to the design management. For example structural design was carried out by a large local based international firm, architectural design was carried out by a well-known Singapore design firm, Interior Design was carried out by a UK firm and detail design was assisted by a local design firm to adopt the local building code, Spa and Sauna design was carried out by a Hongkong design and build firm, while kitchen and Hospitality design was done by an international consultant based in Malaysia. The physical works were also let to multiple contractors including overseas and local contractors. The structural and the base-build works were mainly carried out by an incorporated joint venture between a local contractor and a Chinese contractor. The interior fit-out works were carried out by two direct fit-out contractors who were both new to the local market but have overseas project experiences. Facade trade were let to a Chinese company under the Head Contractor, services trades are mainly local and are all subcontractors under the Head Contractor. Landscape package was joint tendered between the Area Development Authority and the Head Contractor. Kitchen and Hospitality works are direct separate local contractor. Spa and sauna package was a design and build contract under one of the fit-out contractors. Finally, one of the Fitout Contractors was employed to carry out interior shop drawing works to improve buildability of the interior fitout concepts.

The construction contract that commenced around June 2016 can be described as "traditional" in that design liability resides with the principal. In June 2018 a variation was issued under the Contract which deleted signification fitout works from the Head Contract. The intention was to save costs and time as there was no local fitout contractor that could undertake the large-scale work involved. The original plan was to split the fitout works into many small portions (packages) in which the proposed strategy was not preferred by the Principal. The parties also signed certain commercial terms to reflect this arrangement and agreed to add local management resources to help the overseas Fitout Contractors to manage the Fitout works. The Main Contractor is generally responsible for the Fitout Contractors coordination with services subcontractors which is similar to them being a subcontractor of the Contractor. But the Main Contractor is not responsible for the default of the Fitout Contractors or any resultant delays caused by them. The Principal is still responsible for obtaining any necessary documents and/or information to be provided to the Fitout Contractors to allow the Main

Contractor to apply for the Code Compliance Certificate (CCC). In mid-2019 the Main Contractor issued a formal notification to the principal stating that they were experiencing delays beyond their control. The notification suggested a revised Due Date for Completion in 2020 and a revised target date of late 2019. Testing and commissioning exercise were to continue beyond that date. The final decision is still pending from the Engineer of the Contract. However, the delay was mainly due to lack of resources from multiple trades, also design coordination and delay of principal-supplied materials.

and limitations associated with acquiring overseas building materials and equipment through ICJV strategy. The most frequently identified risk is the “Compliance with local Building Code”, the total count of the risk selection is 34 out of 38 responses given 89% of the total. This is followed by “Warranty Risk”, “Leadtime issue” and “Quality control” with response count of 28, 27 and 26 out of 39 responses respectively. The lowest risk selection is “Appropriate labour to install and inspect” which was raised and added by the respondent.

Interestingly, the identified risks and constraints also reflect the issues experienced on the case study project.

Table 3: Level of interest for accessing overseas resources through ICJV

Type of resources	Ave	Med	Max	Min
1. Building materials and equipment	4.42	5	5	2
2. Skilled labour	4.05	4.5	5	1
3. Specialised subcontractors	3.79	4	5	1
4. Design support services	3.47	4	5	1
5. Technical training support	3.68	4	5	1
6. Technology transfer	4.05	4	5	1
7. Procurement support	3.95	4	5	1
8. Project execution knowledge and experiences	4.00	4	5	1
9. Project management resources	3.84	4	5	1
10. Funding support and resources	3.84	4	5	1

5.2 Survey result and case analysis

The survey result in **Table 3** shows a relatively high level of interest in accessing cheaper overseas building materials at an average of 4.42 out of 5 with a median number of 5. This implies that there is potential building material resource shortage in the local market or either a less competitive local market, this is reflected by survey result showing a high level of interests for acquiring overseas resources through the ICJV strategy.

Table 4: Risks & constraints of acquiring overseas materials

Associated risks and constraints	count	
1. Quality Control Risk	26	68%
2. Warranty Risk	28	74%
3. Import restrictions	23	61%
4. Leadtime issues	27	71%
5. Delivery risk	24	63%
6. Compliance Risk (Building Code)	34	89%
7. Currency and fluctuation risk	17	45%
8. Appropriate labour to install and inspect	1	3%

The survey result in **Table 4** shows there are certain risks

Compliance issue was the biggest concern, especially for areas where concerning fire protection, seismic considerations and services trades such as fire rating for timber veneer paneling, slippery resistant for marble stone and Water Mark Certification for sanitary wares. In the case study project, there were a few types of building materials had failed to comply with the local code requirements and then had to source those from the local market. “Leadtime issue” is always critical and requires careful planning for overseas procurement, as delays will most likely to impact the critical path delay for subsequent trade works and conversely early delivery would require extra local storage, hence increase cost. “Warranty risks” can be eliminated through careful selection and review process and also the participation of the spare parts schedule based on relevant project experience. There were very few issues relating to “Quality control risk” as all material samples were reviewed and signed off by the local consultants and the principal to make sure there is no sacrifice of quality from the overseas procurement strategy. “Delivery risks” on the other hand was a bit of

concern on the case study project. This is mainly due to the tight site space and the delays. Noted that the international shipment normally takes about 1 month, hence increased storage fee due to early arrival or would cause project delay vice versa. Lastly, "Currency and fluctuation risks" were relatively low and there is no data available due to confidentiality reasons.

The level of interest for acquiring overseas skilled labour is also considerably high, rated at the 2nd over 10 types of overseas resources. The average interest level is 4.05 out of 5 with a median number of 4, showing considerably high level of interest. The survey results align with the various industry reports reviewed in the **Introduction** section. There is a significant shortage of skilled labour resources in the local market especially in great Auckland region.

There are over 100 overseas skilled labour working for the case study project including Carpenters, Joiners, Stone layer and tiler, Wallpaper liner, Marble polisher, Spa & Sauna installer and Fine painters. The case study project has experienced skilled labour shortage since early 2019 when majority of the "Basebuild" works were completed and fine decoration works kicked in. As of November 2019, there was about 100 number of skilled labour shortage. Both Fitout contractors are continuously seeking for qualified labours in the local market and willing to offer a higher hourly rate. However, the result is a bit disappointing after a dozen groups of "skilled labour" suppliers were trailed on the job site and only a few were kept and deemed to be qualified according the project manager from the overseas Fitout Contractor. Hence, they need to reallocate and transfer more skilled labour resources from their other overseas projects to the case study project, which will cost time and money.

Table 5: Constraints of acquiring overseas skilled labour

Associated limitations and constraints	count	
1. Language and communication barriers	35	92%
2. Culture barriers (national & organisational)	26	68%
3. Differences in rules and regulations	30	79%
4. Differences in construction methodology	22	58%
5. Accommodation arrangement, travel etc.	1	3%
6. Restriction from immigration	2	5%
7. Mental health issues (anxiety due to homesickness)	1	3%

Through the literature review there are risks and constraints of acquiring skilled labour from overseas were

been identified. The survey questionnaires identified first 4 constraints, while the other 3 were identified and added by the respondents. The survey results shown in **Table 5** indicates "Language and communication barriers" is the biggest concern amount other risks and constraints listed, 35 counts out of 38 responses resulting 92% over the total responses received. Communication barriers is one of the major causes of loss of productivity on site. There are cases of two overseas trades workers trying to explain some details which were affecting subsequent trades work and finally have to call their own site manager to translate before execution. Also, misunderstanding of site instructions are workers, which often happens on the job site even for native speakers. Hence, communication barriers due to different languages are fully acknowledged on the case study project. Although, communication barrier is very difficult to overcome because second language requires years of practice, the barrier can be weakened by hiring bilingual management team and also grouping gangs with same language to reduce the level of miscommunication.

"Different rules and regulations" are rated the second highest potential constraints for utilizing overseas skilled labour. The survey result shows 30 counts, which is about 79% out of the total 38 responses indicating a relatively high level of concern. Health and Safety at Works Act and Regulations are relatively robust in New Zealand. Although Site Safe Training and Site Induction have become compulsory for all commercial projects across the industry, there are still difficulties to get all overseas labour to follow the rules and regulations on project sites, examples like not wearing safety glasses, using unauthorized power tools and improper use of mobile scaffold are frequently observed on site. There were a few Stop Work Notices issued to the responsible party at the beginning of the case study project to explain that there will be no compromise on safety working on the project.

"Culture barriers" include national and organizational barriers are rated as the third highest constraints on the list with a total count and percentage rate of 26 and 68% out of the 38 total survey responses. Although most of the labour are from overseas, there is no obvious national culture barriers or issues found in the case study project. This might be due to majority of the skilled labour having worked on other projects overseas and already get used to the multicultural working environment and also the number of different nationalities on the case study are also considered to be high. However, different

organizational working culture does influence project team members in both good and bad way. There are workers always following the project management procedures and respect each other's work, but some only focus on get whose own work done. Some are very cooperative and tend to work collaboratively with other trades workers and some are always complaining. From the observation from the case study project the organizational culture differences probably having more affect compare to the national culture barriers and the significant from the top-level management down to the lower level trades labour.

22 participants ticked "Differences in construction methodology" as their concern with acquiring overseas skilled labour which is about 58% over the total 38 survey responses shown a moderate concern level of risks. Again, there is no major issues found in the case study project. A few incorrect construction methods were found and been stopped immediately by issuing the Nonconformance Notice. There is a case that additive was not used for mixing tiling cement instead, the tiler was using water for mixing the cement which is incorrect and apparently was not following the specified method. The job was stopped immediately, and remedial work took place and cost \$8,000 for repairing the waterproofing damage due to removal of the tiling. It does take time for the overseas labour to get educated and to adopt the correct construction method to but with proper training procedures and management, there should not be a big concern.

Accommodation arrangement, Travels, Restriction from immigration and Mental health issue has been added by the respondents. Although these only stands relatively low percentage over the total responses level but were considered very good point, hence have been added to the **Table 5** and can be added to the future research studies. New working environment can be challenging and stressful for overseas workers, some contractors arrange accommodations and transportation for their overseas workers which adds some cost to the overhead but reduce a lot of risks of management. So that the overseas labour can be easily settled and they can focus on the job quickly. Noticed that there are quite a few numbers of skilled labour been rejected by the immigration offices for the case study project. This is primarily due to inadequate payrolls evidence and or other required information provided to the immigration office. There are considerable numbers of skilled labour with rich project

experiences and workmanship (Special purpose working visa applicants) have been rejected from the application due to lack of provision of required information and documents and this is mainly because in many countries cash payments are very common method of payment and hence there is no bank transitions information available for the visa application. The door is shut to these group of people and may never change. Lastly, there are labour live and work locally without their families, this can cause stress and anxiety issues that could be visible on site that do not stem from work.

6 Conclusion

In this paper, we focus on addressing the resource shortage in the local construction industry by using International Construction Joint Venture (ICJV) strategy. In the context of potential resource acquisition through ICJV, we also look into associated risks and constraints of ten different types of resources. The findings through online survey show relatively high interest level of all resources listed in **Table 3**. Which implies resource shortage issues exists in the local market. This also aligns with the industry feedbacks stated in the **Introduction** section "The unavailability of skills is not only in the construction part but also in professional consultancy services including designers, engineers and other specialists" (Steeman, 2018). Our case study of an ICJV project confirms our survey findings that material and skilled labour acquisition are the two most demanding resources in the local NZ market. Risks and constraints have been identified and analysed in detail. Our case study suggests that "compliance risks" and "lead time risks" are the most critical constraints for overseas material acquisition. The study also suggests that "Language and communication barriers" and "differences in rules and regulations" appear to be the most significant constraints and risks for utilising overseas skilled labour. Furthermore, "culture barriers" are found to be not a critical concern from the case study project, however management levels need to look into organizational culture barriers rather than national culture barriers. Finally, some respondents suggest "accommodation and travel arrangement", "Restriction from immigration" and "Mental health issues" could be added into the list. The researcher also analysed these constraints by using the case study and found that these are all valid and good points to add to this study.

Although there are many risks and constraints associated

with overseas resource acquisition, the survey confirms overall high level of interest from the local practitioners' point of view and the case study also reflects resource shortage issues exists in the market that overseas resources could be acquired to relief project execution pressures and beneficial to the project. It is suggested that overseas resource acquisition should be planned at an early preconstruction stage due to various risks associated with the overseas resource acquisition. Also, a project management team with ICJV project execution experiences would help deliver and address risks when they occur. Two key points could be extracted from the research study. First, forward thinking and collaboration of project programming and design management. Benefits and risks associated with the ICJV have already been discussed in this study and the most critical elements to deliver international resources acquisition is detail forward planning and accurate end-user management. Once the requirements are established, and decision made, it should not be reversed unless necessary. This is due to overseas procurement involving risks of long lead-time as well as materials and products are often custom made to suit different compliant requirements. It would be very costly and time consuming to change, and perhaps even more expensive than procuring locally in the first place. Hence, this requires design requirements to be accurate and decision making to be firmed and act quick.

Second, is given care to the overseas workers and employees. As discussed in the previous context that overseas employees may have psychological/health issues such as homesickness. Therefore, employers shall pay extra attention (care) to their overseas employees and provide a sense of belonging and connection with each other. Overseas construction firms should have designated teams to look after overseas workers. Conduct internal surveys periodically to see what can be improved. The key here is to keep the workers happy, so that their work efficiency can be improved.

6.1 Limitations

This research generated essential insights into the level of interest for ten different types of overseas resources from industry practitioners' point of view. The risks and constraints associated with the acquisition of building materials and skilled labour from overseas were investigated through an online survey and a case study. The study did not address the associated risks and limitations for the other eight factors due to time

limitation and the lack of case study materials.

However, there are clear indications of relatively high interest levels, which imply resources shortage issues exists not only for construction works but also management, consultancy, technologies, and execution works. We also need to be aware of the fact that the case study project is located in Auckland region whereas resources shortage varies from different regions. Auckland resources shortage are higher compared to other parts of the country. Hence the current analysis and results may not be applicable to other regions without taking account of local market condition.

6.1 Suggestions for future studies

The suggestions for further research studies follow from the limitations stated above. Further research could focus on the other resources acquisition areas such as the risks and limitations of acquiring specialised overseas subcontractors, design support services, procurement support, project management, etc. Also, further researchers could use open-ended questions to identify more types of overseas resources that could be acquired through ICJV strategy.

It would be relevant to focus on overseas procurement and management. Our case study has indicated there are challenges related to the overseas material acquisition; however, it did not discuss international procurement planning and management. The above listed risks and constraints could be referenced as a basis for overseas procurement studies.

Also, it could be interesting to study specific area such as immigration restrictions in relation to skilled labour acquisition through ICJV. To study what changes shall be made to get real, skilled people who are beneficial to the local building industry.

Finally, as mentioned in the Introduction section, skill training is inadequate in the local industry. Study of cross-training programmes through ICJV to bring the local labour up to a good standard could be another interesting topic area for future research.

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Applying Secure Information-based Mechanism for Prefabrication Supply Chain Integration: A Review

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Abstract

Various industries are taking advantage of innovations in their supply chain management practices. Construction industry, however, is considered as a slow adopter of technologies and innovative practices due to poor information integration which leads to lack of collaborative interactions and consequently reluctance to utilising technologies. Numerous studies have been conducted on supply chain practices in the construction industry, yet, research on prefabrication supply chain is limited, particularly where the effectiveness of supply chain management techniques is hindered as a result of low level of information technology adoption. Therefore, this paper provides an intuition into the integration of prefabrication supply chain stakeholders. A literature review is employed to identify a newly-introduced technology for information integration amongst supply chain stakeholders in prefabricated construction projects in New Zealand. The study indicates that using an effective and secure information sharing mechanism for prefabrication supply chain could enhance business interactions by generating greater collaborative and trustworthy environment amongst the partners.

Keywords: Blockchain technology, Information integration, New Zealand, Prefabrication, Supply chain interaction

Introduction

The concept of supply chain management is successfully used in different industries, but the use of this concept is very new for the prefabrication sub-sector of the construction industry. Prefabricated construction in New Zealand requires particular attention to the factors obstructing its efficiency and effectiveness, and lack of supply chain integration is observed to be a major issue limiting the performance of this sector (Shahzad, 2016). Collaborative relationships leading to positive prospects of future cooperation amongst supply chain partners is a pivotal point that drives the integration of supply chain within prefabrication construction (Akintoye, McIntosh, & Fitzgerald, 2000; Smyth & Pryke, 2008).

The current practices of supply chain integration mainly suggest that supply chain must be considered as an integrated value-generating flow, rather than merely as a sequence of single activities (Vrijhoef, Koskela, & Howell, 2001). Integrated supply chain ensures the processes of construction projects; design, planning, construction, and maintenance (Čuš-Babič, Rebolj, Nekrep-Perc, & Podbreznik, 2014). It also provides collaboration and trust amongst delivery team as a uniform

project team (Segerstedt Olofsson Anders & Bankvall Bygballe Dubois Jahre Lars Lena, 2010). For acquiring a collaborative and successful supply chain integration, efficient information sharing across stakeholders is essential (Konukcu, 2011).

Prefabrication is considered as an innovative technology in the construction industry which focuses on decreasing onsite construction activities as much as possible by transferring a significant portion of the events to offsite controlled environment (Shahzad, 2016). This research addresses the problem of relatively weak integration within prefabrication construction supply chain of New Zealand. The particular focus of the research is on information integration. The central point is that an effective and efficient exchange of information amongst supply chain stakeholders is imperative for enhancing supply chain integration in the highly fragmented construction industry of New Zealand. Therefore, providing a secure and effective information-integration-based platform for stakeholders involved in prefabrication projects will deliver integration improvement in the whole supply chain system.

Background

Prefabrication supply chain integration

Construction Supply Chain Management (CSCM) encompasses all the processes involved in project delivery from the procurement of necessary components to delivering the project to the end-user (Behera, Mohanty, & Prakash, 2015). It is also defined as managing the flow of information, materials, processes, and activities between upstream and downstream of organisations to deliver high quality and reliable products to the end-user efficiently (Akintoye et al., 2000).

The concept of supply chain management includes efficient flow of materials to the end-user and flow of information to the supplier employing integration, coordination, and cooperation amongst its members (Power, 2005). Still, this definition is being continuously revised by different authors in different industries and different use cases (Tan & Management, 2001). Nevertheless, the underlying premise of supply chain management can be founded in systems thinking, which magnifies the importance of considering all single parties involved in the cycle of delivering a product (or service) as a significant collaborator to a more substantial system (Cai, Jun, & Yang, 2010).

Supply chains are suffering from a lack of collaboration and coordination amongst stakeholders (Stadtler & Kilger, 2002). Within an organisation, inefficient integration of all supply networks hinders the sufficient flow of orders and products between suppliers and customers (Lambert & Cooper, 2000). Also, old-fashioned methods of production are now being replaced by innovations and advanced technologies which require organisational integration (Konukcu, 2011). Low transparency, traceability, and lack of trust can also be deemed as other difficulties resulting in ineffectiveness of supply chain management systems (Mentzer, DeWitt, Keebler, Min, Nix, Smith, & Zacharia, 2001). For a successful supply chain management, a modification from individual roles to the integration of key supply chain processes is required (Lambert & Cooper, 2000).

Supply Chain Integration (SCI) is a key for supply chain management (Konukcu, 2011). The

implementation of an efficient and effective inter- and intra-organisational SCM requires the integration of processes and flows (Cooper, Lambert, & Pagh, 1997). Broadly, a supply chain is made up of several distinctive organisations collaborating to accomplish a product or represent a service for customers to enhance the performance of a supply chain and improve the integrity. Integration refers to the stability and uniformity of project delivery systems and collaborative relationships with adequate flows (Dainty, Millet, & Briscoe, 2001). Suppliers' network complexity in the construction industry depends on the size of projects; generally, in large projects, the number of suppliers can exceed hundreds (Briscoe, Dainty, & Millett, 2001). Consequently, this complexity of various actors leads to the vital need for improving the adaptability of SCM techniques with the latest technologies.

In New Zealand, there is a vital need for adopting innovation instead of traditional construction since the country is confronting a significant shortage of housing (Gordon, 2018). For the next decade, Auckland alone requires approximately ten thousand new houses per year (PrefabNZ, 2018). This means that a more extensive area will face urban design problems, and also limitation of free land becomes more tangible. These constraints intensify the adoption of offsite construction rather than traditional construction (where construction sites accommodate site offices, machines, hangers, and material storages). In Canterbury, many buildings were damaged due to the earthquake in 2010, which means that there needs a vast effort to rebuild or repair the damaged houses (PrefabNZ, 2015). Moreover, there is a considerable number of low-quality and leaky buildings in New Zealand for which employing innovative actions are demanded to prevent the rise of this crisis (Gordon, 2018). Finally, supplying affordable housing is critically low in New Zealand due to geographical isolation and the high cost of materials and human resources. This also strengthens the need for adopting innovative construction practices (Shahzad, 2016).

As an innovative practice of construction, prefabrication technology in New Zealand is snowballing in terms of its percentage of contribution to the delivery of construction

projects. Increasing demand for new houses and lack of affordable accommodations in New Zealand evolve the need for innovative and effective types of project delivery systems instead of conventional types. The prefabrication sub-sector is identified as leverage for eliminating the shortcomings of traditional construction systems. However, this sub-sector of the construction industry struggles with its challenges, such as low level of coordination and integration across its supply chain partners (Zhai, Zhong, Li, & Huang, 2016).

Prefabrication has been the innovative element of the New Zealand construction industry since colonisation in the early 18th century (PrefabNZ, 2013). Even though the construction industry in New Zealand is resilient enough to employ innovative methods of construction, but the current use of prefabrication is relatively low (Shahzad, 2016). Prefabrication offers several functional benefits, including reduced onsite work, enhanced waste production, recycling, and reuse opportunities, raised health and safety, better quality control, and developed a custom design (Kaufmann & Remick, 2009; PrefabNZ, 2015). However, the construction industry, particularly in offsite manufacturing, is lagging in terms of supply chain integration (Segerstedt Olofsson Anders & Bankvall Bygballe Dubois Jahre Lars Lena, 2010; Shahzad, 2016). Complexities in prefabrication supply chains are higher in comparison with the traditional one due to the broken working sites (Mostafa, Chileshe, & Zuo, 2014), and this fact raises the need for better collaboration and more transparent communication. Moreover, managing the flows of information and materials, and responding quickly to any alteration in customers' demands or design require dynamic concurrent-management strategies as well as flexibility of supply chain partners to ensure that the effective integration of prefabrication supply chain is maintained (A. Gibb & Isack, 2010; Mostafa et al., 2014). As such, any challenges on the path of effective information integration need to be eliminated.

Information integration

Information exchange within supply systems requires integration as to offer opportunities for

fundamental improvement of supply chain integration. Information integration refers to sharing the information amongst supply chain partners and its key goal is to attain real-time information transmission across the supply chain system (Prajogo & Olhager, 2012). Integration of information promises logistics integration which is about the coordination of the flow of materials and resources from suppliers to customers (Stock, Greis, & Kasarda, 2000). Although numerous researchers proclaim that information integration is essential for an effective supply chain management (Frohlich & Westbrook, 2001; Patterson, Grimm, Corsi, & Review, 2003; Sahin & Robinson, 2002; Samarasinghe, Tookey, & Rotimi, 2013), it is not practically advanced in construction supply chain management (Cox & Ireland, 2002).

Information exchange in supply chain provides noteworthy improvement to business relationships and associated trust. As Yu (2001) explains, while supply chain is characterised with decentralisation, uncertainties appear when information inside a supply system is altered by a person and others either remain uninformed or get aware late enough to respond to the change correspondingly. This can produce variation in products' delivery time and relative cost. Also, Čuš-Babič et al. (2014) prove that information that is made by various sources leads to scepticism, distrust and disintegration amongst parties involved in supply chain.

With an efficient information flow and preserving information related to projects in a secure platform, the concern of information alteration would be decreased and supply chains can obtain better integration (Casino, Dasaklis, Patsakis, & Informatics, 2018). employing a safe platform for trading information and engaging a secure storehouse for information could efficiently result in improved decision making and collaborative and transparent relationships (Turk & Klinc, 2017). Also, all the information stored acts as the knowledge of project upon completion of the project and could be used in forthcoming projects (Penzes, 2018).

Offsite construction is a more feasible choice for isolated sites with low access (PrefabNZ, 2015). However, it resonates with a more complex supply chain since there are different sites and more

people involved (A. G. Gibb, 1999). Maintaining an efficient way of communication or information exchange throughout the whole processes of completing a prefabricated project would substantially reduce this complexity (Harland, Caldwell, Powell, & Zheng, 2007). The flow of information amongst prefabrication supply chain stakeholders is complex and this may pose challenges to achieving effective collaboration and supply chain integration (Jaillon & Poon, 2010). The issue of inefficient prefabricated construction supply chain can be mitigated by adopting advanced information integration technologies as a solution.

Potentials of Blockchain

Web or cloud-based supply chain management systems have recently been being used across the world for the integration of supply chain networks (Ngai, Cheng, & Ho, 2004). Information technology (IT) systems for SCM such as Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), and Electronic Data Interchange (EDI) are changing their place with cloud-based technologies such as Internet of Things (IoT), drone, and GPS receivers and RFID (Xing, Qian, & Zaman, 2016). These technologies have enabled fast and effective real-time information exchange across supply chain partners. Also, with the help of these technologies, harmful human interventions in information databases have been decreased (Ngai et al., 2004).

The adoption of information technologies in the supply chain, firstly, has reduced product development time by facilitating communication amongst the production team; Secondly, it has shortened cost and prices of products, and lastly, has brought improved quality as per customers' expectations (Chou David, 2004). However, even though the application of cloud-based technologies could add value to SCM, there are a few issues associated with them. (Finch, 2004) explains that information/data security can be considered as a significant issue about these systems since the risk of manipulation of stored contents or alterations by hackers is high. Meanwhile, these types of SCM systems provide all supply chain members, both inter- and intra-organisationally, with access to the

information repository (Chou David, 2004). In the construction supply chain, this can be hazardous since all of the information related to projects is susceptible to be changed either arbitrarily or intentionally by any user (Tse, Zhang, Yang, Cheng, & Mu, 2017). Which, in turn, can adversely affect organisations' market competitiveness and trust amongst partners.

Blockchain technology, on the other hand, can act suitably when it comes to security concerns. Distributed Ledger Technology (DLT) or mostly known as "Blockchain," is a consensus-based ledger that facilitates transactions amongst its users by providing them with a secure and tamper-proof database (Penzes, 2018). The first blockchain originally was invented in 2008 and introduced by Satoshi Nakamoto for crypto-currency transactions (Bitcoin) (Chen, Wang, & Zhang, 2018). It represents a network where various nodes perform their operations either publicly or privately without the intervention of a financial institution (Nakamoto, 2008). This technology would offer a peer-to-peer network where all the transactions are adhered with a digital signature to deter double-spending when there is no supervision of a trusted third party. This network chronologically timestamps all the transactions by the use of hashes in an ongoing block and provides a record that is impossible to be altered without the consensus of users (proof-of-work) (Li, Greenwood, & Kassem, 2018).

Blockchain is very similar to a cloud database on the internet, but the only difference is that blockchain is distributed, which means that the database is decentralised in multiple locations and in lieu of having one source for information with various access, various scattered sources can be updated simultaneously (Penzes, 2018). Once new information or transaction is about to be added to the chain, the peer-to-peer consensus mechanism rises to validate the information without the interference of an intermediary (Lu & Xu, 2017). This can be helpful for organisations to hinder malicious attacks on their information databases. Also, in the construction industry where the number of disputes regarding payments are incredibly high (Sutrisna & Goulding, 2019), blockchain can function as a trustworthy and dependable contract administrator. Blockchain

offers a reliable and error-free practice based on which the payments can be executed securely, and contracts can be created and monitored (Li, Greenwood, & Kassem, 2019). These capabilities and features can neither be found in traditional delivery systems nor in web or cloud-based databases.

Applicability of blockchain in prefabrication supply chain

The prefabrication subsector of New Zealand's construction industry, in some cases, has more complexity in comparison with traditional construction (Jaillon & Poon, 2010). In prefabrication supply chain, distribution of information might be more complicated because there are more actors involved in a given project. The separation of suppliers into two classification of "direct" and "indirect" imposes a more significant challenge for the construction actors to exchange the required information or documents (such as drawings, calculations, schedules and production details) in a quicker time and higher accuracy (Burgess, Buckett, & Page 2013; Shojaei, 2019). Also, acquiring regulatory approvals and consenting procedures are complicated in prefabrication due to the diversity of worksites and time-consuming inspection processes (Shahzad, 2016). This can lead to higher project completion time.

Moreover, in this industry, quality-based issues such as defects or reworks usually arise from ineffective traceability, coordination and collaboration amongst prefabrication supply chain partners (Bell, 2009; Shojaei, 2019). This would adversely affect the development of integration within this subsector. Trust is also a vital issue inhibiting the uptake of prefabrication in New Zealand (Shahzad, 2016). Most conflicts and trust problems emanate from inadequate information sharing and poor transparency in collaboration (Handfield & Bechtel, 2002). Lack of trust in prefabrication projects impedes future collaborations, affects adversely on stakeholders' relationship, and deteriorates the viewpoint of managers towards adopting innovations (Shahzad & Mbachu, 2012).

Although blockchain is relatively a new concept, New Zealand industries with the right policies and approaches could benefit socially, economically, and environmentally from this advanced phenomenon. New Zealand, in spite of being geographically isolated, is showing flexibility in adopting innovations for business development and is playing well in the global market (Burgess et al., 2013). Blockchain technology has the potential to impact significantly on the growth of domestic businesses, particularly on the prefabrication construction industry, where the technology is not practically being deployed. One of the foremost significances of blockchain in prefabrication supply chain is the fact that by stacking all the information in blocks, traceability is streamlined, and clients would be capable of tracing back all the processes related to completion of a project (Li et al., 2018). Thus, logistics efficiency, information flow, trust and transparency can be vastly enhanced (Zhao, Fan, & Yan, 2016). Also, by using this technology, interactions occurring amongst prefabrication supply chain organisations could follow an organised style of information exchange which, in turn, leads to transparency of documentation and accountability of each organisation in respect of their trustworthy and accurate contribution to projects' deliveries (Chowdhury, Colman, Kabir, Han, & Sarda, 2018).

Conclusion

Construction is one of the biggest industries in New Zealand. However, this industry suffers from many inherent issues including low productivity, poor quality of materials, lack of collaboration and information sharing amongst all stakeholders (Vrijhoef et al., 2001). While traditional construction suffers from such issues, prefabrication is recognised as a useful innovation for tackling most of problems by reducing defects, decreasing time and costs, and improving performance. The existing culture of prefabricated construction deters the adoption of advancements and makes the construction industry a sluggish user of supply chain information technologies (Shahzad, Mbachu, & Management, 2013). Therefore, for this industry, information technology platforms need to be improved for accommodating the knowledge

and information of project-based supply chains effectively.

Low level of effective information integration can be regarded as the underlying issue responsible for poor supply chain management. Inefficient information integration also leads to many other drawbacks such as poor collaborative and trustworthy supply chain environment. Employing blockchain technology as an information integration mechanism for improving; security, trust, collaborative relationships, traceability and transparency can be helpful for dispelling complexities arising from prefabrication supply chain fragmentation. Applying this technology in New Zealand's prefabrication supply chain helps obtain a more effective and efficient supply chain integration.

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A Proposed Conceptual Framework for Building and Property Management for State Schools in New Zealand

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ABSTRACT

Building and property management (BAPM) is a critical part of a school's operation since the building conditions and services set physical teaching and learning environment. In addition, state school property is one of the broadest public property portfolios in New Zealand. School managers in state schools in NZ are facing with various difficulties in managing their properties due to the complicated process and lack of knowledge in the area. Therefore, it is crucial to develop an integrated and comprehensive framework for building and property management for state schools in New Zealand. This paper conducts a literature review on asset management, property management, especially ISO 55000 series, and investigates the status of the property management system in state schools in New Zealand. ISO 55000 series of standards represents a generally recognised definition of competent Asset Management. This paper reviews the principles in the ISO 55000 series and addresses six aspects of the asset management system of an organisation which includes internal and external environment, planning processes, operational processes, support requirements, evaluation processes and improvement processes. According to the aspects of asset management and adopting Plan-Do-Check-Act cycle concept, the conceptual framework was developed which consists of five processes in the management, namely (1) Establish property management, (2) Develop property plans, (3) Implement plans, (4) Evaluate projects and (5) Review property management. The results are expected to clarify the complicated process in property management in state schools in New Zealand and provide a guide for the school stakeholders to manage their property effectively.

Keywords: Asset management, Property management, State school, ISO 55000

1 Introduction

The asset management specification PAS 55 (Publicly Available Specification) (PAS 55-1, 2008) defines the definition of asset management (AM) as the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organisational objectives. It is essential to develop a practical management framework for assets and properties in any organisation to achieve the goal of asset management. The framework should outline main aspects in different phases of the management, its impacts and influences such as communication and collaboration of the stakeholders, competencies of employees and information management and sharing. The asset management, property management and building maintenance management have some duties overlap, but

some distinct differences in responsibilities (Banfiled, 2019).

Successful asset management, building and property management require the organisational structure not only to embrace managing the property in use but play a vital role in providing a benchmarking of standards required and performance measurement. Shah Ali et al. (2016) state that good stakeholder communication plays a crucial part to ensure the strategy is carried out as planned. The organisation should determine the necessary competence of staff and provide appropriate education and training to acquire the necessary competence. In addition, future needs and requirements of the competent persons should be predicted and indicated to ensure that these persons conform to the improvement of the property management system.

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The critical challenge for the state school property sector is that there are more potential tasks to implement than resources and budgets will allow, which requires proper decision making in prioritising of tasks. Accurate and adequate information about the property condition and its performance enable managers to make the informed and practical decision in the planning stage. Kelly et al. (2005) suggest that information, expertise and knowledge are essential at all stages of the asset management.

There are various conceptual frameworks which have been developed for asset management, property management, and building maintenance management. PAS 55-1 (2008) was published for a standard for asset management. The PAS facilitates the integration of the asset management system with other related management systems. ISO 55000 series, considered as global standards on Asset Management, was published to enable organisations to achieve their objectives through the effects of their assets (ISO 55000, 2014). The adoption of the ISO 5000 series across a broad range of organisation is based on an integrated and continually improving management system. International Union of Railways (2016) translates the standards of ISO 55000 series into a railway context. "Lifetime reliability solution" organisation (2014) reviews all the requirements in ISO 55001 and then suggests ways to build the asset management system for an organisation. Regarding building maintenance management, Lee and Scott (2008) designed a conceptual framework among the main aspects of building maintenance from strategic and operational perspectives. Akasah, Amirudin and Alias (2010) developed a process model for maintenance management for school buildings which facilitates people's understanding of the process.

In New Zealand, state school properties are owned by the Ministry of Education and managed and operated by the school's board. The Ministry provides strategy, policy and procedures to help the schools in managing their property effectively that can positively affect educational outcomes. The school boards have an essential role in managing school properties. However, the school boards have a limited understanding of the Ministry's strategy and need more training and support in property management (CAGNZ, 2017). This paper aims to develop a conceptual framework to support the school boards to have a clear understanding of property management in state schools in New Zealand. Previous studies and

documented information were critically analysed based on the following three objectives: Objective (1) is to review asset management and property management framework and investigate the current management in state schools in New Zealand. Objective (2) is to review ISO 55000 series requirements, the latest international standards for asset management, and to map the requirements in different phases of the asset management, while Objective (3) is to develop a framework for NZ school property management to meet the strategy of the Ministry of Education.

This paper not only promotes a better understanding of property management of the school boards but also provides a review of the Ministry's guidelines in school property management.

2 Literature Review

2.1 Asset Management, Property Management and Facility Management

The International Standard ISO 55000 (2014) identifies various types of assets owned by an organisation such as physical assets or fixed assets, intangible assets, information assets, and financial assets. Physical assets usually refer to land or buildings, equipment, plants or machinery. The asset management specification PAS 55 (PAS 55-1, 2008) defines asset management (AM) as:

"...systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organisational strategic plan..."

In other words, the organisation controls and manages these assets to transfer value from the assets in the achievement of the organisation objectives over their whole life, through different stages. Effective implementation of asset management enables the organisation to maximise the value of the assets by

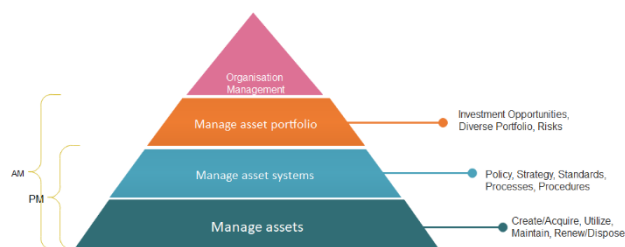


Figure 1: Levels of assets and their management.

Adapted from (PAS 55-1, 2008)

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optimising return on investment, reducing costs, managing risks, improving sustainability, efficiency and effectiveness.

Different organisations have different definitions of asset management and asset management activities will vary in different organisations as well. There are different levels of asset management, as displayed in Figure 1. The management depends on levels of asset units which can be identified and managed from discrete items or components to complex functional systems, networks, sites or portfolio. Asset management includes asset management plans which reflect the organisation’s strategic goals. In the plans, the asset life cycle cost, risks and performance are considered to seek opportunities for investing in the assets to support the delivery of the organisation’s strategic goals. The strategic goals are the foundation of the development of the asset management policy, strategy, standards, processes and procedures. The bottom level of asset management is the asset life cycle activities including creating, maintaining, renewing or disposing. While asset management is more of a process of overseeing the portfolio of assets performance and capital investment to enhance value and maximise return to the owner, property management is focused more on the operational aspects of assets such as physical maintenance, repairs and renovations, as stated by Banfiled (2019). Historically, property management is not well defined. It is commonly accepted as a part of asset management since the property is considered as one form of asset, which refers to real estate and physical assets such as buildings, constructed assets, plants and machinery.

At the same time, property management and facility management are two areas both responsible for maintaining and improving the organisation’s assets for their purposes. Salah (2016) summarised that the primary purpose of facility management is to ensure the functionality of the facility to support the organisation’s primary businesses and boost the performance and efficiency of the building systems. Facility management is generally focused on end-users’ needs and demands and responsible for health, safety and environment management (Balch, 1994). Along with the mentioned duties, facility management is used to coordinate space use and layout, facilitate moves and reconfigurations,

identify troubles and determine when the issue can be handled by in-house staff or need to be outsourced (Penny, 2018). In the context of this research, the development of building and property management framework for schools in New Zealand will be considered within the two bottom layers of Figure 1, excluding capital investment optimisation management.

2.2 Building and Property Management in State Schools in New Zealand

In New Zealand, physical asset management in schools refers to building and property management including all buildings’ structures, fabric, services (water, electrical, heating and ventilation systems), and schools’ infrastructure such as fence, gate, swimming pool, playground, garden, drainage, and pathway. Building and property management (hereafter referred to as BAPM) in schools aim to ensure and maintain educational standards as well as the health, safety and security of their users. State school property portfolio is one of the largest public asset portfolios and is managed by the Ministry of Education (MOE). Annually, around 800 NZD million capital and 170 NZD million operating is spent on maintaining and improving existing schools and on building capacity to meet roll-growth demand (MOE, 2017). The Ministry-managed state school properties include around 2,100 schools with over 30,000 buildings and 35,000 classrooms, approximately 8000 hectares of land (MOE, 2017). In 2011, MOE (2011) published a report on NZ school property strategy 2011-2021, which focuses on three strategic goals:

- “School property is well-managed”
- “School property is fit for purpose”
- “High-performing portfolio of schools”

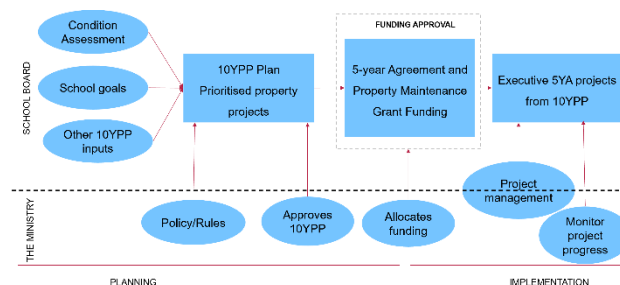


Figure 2: 10YPP process. Adapted from MOE (2019)

To achieve the goals above, school property management takes place at both a school level and a national level.

Nationally, there are different programs such as weather tightness, redevelopments, Christchurch schools rebuild, additional classrooms, and technology in schools. The Ministry leads the work in these programs in order to fix asset failure or pro-actively to manage major property or increases in demand. In 2013, the Education Infrastructure Service (EIS) and Sector Support Group were established, responsible for managing property matters located throughout the country. They provide services to help schools improve capital efficiency and ensure the properties are used to the best effect to meet the strategic goals of the Ministry. At school level, schools prepare their long-term property plan, which is called 10 Year Property Plan (10YPP), to identify all property matters in the next 10 years, and then funding will be allocated to implement these identified projects according to Five-Year Agreement (5YA), based on policies and procedures established by the Ministry. Regarding short-term maintenance, Property Maintenance Grant (PMG) is funded annually for schools to spend on painting, minor replacement, minor repairing, minor ground and site maintenance. Figure 2 shows the 10YPP process and roles between the school board and the Ministry. Once the 10YPP is approved, schools will implement the property projects in 5YA and PMG, with support from the Ministry advisors and external consultants, to ensure that their property is well maintained.

The management of each school property involves the multi-layered relationship among schools' stakeholders, as represented in Figure 3. Structure of the multi-layered relationship in the BAPM in the schools in Figure 3 represents both internal and external communications. The main difference in the organisational structure amongst these schools is the role of the principals in the management leading to the differences between the internal communications.

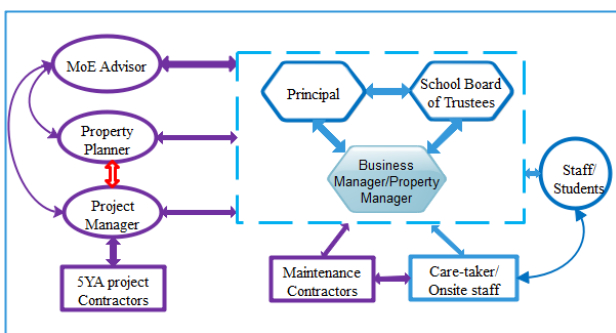


Figure 3: BAPM organisational structure in state schools in New Zealand. Source (Le et al., 2019)

In most primary schools, which have a small number of student enrolments affecting the school's budget allocation, the principals communicate with other stakeholders to operate all steps in the BAPM, while the bigger schools have a business manager or property manager who is responsible for the property management. Inadequate budget prevents the smaller schools from employing a property manager to assist their principals the property management tasks. The external consultants include property planners, who assist schools in preparing their 10YPP, and project managers, who are engaged to manage the 5YA projects for the schools. The Ministry liaises with schools through the network of property advisors who are based in regional offices, and their primary duty is to help schools manage day-to-day property matters (CAGNZ, 2017).

2.3 ISO 55000 Standards and Main Aspects of Asset Management

ISO 55000 series of standards were launched in 2014, representing a generally recognised definition of competent Asset Management. The implementation of the system based on ISO 55000 enables organisations to maximise the value of the assets by optimising return on investment, reducing costs, managing risks, improving sustainability, efficiency and effectiveness. This series can be applied by any organisation. However, it is challenging to adopt the ISO 55000 series since the documents mostly contain "what you must have" so organisations need to invent the "how to achieve" the standards.

ISO 55000 series includes three standards, namely ISO 55000: overview, principles and terminology, ISO 55001: management systems-requirements and ISO 55002: guidelines for the application of ISO 55001. ISO 55001 provides a framework of requirements for managing the use of physical assets. The framework addresses six aspects of the asset management system of an organisation including the internal and external environment, planning processes, operational processes, support requirements, evaluation processes and improvement processes. Figure 4 represents a structure of the framework in ISO 55001 providing requirements in each aspect (from clause 4 to clause 10), excluding clause 1 (scope), clause 2 (normative reference) and clause 3 (terms and definitions).

Organisational Environment

This part lists requirements for developing the asset

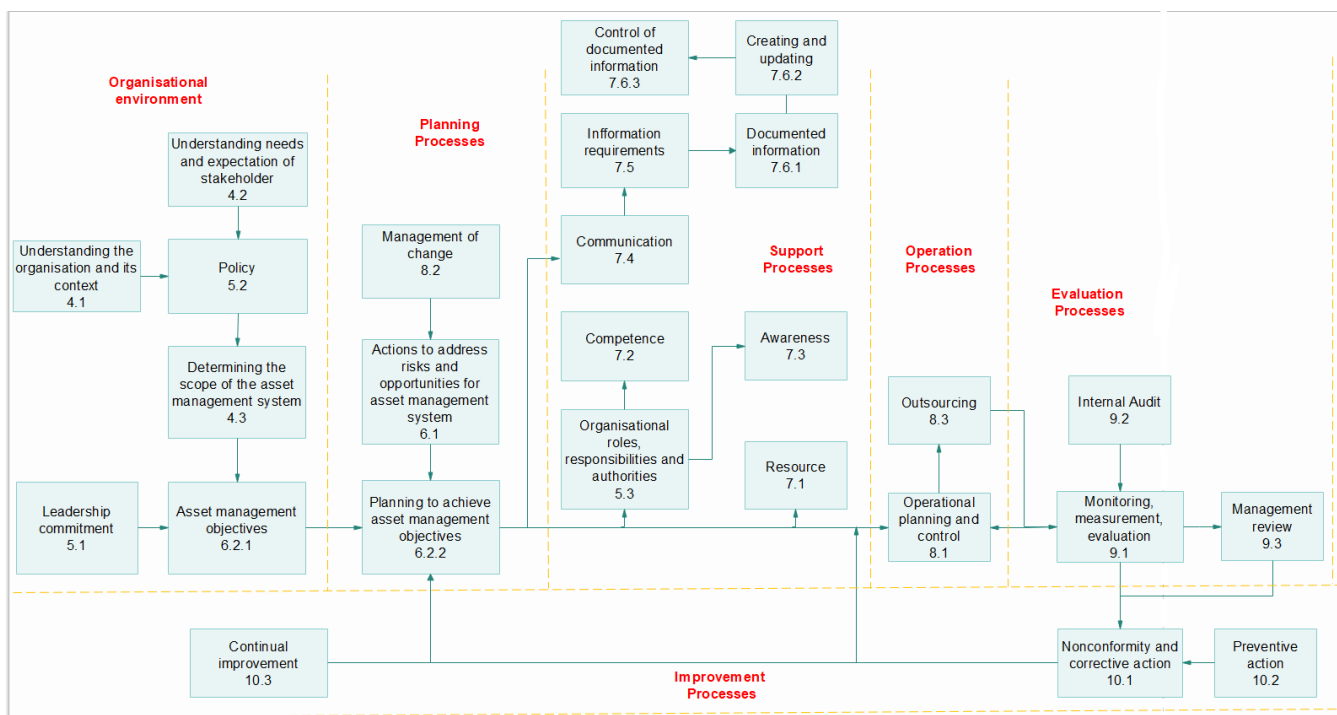


Figure 4: ISO 55001 Asset Management Requirements Framework. Adapted from Lifetime reliability solution (2014)

management objectives. All external and internal issues which affect the asset management, such as regulations, laws and the organisation context, are identified. The stakeholders’ needs and expectations are identified and prioritised to understand what they expect from the asset management and to prevent conflicts between the stakeholders. Then the asset management policy is developed to provide a set of principles for managing the assets. The scope of asset management covers all assets registered in the organisation’s system and their detailed scope-of-work for usage and maintenance. Top management in the organisation is responsible for developing the asset management objectives aligning with the organisational goals and visions and ensuring the success of the asset management.

Planning processes

The organisation establishes its asset management plans to achieve asset management objectives. The plans need to identify communication, roles and responsibilities of stakeholders’ involvement in the asset management, what resource will be required, the processes and methods in managing the assets. Identification and assessment of related risks and opportunities are considered in this stage, and any planned change shall be assessed before the change is implemented.

Support processes

ISO 55001 addresses a list of support factors for intended asset performance for the organisation. The organisation needs to identify all resources needed to deliver the asset management plans, including financial, human, equipment, and any constraints between the organisation's capabilities and the resources needed. Competence means knowledge, skills, experience and attitudes of people involved in the asset management. The organisation needs to identify its current competencies and any further training required. A communication plan is developed to cover all internal and external communications to ensure that the right information will be transferred to the right people at the right time. The organisation needs to address which information needs to be collected, recorded and managed to help the organisation to analyse the current situation and make the informed decisions.

Operation processes

The organisation will determine which activity will be outsourced and how to control the outsourcing process. For other activities implemented within the organisation, by using Process Mapping, all criteria for the required processes including inputs, outputs, control elements and mechanism, will be established. Top management of the

organisation considers, which is the most effective delivery method to achieve the intended outcomes under the resources allocated.

Evaluation processes

Monitoring and evaluating the performance of assets and the asset management is to ensure that the processes have been carried out as planned and the outcomes meet the stakeholders' expectations. The information collected in these processes aims to improve the performance of asset management. The organisation will determine what needs to be monitored and measured, when to perform the monitoring and measuring and which methods and criteria will be applied.

Improvement processes

The processes will generate lessons when incidents occur and how to minimise the effects. Preventive actions will be addressed to prevent the same issues in the future. Further improvement will be considered to improve the effectiveness of asset management.

3 A Proposed Conceptual Framework for BAPM for State Schools in New Zealand

According to the main aspects of the asset management framework in the ISO 55000 series the framework for BAPM has been proposed as in Figure 5. There are five processes in the management namely Establish property management, Develop property plans, Implement plans, Evaluate project performance and Review property management.

Establish property management

The aim of the process is to establish resources and organizational structure for the BAPM. The starting point of this process is understanding MOE strategy, policies, and procedures regarding the building and property management. The school boards need to understand the school internal and external contexts and identify stakeholders' expectations for managing the school's properties. Roles and responsibilities in the BAPM also are defined at this phase. People who are responsible for the property matters need to attend essential training provided by MOE. The MOE provides resources and supports including creating a communication plan among the stakeholders for the BAPM.

Develop property plans

This process aims to develop a long-term and a short-term plan for school property. Schools must appoint a property planner to prepare the 10YPP plan. The property planner coordinates with the school Board to review the history of property projects, and documented information and then conducts a condition assessment to identify all property matters in the next 10 years. Then, the property planner will prioritise the projects in 5YA and estimate the budget required. The Property Planner need to ensure that preparing 10YPP compiles with the guidelines and the Ministry requirements. Once the Board is satisfied with the 10YPP, the Property Planner will submit the plan to the Ministry for approval. The Ministry will check and approve the 10YPP if it meets the policy and funding criteria. Once the Ministry has approved the 10YPP, 5YA will be signed, and the budget will be released for the school to implement the approved projects.

Implement property plans

Schools may employ external project managers to help them manage the projects in 5YA to comply with the Ministry requirements. The project manager coordinates with the principal and the board representative to schedule the projects in 5YA to fit with other school's activities. Then, the school board schedules the maintenance works in line with the 5YA projects to maximise the effectiveness of a sequence of work. Both the project manager and the school board have a vital role in monitoring the projects to keep track of the projects' progress, review the schedule and adjust as needed. When the projects are completed, the project manager collects all the building and product warranties and hands them to the board with the project documentation. School boards decide how to use to the PMG for building and property maintenance (painting, minor repairing and minor replacement and site maintenance). Then maintenance contractors are selected to perform certain work, and school board will record and update the condition of building and property to the database after the work completed.

Evaluate and Review

The board assesses the performance of the project against the project results planned from the beginning. The project performance measurement may include the functional, physical, and environmental performance. It is essential to assess the success of individual projects and

the whole 10YPP cycle and share the results with the Ministry and other schools.

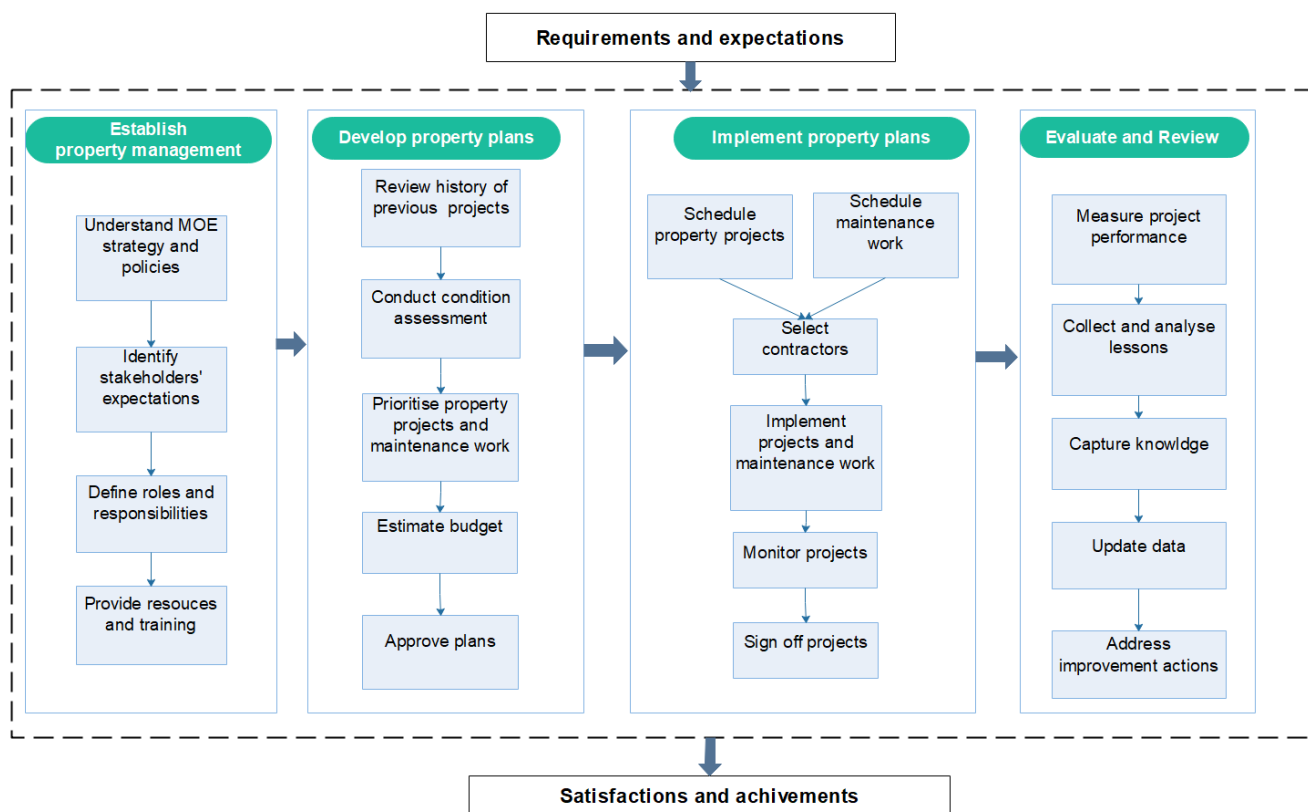


Figure 5: Building and Property Management Framework

Once the performance evaluation reports were issued, lessons can be analysed to identify challenges and barriers of the existing property management, then suggestion actions for improvement can be produced. Systematic performance measurement and data management will provide more insight about the impacts of property strategy, planning and implementation. As changes in principals and school board members often lead to loss of project experience; therefore, sharing experience and knowledge capturing will assist the schools in preparing next 10YPP. The lesson learned should be shared among schools and lead to achieve variety of improvement of property management. Knowledge management and updating data play a vital role for the property management but require a tremendous amount of time and effort. It is suggested that the MOE and schools to adopt innovative technology in the property management for improving the efficiency of data management, knowledge capturing and sharing information.

3 Conclusion

This paper reviews the requirements for asset management in ISO 55000 series and then develops the BAPM framework for state schools in NZ. Managing state school property in NZ requires a detailed and comprehensive framework. The proposed framework consists of five phases of the BAPM, starting with establishing property management, and finishing at reviewing the BAPM performance. Schools need to understand the strategy and policy established by the MOE while the MOE needs to facilitate collaboration and interaction between school board members, external consultants and the Ministry to gain more benefits of this work. Besides, the stakeholders involved in the BAPM need to attend essential training to be equipped with the capability to carry out their roles. Monitoring project and evaluating its performance should not only focus on the spending against set budgets and reporting about the project's progress and technical compliance but also share the lessons amongst the schools and the Ministry. The

updated information management system will prevent the loss of project experience and the information helps the stakeholders make informed decisions on property management. Future work may continue with research on how to create an effective communication platform and how to collect and share the experience systematically amongst schools and between schools and the Ministry.

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Rework Management in Life Cycle of Project: An Outline for Construction Contracts

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ABSTRACT

This paper presents classification of rework root causes (RCC) in the life cycle of projects. Rework is one of the main causes of cost and time overrun and affects project performance. Higher project performance will be achieved by reduction of rework through addressing rework root causes. The research investigates international and local past experiences on construction rework, possible associated standards and relevant regulations and policies for implementation. Through literature review of selected papers from the academic journals and conference papers, the causes of rework are identified in three stages of design, procurement and construction as the key elements of project life cycle. Analysis of rework root causes in the literature over a designed classification model in methodology section was the method used for the results of this study. Critical reviews on each stage are presented by distributing rework root causes in five categories of process, human resources, material and equipment, technical and other related factors. Contract conditions and clauses of NZS3910-2013 as the main used standard document for contracting in New Zealand are evaluated based on this classification. This paper provides a base for industry to bridge the identified knowledge gap between contracting and construction rework. The paper recommends that rework can be managed through contract documents.

Keywords: Classification, Construction, Contracts, Life cycle, Rework,

Introduction

Project performance is measured with the parameters of cost and time. When time overruns cause delay and cost overruns changes the budget, project performance is experiencing fluctuation. Rework is the key factor that mostly responsible for causing these overruns in projects (Hwang et al., 2009). It has been confirmed that rework is a predominant and persistent problem in construction projects. Nonetheless, construction industry has not been investigated well enough as research results still are inadequate in this area. Since construction firm's reputation is affected indirectly with the consequences of rework, the occurrence of rework is not announced willingly by the industry (Love et al., 2016). Institute of Construction Industry has proclaimed the average cost of rework is equal to five percent of total construction cost. In addition, a strong correlation between time overruns and rework has been reported in previous research

studies. Thus, rework in construction industry can be considered as a practical issue that influences project performance.

Project performance can be altered with some other triggers. Procurement and contracting strategy are among those key elements that play a vital role in the success of construction projects. The structure of cooperation amongst project participants is founded on contract documents as a final output of procurement. The potential change of contract conditions and necessity of revising the form of contracts have obviously repeated over again among studies of legal various contract frameworks (Chan and J.H.L, 2017). Contractual relationship development between construction practitioners will result in an acceptable level of construction performance improvement. Conventional way of project delivery almost makes conditions to debate in relationships. When projects are more complicated,

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relations of contractor and client need to be coordinated precisely to avoid contractual disputes (Pesamaa et al., 2009). New contracting strategies can decrease such interference of relations through defining the common goals among construction parties (Construction Industry Review Committee, 2001). Furthermore, collaboration of construction participants will be improved when ambiguity has been removed in contract conditions.

Rework research has contributed to the body of knowledge mainly through identifying rework causes, measuring rework impacts and proposing rework reduction models. On the other hand, research results on different features of contract in recent years have shown a trend towards shifting from traditional procurement system to contractual models. Industry practices show the same tendency for using standard type of contracts. Thus, literature review in this paper will be on two aspects of; Rework as an identified weakness in construction industry and contracts document as the final output of procurement stage. Theories around rework, guidelines for optimizing the impacts of rework and the methods of rework reduction will be presented in the first part of the literatures, and the second part would be on different type of contract, standard contracts and its documents.

Literature review

Section 1: Rework

Rework can be defined as an effort for redoing an activity or a process that was implemented incorrectly for the first time (Ibrahim Mahmid, 2016). Despite various interpretation of rework in the literatures there is a common understanding that relays on repeating a work due to nonconformity with the requirements (Hwang et al., 2009). Such nonconformance can be raised from different sources such as project specifications, client requirements or contract documents (Oyewobi et al., 2011). Rework in construction industry is considered as waste as does not add extra value to the process, while it uses time and other resources (Bhatl et al., 2016). Measurement of rework impacts to determine cost and time will not be accurate when there is no difference between rework, changes, defects, errors, fault, failure and deviations (Forcada et al., 2017). The success rate of rework reduction drops by using these replace words among practitioners instead of rework (Aiyetan & Dillip

Das, 2015; Hwang et al., 2014; Kakitahi et al., 2014; Taggart et al., 2014).

Construction industry is not able to manage rework when the main sources of rework remained unknown (Ye et al., 2014). Rework causes identification is the first step towards rework management. Rework can arise from complicated characteristics of construction processes (Hwang et al., 2009) such as errors, omissions, failures, damage, and change orders (Ibrahim Mahamid, 2016). Since rework occurs at field many of previous rework methods and definitions have not been succeed in addressing the exact causes of rework. Thus, various rework classification models have been emerged in construction industry for categorizing identified rework causes and measuring their impacts.

Classification of rework

Despite the various points of view on classifying rework root causes, having a model to manage rework consequences is essential when sources of rework were identified (Hwang et al., 2009). Following by some rework classification approaches in past few years the most recent system for classifying rework causes have typically been arranged in groups of “Engineering and reviews, Construction planning and scheduling, Leadership and communications, Material and equipment supply, Human resource capability” (Di Zhang et al 2012) and “Client related, Design related, and Contractor related factors including subcontractor and site management” (Aiyetan, 2013). Some more details for above mentioned factors that have been classified by previous scholars have been presented as follows;

- Design related factors: It has been emphasized that the numbers of originated rework at design stage are higher than construction. Inaccurate detailing, incorrect specifications, legislations, inadequate coordination, poor communication, lack of supervision and constructability are the factors that attributing to rework at design stage (Aiyetan, 2013). Errors and omissions are the most significant root causes of design related factors (Hwang et al., 2009).
- Contractor related factors: The contractor related factor can be considered under site management related factors and subcontractor related factors (Aiyetan & Dillip Das, 2015) as mentioned hereafter.

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- Site management related factors: Poor planning and coordination of resources and ineffective use of quality management practices are the most primary causes of rework in site management. Furthermore, the extensive reliance on traditional approaches and non-availability of specific IT for rework tracking is also known as other important contributing factors in this category (Shaik Ayaz Ahmed & B. Harish Naik, 2016).
- Subcontractor related factors: Inadequate managerial and supervisory skills and the carelessness by subcontractor are the primary factors that contribute to rework (Aiyetan, 2013). Multi layered subcontracting, low skill level of laborers in subcontracted works and poor-quality material used by subcontractors have identified as highly contributing factors of rework as well (Aiyetan & Dillip Das, 2015).
- Client related factors: Material replacement and change of plans and scope are the most contributing client related factors. Since change orders are the major source of rework in construction projects, all identified causes of change can be replaced as the main causes of client related rework factors (Hwang et al., 2014). Lack of experience, lack of allocated funds, lack of involvement, poor communication and shortage of contract documentation are the other major client related factors of rework (Shaik Ayaz Ahmed & B. Harish Naik, 2016).

Causes of rework

Designing a classification model that shows all relevant

categories of rework root causes can be founded on identified causes of rework from literature. A model with considerable flexibility for various construction groups will cover many of identified construction weaknesses that are originated from rework. A classification system that consists of all identified rework causes can be used for any consequent required action in process. To achieve this goal all identified causes of rework from literature need to be sorted in a comprehensive list. More details of preparing this list have been presented in methodology section of this paper. Here are some samples of rework causes from literature.

Owner change and design error and omission, (Hwang et al., 2009). Site management and subcontracting, project communication, project planning and resourcing, design time management, client changes (Love et al., 2009). Errors, omissions, failures, changes and poor site practice (Oyewobi & Ogunsemi, 2010). Supervision, workmanship, subcontractor selection, work protection and sequencing (Wasfy, 2010), poor effective use of information technologies, excessive involvement of client in project, lack of clearly defined working procedures, poor communication, ineffective leadership and changes initiated by the contractor to improve quality (Love et al., 2010), damage due to carelessness, poor planning, coordination of on-site resources and use of low quality materials (Aiyetan, 2013).

Interpretation of drawings and specifications, use of superseded drawings and specifications in the supply

Table 1: An overview of total rework cost from literature

Total rework cost	Direct cost	Indirect cost	Type of project	Year	Authors
10.29% of the contract value	5.07% of the contract value	5.22% of the contract value	Civil infrastructure projects	2010	Love et al.,
3.47% of the contract value	9.88% as total cost overruns	-	Building project	2011	Oyewobi et al.,
5.06% of the contract value	-	-	New Building	2011	Oyewobi et al.,
3.23% of the contract value			Refurbished building	2011	Oyewobi et al.,
16.5% of the contract value	-	-	Civil infrastructure projects	2014	Forcada et al.,
3% to 6% of the contract value			Construction	2017	Yap et al.,

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chain, lack of supply chain coordination, poor employee training, low skill level of subcontractors, lack of on-site inspection (Taggart et al., 2014), poor information (Simeh et al., 2015), Non-Conformance (Maheswari et al., 2016), schedule pressures, reduction of motivation to work, communication between clients and design consultants (Ibrahim Mahamid, 2016), poor project documents and ineffective decision making (Adnan Enshassi et al., 2017). Lack of understanding for end-user requirements, poor contract documentation and low consultant fees, lack of a quality focus, design audit and review, interface management, unrealistic schedule, poor project governance, staff turnover and lack of scope definitions (Jimmy Uso Wilson & Odesola I.A., 2017).

Rework cost impacts history

Impacts of rework in construction projects are mainly cost and time overruns and degradation of contractors. Positive relationship between rework costs and variation as well as time overrun implies that an increase in rework cost will give rise to an increase in variation cost and project duration (Oyewobi et al., 2011). Cost growth and schedule overruns are significantly correlated with direct rework costs, which suggest that rework can adversely influence project performance (Forcada et al., 2017). Project time overruns and delay reduces contractors' credential and the unpleasant cost impact of rework is damaging contractor's reputation (Love et al, 2016).

Table 1 shows various reported cost of rework (Jimmy Uso Wilson & Isaac Abiodun Odesola, 2017; Forcada et al., 2017; Love & Smith, 2019).

Rework reduction strategies

Different methods have been used to control of rework occurrence and mitigating its impacts as it has been shown in table 2.

Even though studies of different construction and design processes have successfully contributed to rework management, they have failed to provide strategic directions for rework management with the perspective of project life cycle. Construction rework research normally have focused on the general issues of reduction models, rework impacts and allocating of resources to solve the problem partially and separately in design or construction stages. In other words, rework root causes have not been fully examined within the life cycle of project yet and this would be considered as a research gap. Furthermore, among various rework studies in the literature, there is no approach has been proposed to incorporate rework with contract documents under context of project management. Since investigating contract documents of construction projects based in New Zealand has not been explored yet, looking for an optimize approach of rework management through contracting

Table 2: Methods and strategies on rework reduction and mitigation

Focus "Supporting Tool"	Reference	Year
The effect of BIM	Hwang et al.,	2019
Regression model	Nuria Forcada et al.,	2017
Motivations and leadership	Love et al.,	2016
Supervision	Maheshkumar Ramesh Shinde	2016
Rework probability model	Simeh et al.,	2015
System dynamics methodology	Ying Li & Timothy R.B. Taylor	2014
Role of supply chain	Martin Taggart et al.,	2014
Overlapping strategy matrix of design and construction	M.A. Hossain, D.K.H. Chua	2013
The probability of rework occurrence (risk control)	Love and Sing	2013
Rework reduction program (RRP)	Di Zhang et al.,	2012
Stepwise multiple regression	Love et al.,	2010
Rework cycle	Rahmandad, H., Hu, K.,	2010
Pre-project and quality management plans	Hwang et al.	2009
Characterizing the sensitivity of downstream construction activities	Blacud et al.	2009
Using AAN method	Palaneeswaran et al.,	2008

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process is the novelty of this research.

Section 2: Contracts

Trend of changes in using different types of contract

Contractual agreement for construction projects does as a permit to start the practical work after completing the procurement stage. Contract that is a confirmed document between parties is crucial as it determines the overall construction framework including responsibilities structure for each party, stakeholder's authorities, covering risks and any other relevant issues, which may happen during the execution of construction project. Construction projects are mostly complex process as it generally involves long period with participation of many stakeholders and ambiguous contractual relationships (Adekunle S. Oyegoke & Michael Dickinson, 2009).

Most of the projects were completed under the traditional system of lump sum contracts and this trend continued to middle of twentieth century except for some private sector that developed design and build model to improve relationship, schedule and cost by approaching contractors. Following by that, construction management terms (CM) began to start and soon after fully developed in United Kingdom. Simultaneously the other method of consultative design and build was developed, but client's request to complete complex projects in a more efficient ways caused emergence of program management in 1980 and onwards. During the late 1990s and early 2000s other types of management approaches such as (FA) framework agreement based on teamwork concept, collaboration arrangement and integrated teams became more predominant (Adekunle S. Oyegoke & Michael Dickinson, 2009).

Common contract models in construction

Some of the most applicable contract models in construction industry are as the following:

- Traditional lump sum contracts: This contractual model is very common within industry. Most of contractors and clients have familiarity with this model. The consequences of this flow are design development, tendering, contract awarding and then delivery of construction. It is expected that design

stage to be finished before tendering to get a fixed price of construction cost. In most construction projects design is not completed when construction starts, and it provide opportunities for contractor to ask for variations and claim for extra pays. Thus, one drawback of this model is to prepare ground for confrontational approach over disputes.

- Build, Operate, Own and Transfer: BOOT is a group of models that is common for PPP "Public Private Partnership" and PFI "Private Finance Initiative" type of projects. This model provides a way for governments looking for finance in private sectors. According to this model advocated for schemes such as railways, tolled roads, tunnel and bridges (Kelvin Xi Zuo, 2010). Contractor as part of a consortium is taking all responsibilities of design, construction plus operation and client is taking lower cost risk. However, client that in most of cases is government cannot use this model for small projects without future stream of payback.
- Design and Build: In this model an organization, which is usually a contractor will be fully in charge of two major parts of design and construction of project. The contractor can subcontract or have a joint venture with a design firm to manage the project.
- PM/CM and on call contracting: In both case client hires a master contractor to get consultant and manage the project. In combined project management and construction management "PM/CM", an organization that called "management contractor" will do three main steps of representing to client, leading a design team and giving advice to contractor's team while they are performing construction processes as work packages. PM/CM takes a contractual agreement that carries financial risk within. On call contracting is the same method with slightly deference in executing the last part of processes. In this model, the whole work is divided into task. Task orders are smaller in scope and have more details compare to work packages in PM/CM. The approach of task order removes the uncertainty as it enables the project to be well defined, planned and controlled on budget as mini contracts are involved. Administrating too many subcontractors in this model in compare to PM/CM is one of the disadvantages.
- Guaranteed maximum price (GMP): In this model all parties "Client, Consultant and Contractor" will agree

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on a negotiated maximum sum that will be paid by client with a reimburse method, so any overspending of this agreed figure “GMP” due to mismanagement of contractor and consultant will be under their responsibilities. Thus, the risk of cost for the client is very limited. Relationship in this model is almost the same as D&B, but the major difference between them is that the design is fixed, and it used as the negotiated price limit with open book reimbursement from the client side.

- Full cost reimbursement: In this model contractor is chosen to take the project under a cost reimbursable base with an agreed allowance of overhead and having profit. This model takes the concept of GMP with development to another level as full cost reimbursable instead of using open book for partial. The cost risk for client in this model is the highest among all models. Auditing system is a critical element of this approach as client needs to be confident about both contractor and design team performance.

Evidences indicate that while trends toward using the traditional general contracting has decreased over the past few years, other type of contracts such as design and build contracts and cost reimbursable contracts have been used more frequently in contrast (Adekunle S. Oyegoke & Michael Dickinson, 2009).

Standard contracts

Various parts of construction industry have developed different groups of standard contracts for a variety of reasons such as meet the specific purpose, distributing risk among parties and making it suitable based on used contractual models. There are some international standard contracts are commonly used as well. The most well-known international standard contracts are, FIDIC, NEC and JCT. Apart from international standard forms of contracts there are numbers of contract standards are using in New Zealand as listed as the following,

- NZS 3910: This is one of the most commonly used construction contracts, which is used for building and civil engineering construction.
- NZS 3916: Conditions of contract for building and civil engineering construction-Design and construct
- NZS 3917: Conditions of contract for building and civil engineering construction-Fixed term
- MBS Standard Contracts

- NZIA SCC: Has a leaning towards protection of the architect involved in the project
- RBC1: (NEW BUILD): Prepared for use by Registered Master Builders and it is available for use on building contracts
- NZIA NBC-G
- NZIA NBC-MW
- NEC3

Among all above mentioned contracts the standard form of NZS3910 is the most common used document in New Zealand (Ali N., & Wilkinson S., 2010) that will be the core of evaluation in terms of classified rework root causes obtained from this research study.

Methodology

Rework management is complex and dynamic throughout the project life cycle of design, procurement and construction stages. Knowledge gaps for further research can be identified by the means of literature review (Bao et al., 2018). Although there is an increase of interests in reviewing rework topics over the years, a systematic literature review of rework from the perspective of the project life cycle has not been available. In this study the review was conducted through papers relevant to the topic of rework in construction projects to classifying rework root causes into distinct stages of project to facilitate future study on links between rework and contract documents. Choosing an effective strategy to manage rework will be simplified by better understanding of where the main problems are from a project life cycle perspective.

To find out more about rework root causes details in each stage of project, the papers published between 2005 and 2019 were reviewed in this study. Reference to the method used by (Bao et al., 2018) rework literature published in above mentioned years obtained and analyzed through the following approach. Rework papers in relevant journals were selected by using keywords of “rework” in paper titles within suitable search engines. Over 63 papers were directly relevant to construction projects and were selected to review including 56 journal papers from 38 different sources and 7 conference papers and thesis. More details of used papers have been presented in table 3. All identified rework root causes were listed by reviewing the selected papers in the next step and then

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Table 3: Overview of journals and selected papers

Source of papers "Title of Journals"	Number of reviewed papers
Journal of construction engineering and management	8
Civil engineering and environmental systems	3
Journal of management in engineering	3
Production planning and control	3
International journal of project management	2
Construction management and economics	2
Journal of Construction Project Management and Innovation	2
Structure and Infrastructure Engineering	2
International Journal of Sustainable Construction Engineering & Technology	2
Conference papers and thesis	7
Other journals	29

distributed in each stage of project life cycle based on the following classification model.

Design a classification model

Since this research would provide the base of further study on rework management through contract documents in each stage of project life cycle, a classification model to cover all future requirements need to be designed. Therefore, the following model including three levels has been developed in which all similar identified causes can be categorized in a single section.

Level 1: contract parties

Different organizations may involve in executing of a construction project, but to make this model simpler only two direct parties of a contract have been customized. Client and all subsidiaries working for client such as consultants or other legal entities have been set in one side and contractor and all relevant subsidiaries such as subcontractors and suppliers have been set in the other side of contract.

Level 2: Project Phases

According to PMI "Project Management Institute" a life cycle of project is consisted of developed sequences from initiation to closing. In construction industry this definition will hold three main stages of design, procurement "tendering" and construction. Accordingly, all identified rework root causes have been categorized in these three stages. In this level of classification model, the following steps were considered to maximize the accuracy of assigning each cause to each stage of project:

- Identify rework root cause of relevant paper designation as precisely as possible
- Match this information with project stage details to find a direct relation in between
- Merge similar rework root causes in each stage to simplify and optimize the result

Level 3: Root causes

Investigating of rework causes classification in the main used references for this paper indicated that each author has applied a certain model that is vary from each other. To reach an integrated classification model considering two pre-mentioned levels, this paper has categorized all rework root causes in five subdivisions (Hemanta et al., 2011; Ibrahim Mahamid, 2016).

- Process related factors
- Human resources related factors
- Material/Equipment related factors
- Technical related factors
- Other related factors including financial and environmental

The ultimate expected output of the research would focus on identifying and classifying the main causes of construction reworks and their roots, which embedded in contracts. The study will come up with development of a comprehensive list of classified rework root causes in each stage of project to find out relations with contract documents.

Findings

Analysis of papers showed that all identified rework root causes in literature are available in seven most recent studies between the years of 2009 to 2017. Two significant features of these seven papers are; all published in a well-known journal worldwide and all have a list of rework root causes that make them easier to evaluate (Asadi et al., 2019). All distributed rework root cause from literature at first level of designed classification model showed a total number of 374 as can be seen in tables 4 and 5. Following the steps at each level of deigned classification model will result in a total of 316 items including internal and external root causes of rework in life cycle of project (Asadi et al., 2019). It shows that the total numbers of 58 items have been repeated at the time of distributing rework root causes among the classification matrix. Repeating items were containing of 34 items in design and 24 items in construction stage.

Discussion

To better management of rework in construction projects this study has provided details information of rework root causes through literature review. Based on search method and three level of classification model, a total number of 374 rework root causes were identified and classified through distributing within project life of cycle. Identifying the connections between rework root causes and stages of project may benefit the construction industry as it depicts where problems need to be considered in a certain area. Analysis showed that while distribution of rework root causes is seen within life cycle of project each level of classification model holds different numbers of rework root causes. Since all records in tables 4 and 5 of finding section are counting the numbers of rework root causes for each section, the subsequent results are discussed just in terms of quantity regardless of rework impacts.

Table 4: Numbers of classified rework root causes in client and contractor side of contract

Category	Client	Contractor
Process	39	31
Human resources	22	45
Material and Equipment	2	22
Technical	61	86
Others	32	34
Total	156	218

In terms of contract parties in first level of classification model the total number of 218 rework root causes have been allocated to contractor while this figure for client side is showing as 156 root causes. The Construction stage includes the greatest number of causes of 220 among all tables, while the procurement stage consists of the lowest number of 18 causes. In third classification level, technical related factors with the total numbers of 147 are showing as the most contributing causes of rework. In contrast, Material/Equipment related factors with total numbers of 24 have been ranked as the lowest. The highlighting of procurement stage for holding the lowest number of rework root causes is understandable as this stage is only limited to a few months of tendering and will be closed after contract issuance. When figures of table 5 are judged individually the sum of three specific factors nearly are calculated as the half of the total identified rework root causes. These figures show that process related factors in design stage following by technical related factors in design and construction stages can be considered as critical areas for rework management.

Conclusion

Rework and reduction strategies of rework impacts have received extensive attention in recent years; nonetheless rework is suffering construction industry probably because projects are measured out of the project life cycle context (Xue et al., 2010). This study has provided a platform to give more insights to the matter of rework with the perspective of project life cycle. Although rework has been reviewed as the core of this study, it is acknowledged that this review is only limited to the identification of rework root causes. Considering all identified rework causes from literatures and classified their roots, a comprehensive list of rework root causes for each stage of project is prepared as the main result of this paper. Classification of rework root causes at this level may allow projects to be managed more efficient. However, the analysis of literature over 80 papers showed enough evidences to cover all stages of project life cycle, more study on rework management specifically in procurement stage will be recommended in future.

The outcomes of this research inspire more studies around rework management by focusing on project stages

Table 5: An Overview of distribution of rework root causes in life cycle of project

Stage	Design			Procurement			Construction			Total RRC*
	Client	Contractor	Total	Client	Contractor	Total	Client	Contractor	Total	
Process	25	17	42	4	3	7	10	11	21	70
Human resources	20	14	34	0	0	0	2	31	33	67
Material/Equipment	1	0	1	0	0	0	1	22	23	24
Technical	30	16	46	5	2	7	26	68	94	147
Others	11	2	13	3	1	4	18	31	49	66
Subtotal of	88	48	136	12	6	18	57	163	220	374

*RRC is abbreviation used for Rework Root Causes

or even more detailed on each stage that have been previously underestimated. Particularly, this research suggests that contract document which is the final output of procurement stage as well as starting point of construction needs more investigations in terms of rework management. A preliminary study on covering of rework root causes by the contract clauses and its attachments will prioritize the importance of each related factors based on project stage. The paper suggests that better rework management will be attained through revising contract clauses and its attachments. The results of this paper will consist of independent variables for further research to find relations of rework and contract documents. Searching for this relation can be implemented based on a list of *Rework Root Causes* (RRC) against clauses of contract for each stage of project through a questionnaire. Details of this questionnaire after removing repeated causes among various papers and unifying the same themes are structured as 48 RRC in design stage, 15 RRC in procurement stage (Asadi et al., 2019) and 47 RRC in construction stage.

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Analysis of Factors Affecting Design Buildability in New Zealand Construction Projects

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ABSTRACT

Buildability is an important consideration throughout any construction project. A highly buildable design can actively contribute to the productivity and performance of construction projects. Knowledge gap: In New Zealand, the significance and benefits of design buildability are currently not well recognised within the construction industry. Also, the awareness of the necessity of buildability assessment is still weak. This research aims to identify and analyse the factors or attributes that will have significant impacts on the design buildability in New Zealand. The objectives of the research are: to review the buildability performances in New Zealand and to identify the level of significance of factors affecting design buildability. In this study, more than thirty research papers from eleven different countries and regions will be used for data collection. Document analysis will be conducted based on past literature. The data about buildability factors and performance will be extracted from those research papers and resources. As a part of the research output, clear designer guidelines of buildability concepts will be developed. It is expected that the designer guidelines will help designers to minimise buildability issues at the design stage, and hence the construction project efficiency and performance in New Zealand can be improved.

Keywords: Design buildability, Early contractor involvement, New Zealand

1 Introduction

Buildability is an important consideration throughout the construction project. A highly buildable design can actively contribute to the productivity and performance of the project. Nowadays, construction projects are becoming more complicated and convoluted. Similarly, the construction schedule becomes tighter and the number of parties involved in a project increases. This would easily lead to misunderstandings and conflicts within projects. It is important that the client, the designer, and the contractor fully understand the project goals and communicate well with each other. Therefore, the head contractor's early involvement (providing alternative solutions based on their experience) can possibly contribute to a more buildable design and lower construction expenditure. Early contractor involvement could also help the designer to understand the site condition better and produce a highly buildable design. However, as per the traditional procurement widely used

in New Zealand construction industry, the involvement of the contractor usually lacks at the early project stage. Further, in New Zealand, the significance and benefits of design buildability are currently not well recognised. Moreover, the awareness of the necessity of buildability assessment is still weak. Unfortunately, no building-related institutes discuss any concepts of buildability on their official websites.

The past research revealed that one of the possible barriers for designers not to consider buildability is their lack of awareness of specific concepts of design buildability (IPENZ, 2008; Wong et al., 2011). Another possible barrier could be the designer's lack of engagement with the site conditions since the design and construction processes are separated under the traditional procurement system (Holroyd, 2010). Therefore, in order to enhance project efficiency and performance through highly buildable designs, it is necessary to identify important factors influencing

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buildability. This research aims to identify and analyse the factors or attributes that would have a significant impact on the design buildability in New Zealand construction projects. The research answered two main questions: why is design buildability is significant in the New Zealand construction industry, and what are the key factors affecting design buildability. In addition, as a part of the research output, a clear designer guideline of buildability concepts was developed. It should be mentioned that this study explored design buildability criteria in New Zealand and other countries and regions such as Hong Kong, Mainland China, Singapore, Malaysia, Denmark and Nigeria. Overall, there were thirty articles reviewed in the literature review.

2 Literature Review

2.1 Definition of Buildability

Buildability has been defined in multiple times by different researchers and organisations. The word "buildability" first appeared in the late 20th century, which suggested a new form of designer-builder relationship (Jarkas, 2010). The Construction Industry Research and Information Association (1983, xx) defined buildability as how far the building design can "facilitate the ease of construction, subject to the overall requirements for the completed building," which is the most widely accepted definition of buildability. The definition of buildability from the Singaporean Building and Construction Authority (2017, xx) is "...the extent to which the design of a building facilitates ease of construction as well as the extent to which the adoption of construction techniques and processes affects the productivity level of building works." BCA also mentioned the "3S principle" as an important principle of a buildable design: standardisation, simplicity, and single integrated elements. On the other hand, constructability is another concept that is similar to buildability. It has been defined by the Construction Industry Institute (1986, xx) and Construction Industry Institute Australia (1996, xx) as "the optimum and integration of construction knowledge and experience in the project delivery process to achieve overall project objectives and building performance at an optimal level." In New Zealand, IPENZ (2008) adopted both the definition of buildability from CIRIA and the definition of constructability from CII Australia as the meaning of constructability. According to the above definitions, buildability lays more emphasis on the design of the building and the facilitation of the ease of construction.

Nevertheless, constructability focuses on achieving project goals by optimising and integrating construction knowledge. It considers various stages of the construction process, including planning, designing, tendering, construction, and use stages (Griffith & Sidwell, 1997). However, there is a common ground among the literature that the design stage is a significant stage for buildability assessment. With that said, once the earlier buildability assessment is conducted, the higher the benefits would be (Wong et al., 2011). Therefore, it is essential that the design buildability concept is implemented at the early stage of construction projects.

2.2 The significance of buildability

As mentioned in the introduction, a design that has a high buildability can shorten the construction duration, reduce material waste and save labour force, which would significantly contribute to cost savings. Buildability is also one of the most important and influential factors of labour efficiency. According to a series of researches done by Jarkas (2010), buildability factors "have a statistically significant influence" on rebar fixing labour productivity of beamless slabs, edge formwork labour productivity, and building floor formwork labour productivity, which indicates that design details have a marked impact on installation efficiency. It has been found that the buildability can also help to reduce potential defects of buildings. Nielsen et al. (2009) studied whether buildability can reduce the number of defects in construction projects. However, there was no conclusion provided. Tingiwensi (2000) conducted a case study of a 12-story commercial office building. The project was applied buildability assessment at the design stage. There were a few achievements of this project that are worth to be mentioning: there were no slope stability problems or structural failures although the ground condition was poor; the project was finished 4 months ahead of the schedule while it had been delayed for 4 months at the tender stage; the project cost had been controlled effectively (the cost was reduced from US\$ 1200 – 2000/m² US\$ 800/m²); and the savings were used to improve the quality of certain building elements. This case study indicated that the design buildability assessment could actively contribute to the project cost, schedule and quality improvement.

2.3 Applications of design buildability around the world

Singapore is the first country that developed a system for

buildability assessment called Buildable Design Appraisal System (BDAS). In Singapore, the requirement of a minimum buildability score had been applied as a part of the legislative requirements for all construction projects since 2001. It includes assessments of structural systems, the wall system and design for manufacturing and Assembly (DfMA) technologies. The BDAS listed specific buildable features for each system, such as "precast slab" and "integrated metal roof on steel truss," the design will get specific buildability points if any buildable features are applied. In 2011, the Constructability Appraisal System (CAS) was introduced in Singapore. The constructability was measured in the same way by CAS. The Building and Construction Authority in Singapore further increased the minimum requirement of buildability and constructability scores in 2013 to accelerate productivity improvement and reduce the labour demand.

Based on BDAS and CAS, Hong Kong has developed a scheme design buildability assessment model (SDBAM) (Lam et al., 2012). It is mainly developed for the scheme design stage of construction projects. SDBAM adopted an assessment measure that similar to BDAS, which analyses the building design by its building elements. However, SDBAM also listed non-buildable features that were not mentioned in BDAS nor CAS. Moreover, SDBAM has been validated in a few cases, which proved that it is feasible in real Hong Kong construction projects. The model enhanced the production efficiency and safety of building projects. However, the buildability assessment was not compulsory for Hong Kong construction projects.

Similar to Hong Kong, a few researchers from Mainland China have discussed how far BDAS can be adjusted and applied to the Chinese construction industry (Junying & Sui, 2007). It was suggested that buildability concepts should be widely introduced to the industry through the government to raise the awareness of the significance of buildability assessment. However, buildability is still a new concept in the Chinese construction industry.

The UK, USA, Australia, Denmark, Malaysia, Kuwait, Indonesia, Nigeria, and Uganda have introduced the concept of buildability in the construction industries. They studied the factors or attributes that have an impact on design buildability. Some of them have also introduced and applied buildability assessment in some construction projects. All of the projects that have been applied building assessments at the early stage significantly benefited, confirming that buildability is an important concept that is essential to be applied (Olatunji & Ojuri,

2013; Hussein et al., 2011; I Putu, 2019; Nourbakhsh et al., 2012; Nielsen et al., 2009; Cheetham & Lewis, 2001; Tingiwensi, 2000).

2.4 Buildability related issues

In 2006, the Hong Kong Construction Industry Review Committee indicated that the design buildability had considerable room for improvement since there is a minimal number of studies that have been conducted against the local context (Wong et al.). After that, there were a few researchers started to investigate relevant topics, and they established the SDBAM for the Hong Kong construction industry. Thus far, the buildability assessment is not compulsory for construction projects in Hong Kong. There is still a need for improving the awareness of buildability.

The concept of buildability was introduced to the Australian construction industry in the late 20th century. Construction Industry Institute Australia (1996) further analysed the definition of buildability and identified 12 buildability issues. Buildability concepts have been widely studied during the last two decades in Australia. There were a few improvement methods that have been discussed. However, there was no adaptive buildability measurement or assessment system had been developed in Australia (Gao et al., 2017).

China, Malaysia, Indonesia, and other developing countries have a preliminary understanding of buildability and constructability. However, the number of buildability studies is quite limited. Buildability concepts are not well known or well-studied by professionals in those countries compared to the USA or UK. In summary, many countries still need to further study about buildability against their local context to enhance construction project performance.

2.5 The need for higher Design Buildability In NZ construction projects

The construction industry is the fourth biggest industry for New Zealand, and it contributes a remarkable amount of GDP every year (Stats NZ, 2017). Therefore, the productivity of the construction industry is an essential consideration in New Zealand. According to a research study conducted by Massey University, the buildability issue is one of the most significant internal constraints to on-site labour productivity. This shows that the productivity of the New Zealand construction industry can be further increased by applying buildability concepts

(Durdyev & Mbachu, 2011). Compared to "buildability," "constructability" is more widely accepted in New Zealand. IPENZ (2008) introduced the concepts of constructability to the industry and suggested a matrix for constructability review and analysis. However, the awareness of the importance of buildability is not adequate in New Zealand. The amount of research published on buildability is limited. The possible barriers to applying buildability and constructability include the limitations of the traditional procurement system; the designer's lack of experience about construction; lack of mutual respect between designers and builders and poor communication between the design team and the construction team and so on (Wotherspoon, n.d.). Therefore, there is a strong need to explore the ways of introducing buildability in the New Zealand construction industry.

3 The research process

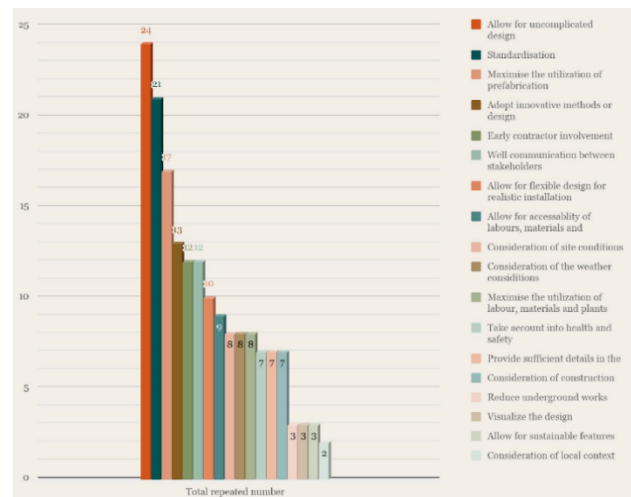
A preliminary literature review was carried out to identify the research gap amongst past studies. The preliminary literature review covered 11 journal articles from seven different countries and regions that show similar characteristics to the New Zealand construction industry. The research topic was formulated based on the preliminary literature review. After the topic, objectives, and questions were established, informal discussions between the authors and construction lecturers were conducted to understand the proposed research project further. Following that, a comprehensive literature review was conducted to create a strong foundation for this study.

As the main part of the study, more than 30 research papers from eleven different countries and regions were used for data collection. The eleven countries/regions are Hong Kong, Mainland China, Singapore, Denmark, Malaysia, Indonesia, New Zealand, Australia, UK, Kuwait, Nigeria and Uganda. They were selected because they have carried out studies which were related to the topic of this research. Their topics mainly focused on the performance of buildability in the local areas. The factors might have an influence on buildability performance and how to achieve effective buildability assessment and improvement. The data about buildability factors and performance was extracted from those research papers and more relevant resources. The Buildable Design Appraisal System (BDAS) from Singapore stands out among the selected articles since Singapore is the only

country that developed a system to quantify and measure buildability. Therefore, the extracted information was compared with the buildability requirements from the BDAS and the building consent application forms from local councils in New Zealand.

4 Data analysis and findings

As mentioned before, a comprehensive literature review was conducted based on 30 journal articles. Similarities and differences amongst the research were identified (for example, their research directions, findings and limitations). The factors affecting buildability collected from the resources were ranked against "word frequencies" in different articles. The factors were then tabulated to record the frequencies of various factors and their provenance. The factors were then ranked based on their frequencies of being mentioned in the literature. A checklist for designers was created based on the 10 most significant factors that affect design buildability. The checklist was adjusted and finalized based on the requirements in the BDAS, CAS, the building consent



application forms from local councils in New Zealand and other relevant legislative/official requirements. The 18

Figure 1: Top 18 factors affecting design buildability

factors (based on frequency analysis) extracted from the past literature are shown in Figure 1.

5 Discussion of findings

There were 11 factors identified that had significant effects on design buildability in worldwide construction projects as listed above. The three most important factors were also described as the "3S principle" (BCA, 2017). Among the 3 factors, the top one is "allow for uncomplicated design", which means the designer should make the design as simple as possible. A redundant design will add unnecessary workload to the project, and a complex design will significantly increase the risk level of the project. The second factor is "standardisation". Standardisation principle encourages the designer to adopt standardised elements and repeated design in the drawing to increase construction efficiency. The third factor is "maximise the utilisation of prefabrication". Prefabrication technology can be used for large-size elements in the project. Prefabrication can actively shorten construction time and increase the outcome quality (PrefabNZ, 2015). BCA (2017) has emphasised the importance of these three factors in the Code of Practice on Buildability.

Factor 4 is "adopt an innovative method or design", which means the designer should use an innovative method in the design process or adopt innovative elements in the design, such as 3D printing, prefabrication, building information modelling (BIM) and lean thinking. There are several benefits of adopting innovation: reduce construction costs and time, enhance project safety and increase labour efficiency (Wilkinson et al., 2015).

Factor 5 "early contractor involvement" means allowing the contractor or builder to be a part of the project at the early design stage. Their experience can provide the designer with more buildable and cost-effective design options (Rahmani et al., 2014).

Factor 6 "Well communication between stakeholders" emphasises the communication and cooperation between the client, designer, contractor and other consultants. Effective communication can increase project efficiency and avoid mistakes due to misunderstanding.

Factor 7 is "allow for the flexible design for realistic installation", it means the designer should increase the tolerance level of design to allow the contractor flexibility for choosing construction or installation methods which suits them to increase the construction speed.

Factor 8 "allow for accessibility of labours, materials and equipment" means the designer should take into account whether labours, materials and equipment are accessible and if there is sufficient site space for storage.

Factor 9 is "consideration of site conditions". The designer should take into account the realistic site conditions in the design, such as the design for the foundation. The design that does not suit the site condition is not buildable.

Factor 10 "consideration of the weather conditions" means the designer should try to minimise the impact of weather in the design, especially for the construction project that will be carried out in winter, since the winter in New Zealand is likely to be rainy and windy.

Factor 11 is "maximise the utilisation of labours, materials and equipment". This means the designer should maximise the utilisation of resources in the design to minimise waste and increase efficiency.

Using the top 11 factors identified, a checklist was created as a designers buildability guide (see Table 1).

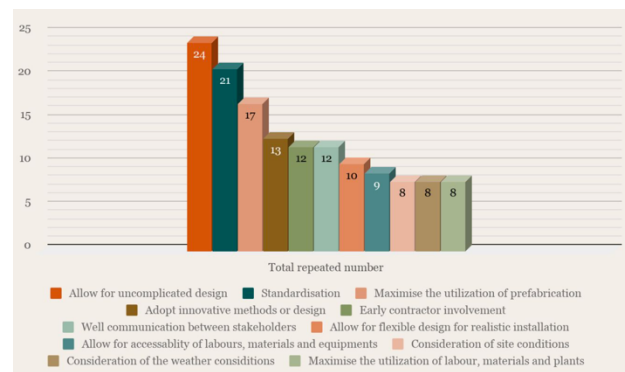


Figure 2: Top 11 factors affecting design buildability

Table 1: Designers buildability guide

No	Consideration	Remarks
1	Make the design as simple as possible to reduce the construction project workload	<input type="checkbox"/>
2	Maximise the use of standardised and repeated elements	<input type="checkbox"/>
3	Maximise the use of prefabricated elements in the design	<input type="checkbox"/>
4	Apply innovative methods and thinking for the design job, such as BIM, Lean Construction and AutoCAD	<input type="checkbox"/>
5	Encourage the contractor/builder to be a part of the design job and ask for advice and better alternatives	<input type="checkbox"/>
6	Share design details and information with the client, contractor and other consultants at the time	<input type="checkbox"/>
7	Ensure there is a sufficient tolerance level of the design to allow for flexible choices of construction methods	<input type="checkbox"/>
8	Ensure the labour, materials and equipment are accessible, and there is plenty of spaces on the site for storage	<input type="checkbox"/>
9	Take into account specific construction site conditions of each project	<input type="checkbox"/>
10	Take into account climatic influence and minimise it	<input type="checkbox"/>
11	Maximise the utilisation of labourers, materials and equipment to reduce waste and increase efficiency	<input type="checkbox"/>
12	Provide sufficient details in the drawing (recommended by councils)	<input type="checkbox"/>
13	Ensure the drawing details are accurate and readable (recommended by councils)	<input type="checkbox"/>
14	Take into account the availability of labourers, materials and equipment	<input type="checkbox"/>

The above checklist has included key elements mentioned in the Code of Practice on Buildability from Singaporean Building and Construction Authority (BCA): standardisation, simplicity and single integrated elements. Also, according to the building consent application forms from Auckland City Council (2019), Wellington City Council (2018), Christchurch City Council (2019), Waikato City Council (2018), Rotorua City Council (2017) and Central Otago City Council (2017), there are certain common considerations mentioned in their checklists: sufficient details should be provided in the drawings and specifications, and the accuracy of drawing details must be assured. Moreover, the New Zealand Herald reported that New Zealand is currently experiencing a critical shortage of skilled construction labourers, and the existing

labour force is facing an ageing problem (Gibson, 2019).

No	Consideration	Remarks
1	Make the design as simple as possible to reduce the construction project workload	<input type="checkbox"/>
2	Maximise the use of standardised and repeated elements	<input type="checkbox"/>
3	Maximise the use of prefabricated elements in the design	<input type="checkbox"/>
4	Apply innovative method and thinking for the design job, such as BIM, Lean Construction and AutoCAD	<input type="checkbox"/>
5	Encourage the contractor/builder to be a part of the design job and ask for advice and better alternatives	<input type="checkbox"/>
6	Share design details and information with the client, contractor and other consultants in the time	<input type="checkbox"/>
7	Ensure there is a sufficient tolerance level of the design to allow for flexible choices of construction method	<input type="checkbox"/>
8	Ensure the labours, materials and equipment are accessible and there is plenty of spaces on the site for storage	<input type="checkbox"/>
9	Take into account specific construction site conditions of each project	<input type="checkbox"/>
10	Take into account climatic influence and minimise it	<input type="checkbox"/>
11	Maximise the utilisation of labourers, materials and equipment to reduce waste and increase efficiency	<input type="checkbox"/>

Table 2: The Design Buildability Pre-Assessment Checklist for New Zealand

Therefore, the designer should also take into account the local context in their design, such as the availability of labour and materials. These three extra considerations were added to the checklist to create the design buildability pre-assessment checklist for New Zealand construction projects (see Table 2).

6 Conclusion and recommendations

The aim and objectives of this research are to identify and analyse the factors that have a significant influence on design buildability in New Zealand construction projects and to generate a checklist for New Zealand designers. In order to carry out data collection and analysis in a short time, thirty articles were selected as the primary resources. They were analysed by using the qualitative approach and word count analysis. The level of their significance was ranked based on their word frequencies,

as shown in Figures 1 and 2.

The study found that there are 11 design buildability considerations that designers should take into account at the design stage: allow for uncomplicated design, standardisation, maximise the utilisation of prefabrication, adopt innovative methods or design, early contractor involvement, well communication between stakeholders, allow for flexible design for realistic installation, allow for accessibility of labour, materials and equipment, consideration of site conditions, consideration of the weather conditions and maximise the utilisation of labour, materials and equipment. The design buildability pre-assessment checklist for the New Zealand construction industry was produced based on the significant design buildability factors found through the study.

In terms of recommendations, the authors encourage future researchers to validate the design buildability pre-assessment checklist to reflect the nature of construction projects (small buildings, medium-to-large buildings, infrastructure projects and so on) in New Zealand. In the long run, the Ministry of Business, Innovation and Employment (MBIE) could consider improving this checklist and convert it as a part of New Zealand Standards (NZS). Eventually, highly buildable designs could be achieved through the collaboration between designers, builders and regulatory bodies.

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The Potential of Industry 4.0 to Improve Construction Health and Safety (H&S) Performance

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ABSTRACT

Limited research has been conducted relative to the potential of Industry 4.0 technologies to mitigate historical H&S challenges. The aim of the study is to determine the potential of Industry 4.0 to contribute to resolving the persistent historical H&S challenges, the objectives being to determine the: frequency that phenomena are experienced on projects; extent of the need for performance improvement on projects; respondents' self-rating of their awareness of / exposure to Industry 4.0 technologies, and potential of Industry 4.0 technologies to reduce the occurrence of phenomena. A quantitative study, which entailed a self-administered questionnaire, was conducted among delegates attending an H&S summit. The analysis of the data entailed the computation of frequencies, and a measure of central tendency in the form of a mean score to enable the ranking of variables. Findings include: a range of historical H&S challenges continue to be experienced in construction; there is a low level of Industry 4.0 awareness; Industry 4.0 technologies can contribute to resolving the H&S challenges, and enhance H&S - related interventions / outputs / processes. The findings amplify the need for construction management, and construction H&S-related tertiary education, and training to embed Industry 4.0 in their programmes, and for employer associations, and professional associations and statutory councils to engender Industry 4.0-related H&S continuing professional development (CPD), and evolve related guidelines and practice notes.

Keywords: Construction, Health and Safety, Industry 4.0, Performance

1 Introduction

The considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry are highlighted in the Construction Industry Development Board (cidb) (2009) report 'Construction Health & Safety Status & Recommendations'. Furthermore, the construction industry experiences 0.98 disabling injuries per 100 workers, which is referred to as the disabling injury incidence rate (DIIR), the all industry average being 0.78. The fatality rate (FR) is 25.5 per 100 000 workers, which does not compare favourably with international rates, the Australian construction industry FR was for 2016 was 3.3 (Safe Work Australia, 2017), and for the United Kingdom (UK), was 1.94 in 2015 / 2016 (Health & Safety Executive, 2016). The report also states that the total cost of accidents (COA) could have been between 4.3% and 5.4%, based upon the value of construction work completed in South Africa (cidb, 2009). The high-level of non-compliance with H&S legislative requirements, which the cidb contends is indicative of a deficiency of effective management and supervision of H&S on construction sites, as well as planning from the inception / conception of projects within the context of

project management, is also noted in the report.

Park and Kim (2013) reveal that most accidents associated with construction work were attributable to a lack of proactive and preventive measures such as H&S workforce training, HIRA, H&S awareness, and H&S education.

The Council for Scientific and Industrial Research (CSIR) (2018) states that the rapid rise and convergence of emerging technologies is driving the Fourth Industrial Revolution (FIR), also known as Industry 4.0. Industry 4.0 is a collective term for technologies and value chain organisation, which draw together cyber-physical systems, the Internet of Things (IoT) and the Internet of Services (IoS), together with other emerging technologies such as cloud technology, big data, predictive analysis, artificial intelligence, augmented reality, agile and collaborative robots, and additive manufacturing.

According to Autodesk & CIOB (2019), digital technologies are transforming every industry, and construction is no exception. Infinite computing, robotics, machine learning, drones, the IoT, augmented reality, gaming engines, and reality capture, to name just a few, are innovating the design, build, and operation of buildings and

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infrastructure. Considering the numerous challenges experienced in construction, especially the delivery of projects, it is inevitable that Industry 4.0 is considered to overcome these.

Given the continuing poor H&S performance in South African construction, and the cited benefits of implementing Industry 4.0 technologies, an exploratory study was conducted to determine the:

- Frequency that phenomena are experienced on projects;
- Extent of the need for performance improvement on projects;
- Respondents' self-rating of their awareness of / exposure to eleven Industry 4.0 technologies;
- Potential of Industry 4.0 technologies to reduce the occurrence of phenomena, and
- Potential of Industry 4.0 technologies to enhance interventions / outputs / processes.

2 REVIEW OF THE LITERATURE

2.1 Industry 4.0 Technologies

A study conducted by Gheisari and Esmaili (2016) determined that using unmanned aerial systems (UASs), commonly referred to as 'drones', to monitor construction activities could help identify potential on site hazards and therefore improve H&S management. They state that UASs provide an effective solution to carry out real-time monitoring and improve H&S monitoring and control practices on site. Alizadehsalehi et al. (2017) contend that UAS technology can enable H&S managers to identify hazards at different stages of the project and develop suitable mitigation strategies.

Seo et al. (2015) state that due to the nature of construction work, workers are frequently faced with hazards and risks throughout the entire construction process. Furthermore, construction work is physically demanding, and workers can exceed their physical capacity (Nath et al., 2017), the challenge being to mitigate same. However, the traditional approach to monitoring and measuring H&S-related issues are largely manual in nature (Awolusi et al., 2018). To overcome these limitations of manual efforts, automated H&S monitoring is considered one of the most promising methods for accurate and continuous monitoring of H&S performance on construction sites (Awolusi et al., 2018). Wearable technologies can enable the continuous monitoring of a wide range of vital signals which can provide early warning systems for workers with high-risk

health issues (Ananthanarayan and Siek, 2010). According to the HSE (2019), there is growing evidence that wearable devices can significantly benefit H&S in the workplace through positioning and sensor technologies. To this end, the priority areas for a pending research project are monitoring occupational personal exposure to hazardous substances and physical hazards on construction sites, and musculoskeletal disorders (MSDs) in workers identified at greater risk. Cousins (2018) in turn highlights that wearable devices can detect fatigue risk, high heart rates, and stress. A study conducted by Nath et al. (2017) determined that wearable technology was able to prevent work related injuries and fatalities by ergonomically designing the work environment based on previous data collected. The use of this technology was able to identify and eliminate the ergonomic risks at the source to prevent similar incidents from re-occurring (Nath et al., 2017).

2.2 Stages of projects

The Council for the Built Environment's (CBE) 'The Scope of Work for Categories of Registration of the Project and Construction Management Professions' (Republic of South Africa, 2019) indicates, among other, the stages at which seven built environment professionals are involved when undertaking projects: Project Initiation and Briefing (S1); Concept and Feasibility (S2); Design Development (S3); Tender Documentation & Procurement (S4); Construction Documentation & Management (S5), and Project Close Out (S6).

3 Research

3.1 Sample stratum and method

A 14-question questionnaire was administered to delegates attending a two-day construction H&S summit in Durban, South Africa, prior to the commencement of the proceedings to avoid influencing the delegates' responses through any presentations as the theme of the summit was 'The role of Industry 4.0 in construction H&S'. The sample is best described as a convenience sample. Seven of the questions were demographic related, 6 were closed-ended and Likert Scale type questions, and one was open-ended. 28 Responses were included in the analysis of the data, which entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS).

3.2 Findings

Table 1 indicates the importance of six parameters to the

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construction industry in terms of mean scores (MSs) between 1.00 and 5.00, based upon percentage responses to a scale of 1 (not) to 5 (very) important. It is notable that all the MSs are $> 4.20 \leq 5.00$, which indicates that the parameters are between more than important to very important / very important. It is notable that the subject of the study, namely H&S is ranked first.

Table 1: Importance of six parameters to the construction industry.

Parameter	MS	Rank
Health and safety	4.72	1
Quality	4.56	2
Time	4.50	3
Productivity	4.50	4
Environment	4.46	5
Cost	4.41	6

Table 2 indicates the frequency at which nineteen phenomena are experienced on projects in terms of MSs ranging between 1.00 and 5.00, based upon percentage responses to a scale of never to constantly. It is notable that 17 / 19 (89.5%) of the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the phenomena to be experienced on projects. It is notable that no phenomena are experienced between often to constantly / constantly (MSs $> 4.20 \leq 5.00$). 16 / 19 (84.2%) of the MSs are $> 3.40 \leq 4.20$, which indicates the frequency is between sometimes to often / often. The MSs of non-compliance similar or alike errors are repeated, late information, data / statistics is / are not available, fatigue among workers, underpricing, and inadequate coordination of subcontractors are $> 3.80 \leq 4.20$ – the upper part of the range. The remaining 9 / 16 (56.3%) MSs are $> 3.40 \leq 3.80$ - materials containing hazardous chemical substances, information anomalies / ambiguities, unhealthy / unsafe plant and equipment, difficulty monitoring the process and activities of construction (in terms of H&S), sprains and strains among workers, management information is not available, heat stress among workers, unauthorised people fulfil functions, and injuries. 2 / 19 (10.5%) MSs are $> 2.60 \leq 3.40$, which indicates the frequency is between rarely to sometimes / sometimes – accidents, and fatalities. The MS of the last ranked phenomenon, namely occupational disease, is $> 1.80 \leq 2.60$, which indicates it is experienced between never to rarely / rarely.

Many of these phenomena are frequently referred to in the literature (HSE, 2017; Autodesk & CIOB, 2019; HSE, 2019a; HSE, 2019b), and furthermore, Industry 4.0 technologies have been identified as being able to reduce the occurrence of phenomena as per the literature (Autodesk & CIOB, 2019).

Table 2: Frequency at which nineteen phenomena are experienced on projects.

Phenomenon	MS	Rank
Non-compliance	4.11	1
Similar or alike errors are repeated	4.07	2
Late information	4.07	3
Data / Statistics is / are not available	3.96	4
Fatigue among workers	3.96	5
Underpricing	3.92	6
Inadequate coordination of subcontractors	3.81	7
Materials containing hazardous chemical substances	3.78	8
Information anomalies / ambiguities	3.73	9
Unhealthy / Unsafe plant and equipment	3.67	10
Difficulty monitoring the process and activities of construction (in terms of H&S)	3.63	11
Sprains and strains among workers	3.59	12
Management information is not available	3.57	13
Heat stress among workers	3.56	14
Unauthorised people fulfil functions	3.56	15
Injuries	3.44	16
Accidents	3.22	17
Fatalities	2.63	18
Occupational disease	2.58	19

Table 3 indicates the extent of the need for performance improvement on projects in terms of MSs ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (minor) to 5 (major). It is notable that all the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the need for improvements to be major as opposed to minor. It is notable that 10 / 17 (58.8%) MSs are $> 4.20 \leq 5.00$, which indicates the respondents perceive the need for improvement to be between near major to major / major - integration of information (design), link processes across the stages of projects, integration of information (procurement), healthier and safer plant and equipment, workers with technical skills, improved communication, integration of information (construction), improved planning and control of activities on site, identification of hazardous materials, and workers with technology skills.

The seven (41.2%) needs ranked eleventh to seventeenth have MSs $> 3.40 \leq 4.20$, which indicates the respondents

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perceive the need to be between some improvement to a near major / near major improvement - deployment of technology, improved security, digitalisation of information, improved materials management, simulation of activities, automation of activities on site, and workers with IT skills. It should be noted that deployment of technology, and improved security have MSs of 4.19, which means they fall below the upper range by 0.02.

These needs are varied, however, the empirical findings reflect the findings of the literature in terms of the implied need for performance improvement (Autodesk & CIOB, 2019; cidb, 2016). Furthermore, they can be responded to by Industry 4.0 technologies (Autodesk & CIOB, 2019).

Table 3: Extent of the need for performance improvement on projects.

Need	MS	Rank
Integration of information (design)	4.54	1
Link processes across the stages of projects	4.50	2
Integration of information (procurement)	4.48	3
Healthier and safer plant and equipment	4.44	4
Workers with technical skills	4.44	5
Improved communication	4.37	6
Integration of information (construction)	4.33	7
Improved planning & control of activities on site	4.30	8
Identification of hazardous materials	4.30	9
Workers with technology skills	4.26	10
Deployment of technology	4.19	11
Improved security	4.19	12
Digitalisation of information	4.07	13
Improved materials management	4.04	14
Simulation of activities	4.00	15
Automation of activities on site	3.78	16
Workers with IT skills	3.70	17

Table 4 indicates the respondents' self-rating of their awareness of / exposure to eleven Industry 4.0 technologies in terms of MSs ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (limited) to 5 (extensive). It is notable that only 2 / 11 (18.2%) of the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to rate themselves as above average, as opposed to below average. However, drones has a MS of 3.00. It is notable that no technology is rated above average to extensive / extensive (MS is $> 4.20 \leq 5.00$), and only 1 / 11 (9.1%) is rated average to above average / above average (MS is $> 3.40 \leq 4.20$) - Internet of Things. 6 / 11 (54.5%) of the MSs

are $> 2.60 \leq 3.40$ - digitalisation of information, drones, virtual reality, smart sensors, 3-D printing, and artificial intelligence (AI) / machine learning.

The remaining 4 / 11 (36.4%) MSs are $> 1.80 \leq 2.60$, which indicates a rating of limited to below average / below average - robotics / exoskeletons, nanotechnology, augmented reality, and blockchain.

Table 4: Respondents' self-rating of their awareness of / exposure to eleven Industry 4.0 technologies.

Technology	MS	Rank
Internet of Things	3.68	1
Digitalisation of information	3.11	2
Drones	3.00	3
Virtual Reality	2.96	4
Smart sensors	2.71	5
3-D printing	2.68	6
Artificial Intelligence (AI) / Machine Learning	2.63	7
Robotics / Exoskeletons	2.48	8
Nanotechnology	2.43	9
Augmented Reality	2.38	10
Blockchain	2.30	11

Table 5 indicates the potential of Industry 4.0 technologies to reduce the occurrence of nineteen phenomena in terms of MSs ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (minor) to 5 (major). It is notable that all the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average. It is notable that no MS is $> 4.20 \leq 5.00$ - near major to major / major potential. 17 / 19 (89.5%) MSs are $> 3.40 \leq 4.20$, which indicates between potential to near major / near major potential - the MSs of data / statistics is / are not available, late information, and similar or alike errors are repeated fall within the upper half of this range, namely $> 3.80 \leq 4.20$. The phenomena whose MSs are $> 3.40 \leq 3.80$ include non-compliance, unhealthy / unsafe plant and equipment, management information is not available, accidents, information anomalies / ambiguities, materials containing hazardous chemical substances, difficulty monitoring the process and activities of construction (in terms of H&S), inadequate coordination of subcontractors, injuries, fatigue among workers, heat stress among workers, sprains and strains among workers, fatalities, and underpricing.

Only 2 / 19 (10.5%) of the MSs are $> 2.60 \leq 3.40$, which indicates between near minor potential to potential / potential - occupational disease, and unauthorised people

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fulfill functions.

Despite the respondents' generally low self-rating of their awareness of / exposure to the eleven Industry 4.0 technologies, they recognise the potential of Industry 4.0 technologies to reduce the occurrence of the phenomena as per the literature (Autodesk & CIOB, 2019).

Table 5: Potential of Industry 4.0 technologies to reduce the occurrence of phenomena.

Phenomenon	MS	Rank
Data / Statistics is / are not available	3.93	1
Late information	3.92	2
Similar or alike errors are repeated	3.85	3
Non-compliance	3.78	4
Unhealthy / Unsafe plant and equipment	3.74	5
Management information is not available	3.73	6
Accidents	3.70	7
Information anomalies / ambiguities	3.70	8
Materials containing hazardous chemical substances	3.63	9
Difficulty monitoring the process and activities of construction (in terms of H&S)	3.63	10
Inadequate coordination of subcontractors	3.63	11
Injuries	3.61	12
Fatigue among workers	3.52	13
Heat stress among workers	3.48	14
Sprains and strains among workers	3.48	15
Fatalities	3.46	16
Underpricing	3.44	17
Occupational disease	3.35	18
Unauthorised people fulfill functions	3.35	19

Table 6 indicates the potential of Industry 4.0 technologies to enhance interventions / outputs / processes in terms of MSs ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (minor) to 5 (major). It is notable that all the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average. It is notable that only 3 / 49 (6.1%) MSs are $> 4.20 \leq 5.00$, which indicates near major to major / major potential - 'designer' H&S specifications, 'design and construction' method statements, and 'designing for construction H&S (process)'. More notable is that the first ranked is client-related, and second and third ranked are designer-related, and that all three occur during stages 1 – 3. The remaining 46 / 49 (93.9%) MSs are $> 3.40 \leq 4.20$, which indicates between potential to near major / near major potential. Then, 43 / 49 (87.8%) MSs are in the upper half of this range, namely – the MSs of data / statistics is / are not available, late information, and

similar or alike errors are repeated fall within the upper half of this range, namely $> 3.80 \leq 4.20$. There is a MS difference of 0.09 between the 4th and 11th ranked interventions / outputs / processes - H&S measurement, financial provision for H&S, site entrance control, H&S investigations, client baseline risk assessments, H&S research and development, consideration for H&S during pre-tender planning, and design hazard identification and risk assessment. This grouping is related to stages 1 to 6, and a range of stakeholders, namely clients, construction project managers (CPMs), construction H&S practitioners, designers, quantity surveyors (QSs), contractors, the Department of Employment and Labour H&S inspectorate, and researchers. There is a MS difference of 0.04 between the 12th and 24th ranked interventions / outputs / processes - H&S management systems (H&SMSs), designer reports in response to 'designer' H&S specifications, consideration for H&S during site layout planning, environmental measurement e.g. dust, noise, H&S feedback, emergency planning, integration of design, procurement, and construction (in terms of H&S), H&S awareness and promotion, H&S training, H&S statistics, construction hazard identification and risk assessment, H&S inspections, and temporary works design. This grouping is related to stages 1 to 6, and a range of stakeholders, namely clients, construction project managers (CPMs), construction H&S practitioners, designers, quantity surveyors (QSs), contractors, and the Department of Employment and Labour H&S inspectorate.

There is a MS difference of 0.12 between the 25th and 41st ranked interventions / outputs / processes - determining the cost of accidents, H&S plans, fire protection and prevention, H&S method statements, management of personal protective equipment, close out reports (in terms of H&S), determining the cost of H&S (prevention), H&S compliance, H&S files, 'contractor' H&S specifications, method statements (generic), workplace organisation, management of plant and equipment, H&S disciplinary procedure, security, H&S administration, safe work procedures (SWPs), safe work procedures (SWPs), determining H&S requirements from programmes / schedules, H&S audits (not inspections), management of materials, safe operating procedures (SoPs), and H&S induction. It is notable that this grouping is only related to stages 4 to 6, however, most stakeholders, namely clients, construction

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project managers (CPMs), construction H&S practitioners, designers, quantity surveyors (QSs), and contractors. The MSs of the last three ranked interventions / outputs / processes, namely stacking and storage, housekeeping, and appropriate H&S appointments (competent), span a range of 0.15, are only related to stage 5, and then only contractors.

Yet again, despite the respondents' generally low self-rating of their awareness of / exposure to the eleven Industry 4.0 technologies, they recognise the potential of Industry 4.0 technologies to enhance interventions / outputs / processes as per the literature (Autodesk & ciob, 2019).

Table 6: Potential of Industry 4.0 technologies to enhance interventions / outputs / processes.

Intervention / Output / Process	MS	Rank
'Designer' H&S specifications	4.23	1
'Design and construction' method statements	4.23	2
Designing for construction H&S (process)	4.23	3
H&S measurement	4.19	4
Financial provision for H&S	4.15	5
Site entrance control	4.15	6
H&S investigations	4.15	7
Client baseline risk assessments	4.15	8
H&S research and development	4.15	9
Consideration for H&S during pre-tender planning	4.12	10
Design hazard identification and risk assessment	4.11	11
H&S management systems (H&SMSs)	4.08	12
Designer reports in response to 'designer' H&S specifications	4.08	13
Consideration for H&S during site layout planning	4.07	14
Environmental measurement e.g. dust, noise	4.05	15
H&S feedback	4.04	16
Emergency planning	4.04	17
Integration of design, procurement, and construction (in terms of H&S)	4.04	18
H&S awareness and promotion	4.04	19
H&S training	4.04	20
H&S statistics	4.04	21
Construction hazard identification and risk assessment	4.04	22
H&S inspections	4.04	23
Temporary works design	4.04	24
Determining the cost of accidents	4.00	25
H&S plans	3.96	26
Fire protection and prevention	3.96	28
H&S method statements	3.96	29
Management of personal protective equipment	3.96	29
Close out reports (in terms of H&S)	3.96	30
Determining the cost of H&S	3.96	31

(prevention)		
H&S compliance	3.96	32
H&S files	3.93	33
'Contractor' H&S specifications	3.93	34
Method statements (generic)	3.93	35
Workplace organisation	3.93	36
Management of plant and equipment	3.92	37
H&S disciplinary procedure	3.92	38
Security	3.89	39
H&S administration	3.89	40
Safe work procedures (SWPs)	3.88	41
Determining H&S requirements from programmes / schedules	3.85	42
H&S audits (not inspections)	3.85	43
Management of materials	3.85	44
Safe operating procedures (SoPs)	3.85	45
H&S induction	3.85	46
Stacking and storage	3.78	47
Housekeeping	3.63	48
Appropriate H&S appointments (competent)	3.63	49

4 Conclusion

Given the degree of importance of the six parameters to the construction industry, and more importantly that H&S predominated, it can be concluded that the respondents, namely delegates attending an H&S conference, may have responded through 'H&S practitioners' lenses.

Given the frequency that phenomena are experienced on projects by respondents, it can be concluded that the respondents' H&S perceptions reflect the general research findings relative to H&S performance in South African construction, and that there is a need for improvement, potential to improve, and a need for the implementation of Industry 4.0 technologies.

Given the extent of the need for performance improvement on projects in terms of integration of information (design), link processes across the stages of projects, integration of information, (procurement), healthier and safer plant and equipment, workers with technical skills, improved communication, integration of information (construction), improved planning & control of activities on site, identification of hazardous materials, and workers with technology skills, it can be concluded that the respondents' perceptions reflect the general research findings relative to H&S performance in South African construction, and that there is a need for the implementation of Industry 4.0 technologies.

Given the respondents' below average self-rating of their awareness of / exposure to eleven Industry 4.0 technologies, it can be concluded that there is a need for interventions to raise the level of awareness, and to integrate such technologies into built environment /

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construction / construction H&S education and training. However, this should be expedited in a contextual manner. Given the potential of Industry 4.0 technologies to reduce the occurrence of nineteen construction resource-related H&S phenomena, and to enhance interventions / outputs / processes, the need for the implementation of Industry 4.0 in construction is amplified.

5 Recommendations

Construction management, and construction H&S-related tertiary education, and construction H&S-related training must include, or rather embed Industry 4.0 in their programmes.

Construction employer associations, and built environment associations and statutory councils must promote, and preferably provide Industry 4.0-related H&S continuing professional development (CPD) and evolve related guidelines and practice notes.

The Construction Industry Development Board (cidb) should evolve a position paper relative to Industry 4.0 in construction, and deliberate the development of a related industry standard.

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Characteristics of Small Accidental Fires in New Zealand Dwellings

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ABSTRACT

An accidental dwelling fire is either extinguished early on by the occupants or it develops into a larger fire which is extinguished by the Fire Service. Data is only collected for fires attended by the Fire Service and this defines the published characteristics of dwelling fires worldwide. This means that very little is known about the characteristics of smaller fires. The aim of this research was to investigate occupant behaviour and features of small dwelling fires. Survey data from New Zealand home occupants who had extinguished a small fire (called Group A) and from occupants who had not experienced a house fire (Group B) are compared to determine whether differences in fire-related behaviours affect the likelihood of an accidental fire occurring. The characteristics of large and small dwelling fires are compared.

The findings show that Group A has significantly higher fire-risk behaviours compared with Group B, including smoking (77% versus 17% respectively), recreational drug use (8% versus 0%) and removing the batteries from smoke detectors (9% versus 0%). Group B participants were more likely to educate their children on fire safety, supervise children around fire hazards and keep matches and lighters out of reach. Small and large dwelling fires share many characteristics; both occur mostly during the winter and at night; are more common for certain ethnicities; are caused by human error and are primarily located in the kitchen, living room and bedroom areas. These findings highlight safety strategies that may reduce the risk of an accidental dwelling fire.

Keywords: Dwelling, Fire, Fire-risk behaviour, Fire-safety

1 Introduction

Accidental dwelling fires (ADFs) are fairly common and often result in both injury to occupants and severe damage to the residence. Worldwide there are about 180,000 fire-related deaths annually (World Health Organization, 2018). Hastie and Searle (2016) report that dwelling fires account for 76% of deaths from fires in all buildings and dwelling fires cause substantial property damage. The Fire and Emergency New Zealand (FENZ) service attends approximately 20,000 fires annually, of which about 5,000 occur in residential homes (Fire Preventors Ltd., 2019).

When FENZ attends a residential fire it collects detailed data on aspects such as the demographics of the occupants (for example their age, ethnicity, income, etc.),

the characteristics of the fire (such as the time, location, cause, extent of property damage, etc.), the level of injury to the occupants and whether safety measures, such as a smoke detector, were present and functional. The data is collated into annual fire statistics reports by FENZ and is used to focus fire safety strategies on those areas where the risk of fire is greatest. Other countries have a similar procedure where the fire service collects and reports data on all the attended fire incidents. Consequently much is known about the characteristics of residential fires that are serious enough to involve the local fire service. There are other accidental fires in dwellings that are extinguished by the occupants themselves at an early stage when the fire is relatively small. Since these fires are not reported, there is no data on them and very little is

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known about them. However, they may contribute useful information on how they differ from larger fires (those attended by the fire service) and why they were extinguished at an early stage. This research aims to identify the characteristics of small ADFs in New Zealand and to compare these with published statistics on dwelling fires attended by FENZ. It looks at the ways in which occupants respond to small fires and their knowledge of fire safety. It also looks at the differences in the characteristics of people who have experienced a small ADF (termed 'Group A') and of people who have not experienced an ADF (termed 'Group B'). The findings may help to improve fire-safety strategies and increase awareness of the risks posed by residential fires.

2 Literature review

Global statistics on annual ADFs present a grim picture in terms of injury, death and damage to property (Hastie & Searle, 2016). In an effort to reduce the number of ADF incidents, the fire services in many countries collect and report data on each fire they attend. The data shows the following common characteristics of ADFs:

- They are more prevalent in the colder months of the year when heating devices are used and in the middle of the night/early hours of the morning when occupants are asleep and take longer to react (Andersson et al., 2015; Lilley et al., 2018; Miller, 2005; US Fire Administration 2017).
- Deaths and injuries from ADFs are caused by smoke inhalation and burns (Lilley et al., 2018; Miller, 2005).
- Most ADFs are caused by human error (Xiong et al., 2017) associated with smoking, material placed too close to heaters, cooking and electrical appliance malfunction (Andersson et al., 2015; Lilley et al., 2018; Sadaka, 2017; SGI Canada, 2019; Troitzsch, 2016; UK home office, 2018).
- ADFs occur most commonly in kitchens, living areas and bedrooms, especially when smoke detectors are not present (Andersson et al., 2015; Lilley et al., 2018). Cooking-related fires are likely to be smaller, with fewer fatalities since they are often noticed quickly by the occupants (Andersson et al., 2015).
- The most vulnerable populations in ADFs are males, children under 5 years old and the elderly

(over 65 years old), low income earners, people with disabilities, those suffering from substance (drugs and/or alcohol) abuse and people with lower educational achievement (Clare & Kelly, 2017; Doughty & Orton, 2014; Fan et al., 2017; Gilbert & Butry, 2018; Harpur et al., 2013; Hastie & Searle, 2016; Jonsson et al., 2017; Lilley et al., 2018). In New Zealand, people of Maori descent have many of these risk factors and have the highest rate of fatal fire injuries compared with other ethnicities (Lilley et al., 2018; MacBrayne, 2000).

- Smoke alarms significantly reduce the likelihood of fatal ADFs and hard-wired alarms work better than battery-powered alarms (Clark & Smith, 2018; Sadaka, 2017; Surrey County Council, 2013). Curtis & Page (2013) note that the use of smoke alarms in New Zealand residences has increased steadily over the past 20 years, but is lower in poorer households. Functionality of smoke alarms is an issue and home sprinkler systems are recommended for households with high risk of injury from ADFs (Bromley, 2018; Crawford, 2005; Flemmer & Flemmer, 2010; Pless, 2002).

Fire safety measures target these common characteristics, promoting the use of smoke detectors in homes and more specialized alarms and safety systems where the occupants are most vulnerable (NFPA, 2015; Surrey County Council, 2013). There are campaigns such as those supporting smoke-free homes (Aligne 2001; Kegler et al., 2018) and education on keeping materials away from heaters, on fire hazards from cooking, on teaching children about the dangers of fires and on the safe operation of electrical appliances (Bromley, 2018; Crawford 2005; Harpur et al., 2013; NZFS 1000, n.d.). Whilst these measures are obviously useful in reducing ADFs, they are all based on the collected data from ADFs attended by the fire service. There is no published data on two population groups that exhibit good dwelling fire safety. The first, termed 'Group A' are those people who have extinguished an ADF themselves and the second, termed 'Group B', are those who have not had an ADF. This research addresses this knowledge gap by investigating the characteristics of the two groups in order to understand why they are at a reduced risk of injury from ADFs.

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3 Methodology

A survey of 30 questions (both qualitative and quantitative) was developed in order to collect information on household characteristics, small ADF characteristics and occupant awareness of fire safety (Table 1). The questions on the cause of the ADF, the actions taken to extinguish the fire and the level of fire safety awareness were qualitative; relying upon the descriptions and perceptions of the respondents.

Table 1: Summary of survey questions

Question number	Aspect	Detail
1-12	Household information	Occupant ages; gender; ethnicity; income; home ownership; use of cigarettes, drugs and alcohol; physical and mental disabilities; presence of smoke alarms, location and functionality; additional safety measures
1-10	Small ADF characteristics	Cause of fire; date and time; ignition area; extent of damage; smoke alarm presence and function; method of extinguishment; injuries; alcohol and drug involvement; age(s) and gender involved; actions taken
1-8	Fire safety awareness	Fire education source; fire protection measures; response to fire and alarm; child safety measures; cooking protocol; smoke detector functionality; heater protocol

The survey questions were written as simply as possible to avoid ambiguity and thus to improve the reliability of the research. The survey was administered online and face-to-face to New Zealand residents known to the researchers (i.e. using selective sampling). A total of 63 surveys were completed; 39 respondents had experienced a small ADF (Group A) and 24 respondents had not experienced a small ADF (Group B). It is recognized that the small number of responses precludes the use of statistical testing and reduces the validity of the research findings. The characteristics of the two groups were fairly similar (Table 2) in terms of living situation (most respondents owned or rented their home); number of occupants (over two thirds of the respondents lived in homes with 2 to 4 occupants); age of occupants (around 60% in the 18 to 64 year old range and both groups having occupants in all six age ranges); ethnicity (about 80% of respondents were European) and income level. Although the similarity in

characteristics of the two groups makes comparison between them more valid, it does limit the comparison with findings on large ADFs. For example, only 2 out of the 63 respondents were of Asian ethnicity.

Low-risk ethics approval was granted for the research.

Table 2: Comparison of the characteristics of Group A (ADF) and Group B (no ADF)

Characteristic	Group A (%)	Group B (%)
Own or rent home	84.6	83.3
2-4 occupants	74.4	75.0
Occupants aged 18-64	60.3	63.3
European	76.9	83.3
Maori	20.5	4.2
Annual income \$25K-100K	66.7	81.8
Annual income < \$25K	8.3	4.5

4 Results

4.1 The risk of small ADFs for vulnerable populations

Figure 1 shows the ethnicities of the respondents from Group A (those who had experienced a small ADF) and Group B (those who had not experienced a small ADF). The percentage of respondents with an average annual income less than \$25,000 was 8.3% for Group A and 4.5% for Group B (Table 2).

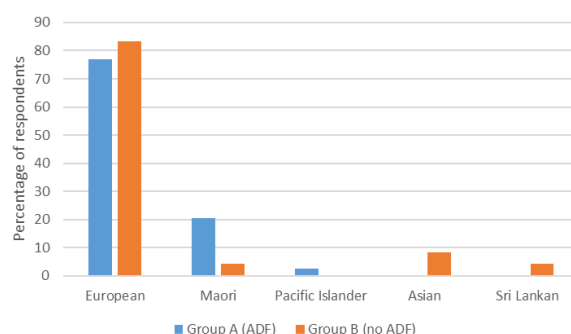


Figure 1 Ethnicity of respondents

The results show the risk of experiencing a small ADF is significantly higher for those of Maori ethnicity (Figure 1 and Table 2) and for those in the lowest income range (Table 2).

4.2 Characteristics of the small ADFs

16 of the 39 respondents who had experienced a small ADF (i.e., 41%) did not remember the precise day and time of the incident. However, approximately two thirds of the remaining 23 respondents experienced their ADF during winter and approximately half of the fires occurred after

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dark, which confirms the published findings for New Zealand and other countries (Andersson et al., 2015; Lilley et al., 2018; Miller 2005; U.S. Fire Administration 2017). The place of ignition of the small ADFs was the kitchen (49%), living room (33%) and bedroom (10%) and this is in line with FENZ findings that 90% of fatal fires start in these areas (Duncan, Wade & Saunders, 2001).

Table 3 summarizes the causes of the 39 small ADFs; over half of the fires were cooking-related and 38% were caused by material placed too close to heaters (both wood-burning and electrical types).

Table 3 Causes of the 39 small ADFs (Group A)

Cause	Number	%
Cooking	20	51.3
Space heating – wood burner	8	20.5
Space heating - electrical	7	17.9
Electrical appliance malfunction	2	5.1
Cigarette smoking	1	2.5
Disability	1	2.5

The cooking related ADFs resulted from various factors such as leaving cooking unattended and from spilt oil igniting.

Although smoking was only the cause of one of the 39 small ADFs, 77% of Group A respondents were smokers compared with just 17% of Group B respondents. Smoking is well known to be a common cause of ADFs worldwide (Andersson et al., 2015). Similarly, Group A respondents had higher recreational drug use; 8% admitting to frequent drug use compared with no drug use in Group B respondents. Interestingly, fewer respondents in Group A admitted to regular alcohol consumption than those in Group B but alcohol was listed as a factor contributing to 8% of the 39 small ADFs experienced by Group A. The New Zealand fire service has stern warnings against alcohol and drug use while cooking.

18% of the small ADFs involved children and the respondents in Group A were less aware than those in Group B about the risks associated with children and ADFs (Table 4).

Table 4 Group A (ADF) and Group B child-safety awareness

Fire safety method practiced	Group A (%)	Group B (%)
Educate children about the danger of fire	80	100
Supervise children near stovetops	67	100
Keep matches/lighters out of reach of children	60	100

Group B respondents were more likely to tell their children about the dangers of fire.

There was a single small ADF incident in which the disabled person was directly responsible for the fire. Of the 39 small ADFs, only 5 resulted in injuries and all of the injuries were burns to the hands, fingers or arms.

4.3 Fire safety measures and awareness

Table 5 show the fire safety measures in the two groups of respondents.

Table 5 Fire safety measures

Description	Group A (%)	Group B (%)
Smoke detector present	95	88
Respondent has removed smoke detector batteries for use elsewhere	9	0
Other fire safety measures present (eg. Fire blanket, extinguisher, sprinklers)	32	33

It is noteworthy that more of the Group A respondents (who had experienced a small ADF) had removed the batteries from the smoke detector for use elsewhere. In a third of the small ADFs, the smoke detector was activated by the fire. In 10% of the ADFs, the smoke detector batteries had been removed and for the remainder of the ADFs the fire was extinguished so quickly that the smoke concentration was too low for detection. There were smoke detectors installed in 92% of the homes of all 63 respondents and this is in line with the trend found by Curtis & Page (2013) since 1999 (Figure 3).

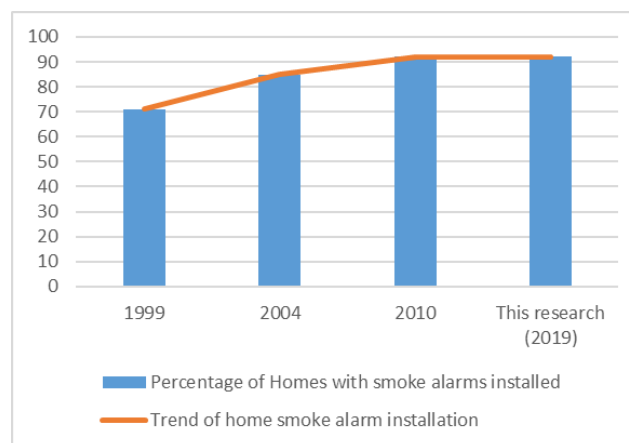


Figure 3 Smoke detector prevalence in New Zealand homes (Source for data from 1999 to 2010: Curtis & Page, 2013)

Group A respondents listed the following additional measures that were taken in response to the small ADF:

- Shouting for help

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- Explaining to children how to prevent a fire
- Removing children and an intellectually disabled person from the ignition area
- Exiting the home
- Ensuring the door of the wood burning heater was properly closed

The 63 respondents were asked to list all the sources of their knowledge of fire safety (Table 6).

The ranking of the main sources of fire education were the same for both groups, i.e., in both groups most fire safety knowledge came from television, followed by school education and radio messages. Somewhat surprisingly, the respondents in Group A (those who had experienced a small ADF) were more aware of fire safety from all sources, compared with Group B respondents. Perhaps the experience of the small ADF had made them more aware of the risk of fire and thus more attentive to fire safety messages.

Table 6 Source of fire safety knowledge for Groups A and B

Source	Number of respondents in Group A	Number of respondents in Group B
Television	21 (54%)	11 (46%)
School education	15 (38%)	6 (25%)
Radio	15 (38%)	7 (29%)
Workplace training	9 (23%)	2 (8%)
Internet	6 (15%)	3 (13%)
Firefighter visits and training	7 (18%)	2 (8%)
Personal research	1 (3%)	-

Note: the total percentages for each group are greater than 100% because respondents could have more than one source of fire safety education

5 Conclusion

The characteristics of small ADFs show many similarities with larger ADFs; they occur mostly in the winter months and after dark; they begin in kitchens, living rooms and bedrooms; they are most often caused by cooking-related factors (such as the ignition of oil) and by placing materials too close to space heaters. Vulnerable populations including those having low income, Maori ethnicity, high use of alcohol and drugs and high rates of smoking are at a significantly higher risk of experiencing a small ADF in agreement with published findings on larger ADFs in New Zealand and other countries (Lilley et al., 2018; MacBrayne, 2000; Miller, 2005).

A comparison between Group A respondents who had experienced a small ADF and Group B respondents who had not experienced an ADF showed that Group A had higher use of drugs and smoking than Group B and that although Group A did not admit to higher alcohol use it was listed as a contributing factor in 8% of the small ADFs. Group A respondents were less aware of the increased risks of ADFs for children with Group B respondents being more likely to educate their children on fire safety, supervise them near stovetops and keep matches and lighters out of reach.

In terms of fire safety measures, 92% of the homes had a smoke detector and approximately one-third of the respondents from both groups had additional safety measures such as fire blankets, extinguishers and sprinklers. However, 9% of Group A respondents admitted that they had removed the smoke detector batteries for use elsewhere.

Both groups got their knowledge of fire safety from similar sources, in particular from the television, school education and radio messages. However, respondents in Group A were more aware of fire safety from all sources than respondents from Group B. It is possible that the experience of a small ADF heightened their awareness of the risks and dangers of fire and increased their engagement with fire safety messages.

ADFs are common and cause significant physical and psychological injury to people as well as large property damage. There is a lot of data worldwide on the characteristics of ADFs that are large enough to be attended by the local fire service and these have been used to shape fire safety efforts. There is little published information on smaller ADFs that are extinguished by the occupants themselves. This research makes two contributions to the field of ADFs. Firstly it provides new information and data on small ADFs and compares the characteristics of these with those of larger ADFs. Secondly it presents data from home occupants who have not experienced an ADF and, again, compares their characteristics with those who have experienced a fire. This is just a small pilot study but more data from these two cohorts may help to improve fire safety. For example, the study has shown that some people who have experienced a small ADF removed batteries from the smoke detector to use elsewhere; pointing to the benefit of hard-wired detectors. Small ADFs are commonly caused by placing materials too close to space heaters which suggests that safer types of heaters such as heat pumps

might be less risky, particularly for people identified as being more vulnerable to ADFs. Finally, people who had experienced a small ADF appeared to know more about fire safety, which suggests that experiencing an ADF makes people more aware of their danger. This could mean that more realistic fire safety tools such as those using augmented virtual reality would be more effective compared with the existing education tools like printed information pamphlets. The more that is known about dwelling fires and about the behaviour/knowledge of occupants, the more effective the fire safety strategies can be.

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Air Tightness, Friend or Foe?

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ABSTRACT

Industry standard calculations recognise airtightness as a positive characteristic when houses are designed to consume low levels of energy for heating or for cooling. In addition, airtightness will insulate the internal environment from externally generated contaminants such as particulates and volatile organic compounds (VOC's). However, it will also contribute to the containment of internally generated contaminants to lower the quality of the internal environment. The overall impact of airtightness on the internal environment in New Zealand houses is not widely known and warrants further investigation. Air temperatures, relative humidity levels, dew points, particulate matter and VOC levels were monitored in the bedrooms of two, co-located houses, identical in layout and construction apart from details affecting their airtightness. Both spaces had controlled occupancy simulation that produced heat, moisture and contaminants from identical furnishings and decorations. The airtightness was found to have little impact on the internal thermal conditions and energy consumption. As expected, the vapour check, airtight house kept moisture levels above those seen in the conventional building but only slightly. PM₁₀ levels in the conventional house exceeded guidelines for 41% of the time compared to 17% in the airtight house over the seven day period. The airtight test house reached VOC concentrations more than 300% above those in the conventional control house. This challenges conventional thinking on the contribution of airtightness to internal environmental conditions and warrants consideration in the review of building regulations.

Keywords: Airtightness, Internal conditions, PM₁₀ values, VOC's

1 Introduction

A comfortable and healthy indoor environment is influenced by thermal, hygroscopic and indoor air quality parameters. Internationally and nationally, building codes, guidelines and codes of practice set required or desirable levels for each separately, but their combined effects in real spaces are rarely considered.

Industry standard assessment methods of the thermal envelope and internal environment outlined by the Chartered Institute of Building Services Engineers (2016) using steady and unsteady state mechanisms all show that infiltration will negatively affect internal comfort conditions. It will also increase energy consumption in winter and summer. Increasing a building's airtightness will reduce the infiltration, contributing to comfort being achieved with lower levels of energy consumption.

In contrast, increasing infiltration or ventilation through positive pressure systems (Pollard & McNeill 2012) will tend to reduce moisture particularly in winter conditions

and reduce the risk of condensation, mould formation and its associated negative health impacts. Overton (2013) outlined a range of international airtightness standards and clarified these referred to uncontrolled airflow through gaps and cracks in a building structure, often referred to as infiltration, rather than to controlled ventilation either natural or mechanical. Despite there being no legislation in New Zealand limiting the airtightness of a building, McNeil, et al. (2015) identified that over the years New Zealand homes were becoming more airtight but in many cases were also under ventilated leading to high moisture levels.

Indoor air quality (IAQ) comprises many measures detailed in the comprehensive literature review undertaken by Taptiklis & Phipps (2017), which also outlines the negative effects and the mechanisms that can contribute to poor IAQ. This paper will focus on particulate matter (PM) smaller than 10 microns (PM₁₀) as this is the key measure used in New Zealand (Ministry for the Environment, n.d.) and total volatile organic compounds

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(TVOC). Outdoor air contains a wide range of these contaminants. Wan, et al. (2015) found that in an office building, internal PM_{2.5} values increased with increased levels of infiltration. Taylor et al. (2014) used software to simulate internal PM_{2.5} values for 15 detached and semi-detached houses in the UK and found that internal values represented by Indoor Outdoor ratio (I/O) values increased as infiltration increased by opening windows. Neither of the previous works explicitly compared measured and predicted levels to acceptable standards. Whilst the reduction of infiltration improves thermal and some IAQ measures, it potentially increases the risk of high humidity. In the research cited above, the impact of occupant generated moisture, VOC's and PM levels has not been quantified and therefore does not account for the impact of infiltration on these conditions. The risk is that airtightness exacerbates unhealthy or uncomfortable conditions.

A number of authors outline the variability that real occupants have on internal conditions. Lutzenhiser (as cited in Clevenger and Haymaker 2006), (Beerport & Beerport 2007). (Guerra Santin et al., 2009) and (Gram-Hanssen 2010), reported variations of between 150% and 300% on energy use in identical residential units. Mavrogianni et al. (2017) and Morgan et al. (2017) identified that occupant behaviours impacted significantly on overheating risks. Wallis et al. (2019a) investigated the impact of external and internal influences but controlled the human variable by exploring simulated occupancy conditions. The impact of increased airtightness on two, single story, New Zealand houses was measured over a wide combination of scenarios including natural and mechanical ventilation. Heat and moisture is generated replicating human activity. VOC's and PM are produced using identical decoration and furnishings. This paper analyses specific data from this previous work, with a particular attention to the effects on the combined comfort and IAQ measures from airtightness of the external envelope. Recognising the tendency for New Zealand houses to have increasing airtightness and reduced ventilation, this paper focuses on naturally ventilated conditions.

2 Methodology

2.1 Case Study Houses

The overall methodology used a comparative case study. The case study houses are constructed as part of carpentry student's educational programme and are of

identical volume and layout. The houses are single storied with three bedrooms and two bathrooms. Electrical and plumbing fittings are installed but not connected. The full methodology is outlined in Wallis et al. (2019b). Figure 1 shows the location of the two houses with proximities to roads. North is to the top of the photograph. Bedroom 2 shown in grey, is the focus of this study.



Figure 1: House location and layout

Table 1 outlines the construction details that are common to both houses and the separate details that contribute to the airtightness of the second house. Figure 2 shows an example of the wall construction detail of both houses indicating the detail that contributes to the increased airtightness by incorporating a vapour check barrier and a rigid air barrier.

Table 1: Construction details of the Control and Airtight Houses

Element	Common Details			
	Timber Frame on pile foundation			
Sub-Floor	150x25 radiata pine boards with 20mm gap			
Floor	Particle board, foil insulation draped 100mm between joists (R= 1.3)			
Ceiling	R3.6 polyester ceiling batts (R= 2.9), 10mm plasterboard			
Glazing	R m ² K/ W	SHGC	Shading Coefficient	Visible transmittance
	0.26	0.74	0.86	80%
	Control House		Airtight House	
Roof	Trussroof Coloursteel roofing on building paper		Trussroof Coloursteel roofing on building paper vapour check wrap on bottom chord of trusses.	
Walls	Cedar weatherboard cladding, natural finish		Cedar weatherboard cladding, natural finish	
	20mm cavity battens	20mm cavity battens		
	Building wrap		7 mm ply	
	90x45 radiata pine framing		90x45 radiata pine framing	
	R2.5 polyester batts (R = 1.9 m ² K/W)		R2.5 polyester batts (R = 1.9 m ² K/W)	
			vapour check	
			45mmx45 battens	
	10mm plasterboard		10mm plasterboard	

Polyester batt R values in Table 1 are from Autex Industries (2019a, 2019b). Glazing data is from Nu Look (2019)

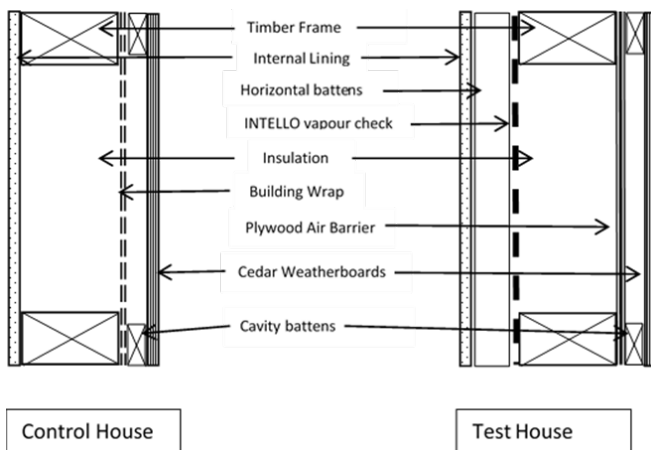


Figure 2: Wall construction details

Both houses were fitted with a mechanical ventilation heat recovery system (MVHR) but this was de-activated and openings sealed for the period of this investigation to

eliminate its effect on the airtightness of the building envelopes.

2.2 Airtightness

Both houses were tested for air tightness using the standard blower door test following European standard EN 13829:2000. Openings associated with supply and extract ventilation and unconnected waste pipes were sealed for testing and monitoring.

2.3 Data Collection

Temperature, Relative Humidity and Dew Points

Lascar EL-USB-2 Humidity and Temperature data loggers were set up to log the internal air temperature, relative humidity (RH) and dew points at hourly intervals. These units have a range of 0-100% RH and -35-80°C temperature. The sensors were located identically in both houses, suspended from the ceiling to 1.5m above the floor. Calibration against a mercury thermometer indicated an accuracy of ± 0.5°C.

PM Readings

Proprietary Dust Profilers employing optical particle counters were used to measure hourly PM₁₀ concentrations mounted at a height of 1.1m above floor level in line with ISO 7726:1998 (International Organization for Standardization, 1998) The sensor range for PM₁₀ was 5000 µg/m³; with accuracy of < ± 5 µg/m³ + 15% of reading. The minimum detection is 0.3 µm.

TVOC

Whole air samples were collected over a number of separate 24-hour periods at a nominal flow rate of 3.5 mL/min using CS1200E flow controllers (PN 39-CS1200ES4, Entech Instruments Inc.).

2.4 Simulated Occupancy

Two occupants were simulated over the periods of 6-8am and 5-10pm. Thermal manikins (designed and built according to EN 14240:2004(E) (European Standard, 2004) simulated thermal output producing 100W per manikin. In addition 1500W electric heaters set to a constant thermostat setting and a 60W incandescent lamp also operated during the same time. Moisture output was simulated with two centrifugal humidifiers, located 1.1 m above the floor. These provided, a moisture output of 0.09 kg/hr, equivalent to two people according to the Chartered Institute of Building Services Engineers (CIBSE)

Environmental Design Guide (2017). The shower in the bathroom was also operated at 7 minute intervals, 9 times during the daytime period to simulate moisture production equivalent of 13 litres/day to reflect cooking clothes washing and drying, washing dishes and showering.

Both rooms had carpets and underlay installed on the same day. Furniture comprised a fabric chair and ottoman, composite wood coffee table and a side table. Walls were painted with an acrylic paint.

2.5 Measurement Period

Measurements were taken over a period from June 14th to July 6th as part of a programme monitoring the spaces under other interventions. At the end of this period conditions were changed with the MVHR system being turned on. Samples of the total measurement period have been selected to illustrate key, but representative trends and relationships of the whole data set.

3 Results and Discussion

3.1 Airtightness

Table 2: Results of airtightness testing

	Control ac/h	Airtight ac/h
Mean	8.27	2.15

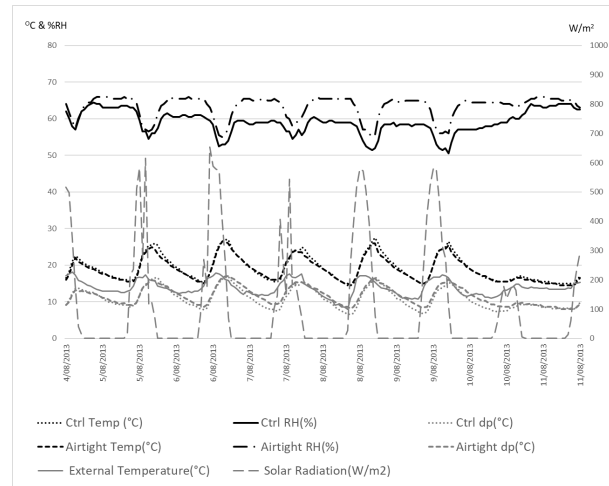
The figures above represent average air changes per hour of the whole house volume under the standard test conditions of 50Pa +ve and 50 Pa -ve. It indicates that the Airtight House has an air leakage rate of just over a quarter of the Control House. The Control House sits just outside the airtight classification for New Zealand houses which peaks at an airtightness of 5 ac/h. (Stocklein & Bassett 1999). The Airtight House is comfortably in the airtight classification but is still well above the requirements of the Passive House Institute (2012) of 0.6 ac/h.

3.2 Dry Bulb, Dew Point and Relative Humidity

Figure 3 compares the levels measured from previous experimentation on the same houses over a winter period in 2013. Both houses had a free running internal environment with no active heating, cooling or humidity modification. Previous work (Birchmore et al., 2015) has indicated the strong influence that solar gain has had on internal conditions in the houses observing that both internal temperatures dew points varied closely with solar gain but with a lag of up to four hours. Therefore, Figure 3 compares the measures and uses external solar gain as an

indicator of external conditions. The pattern of days includes six days with high solar gain followed by a day with very low gain. It shows that internal air temperatures in both the Control and Airtight rooms follow very similar patterns with the Control room exhibiting slightly higher temperatures, but lower dew points and relative humidity.

Figure 3: Control / Airtight Comparison - free running



The difference was expected for the relative humidity and dew points as this is demonstrating the moisture vapour management properties of the vapour check materials. The properties are to keep vapour out of the structure in winter time by keeping it within the occupied space. It was expected that the airtight room with lower infiltration would show a higher internal air temperature as it was experiencing a smaller exchange with the cooler external air. However Figure 3 shows that this difference was very small with the control house actually experiencing slightly higher peak temperatures at a slightly later time. It was felt initially, that any lack of difference was due to the absence of any active internal climate control and that heating the space would show a larger difference.

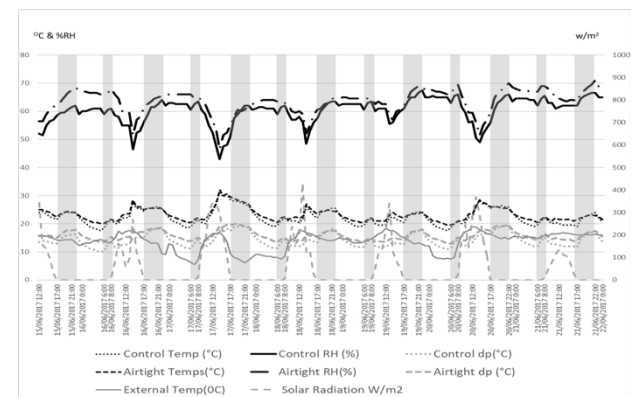


Figure 4: Control/ Airtight Comparison - Heat and Moisture On

Figure 4 shows comparable analysis over a winter period but with the room being exposed to the heating and moisture generation from the simulated occupancy equipment. The external weather patterns are similar: six days of solar gain followed by a day of very low gain; however the gains overall are lower. The external air temperature drops lower overnight than the free running period. The heating and humidification periods are shown by the pale grey boxes on the graph. The impact can be seen by the slower drop in air temperatures and an increase in dew point temperature after 5.00pm. During the morning simulated occupancy there is a slight increase in internal temperature and dew point, most noticeable in the Control room. Internal maximums are higher, reaching 30°C, (despite the medium setting on the heater), compared to maximums of high 20's in the free running scenario. The impact of heating and moisture on the Airtight room is slightly larger. Figure 4 shows a lower variation in the dew point compared to the unheated condition. Again, the additional vapour is being maintained in the occupied space by the vapour check membrane. Table 3 shows the differences of subtracting the Airtight conditions from the Control conditions in free running and heated and humidified conditions over the weeklong monitoring period. A positive difference indicates that the mean Control house readings are higher than means in the Airtight house.

Table 3: Differences between Control and Airtight Houses

	Free Running			Heat and Humidity		
	Temp	Humidity	DP	Temp	Humidity	DP
	°C	%	°C	°C	%	°C
Mean	0.3	-4.5	-0.8	-0.8	-3.2	-1.6
Max	2.5	0.0	1.3	1	1.5	0.7
Min	-0.5	-8.0	-2.1	-2.5	-8.5	-3.6
Degree hrs	-15			96		

This is not what the theory of reduced infiltration would expect. In a free running condition however, it could be possible that despite having identical insulation levels there are some 'as built' variations between the two houses. Under the heating and humidified conditions, the mean difference reverses with the Airtight temperature being slightly higher than the Control room. The average relative humidity is very similar but now with a much wider variation between maximum and minimum. The dew point is clearly higher in the airtight house with a

similar variation between minimums and maximums. This is in line with theoretical expectations for the performance for the vapour check membrane in the Airtight room. However, the differences are very small and are unlikely to be sensed by occupants as different levels of comfort except at the extreme minimum conditions.

The total difference in air temperature can be expressed in degree hours for the period and is shown in the bottom row of each table. A calculation of the actual energy usage and therefore costs was undertaken to further quantify the impact of the airtightness. The degree day technique is a simple manual method of predicting energy usage based on a comparison of external weather data to a known base temperature. The base is an outside temperature which triggers the need for active heating. The technique has been long used for estimating heating energy. Accounting for intermittent heating and useful heat gains requires the inclusion of factors that adjust the effective base temperature and can reduce accuracy of the predictions. In this case the base is not a theoretical calculation, but the actual temperatures measured in the Control and Airtight houses, removing the need for adjustment factors. In this instance instead of calculating the degree days to an external base, the difference of degree hours between the Control and Airtight house temperatures is available from the measured data. The degree hours are the product of the temperature difference between the control and the test house for each hour, measured outside the comfort level of 21°C. The equation below from CIBSE (2017) outlines the technique.

$$F = 24 U' Dd / \eta$$

F = the seasonal fuel consumption kWh

24 = factor to adjust to degree hours

U' = room heat loss coefficient kW/K

Dd = degree days to a base

η = seasonal system efficiency (COP)

The heat loss from the room was manually calculated to be 294 watts with an inside outside temperature difference of 15 °C and assuming an all-electric resistance heater with a seasonal system efficiency of 1, the difference in fuel consumption over the seven days would be 1.88 kWh.

Table 4: Energy consumption implications

Indoor °C	Outdoor °C	Heat Loss kW	U' kW/K	Degree hours	F kWh	η	Cost \$/kWh	weekly cost \$
21	6	294	0.02	96	1.88	1	0.25	0.47

A simple extrapolation on a floor area basis to assume the same improvement over the whole house, with similar window to wall ratios and assuming all rooms and bedrooms are heated to the same extent, brings this to 18kWh and a cost saving of \$4.45 per week or approximately \$90 over a 20 week heating season. In competition for customers, electricity supply companies may well propose \$90 as worthwhile saving, however this depends upon the perspective of the occupants and the additional costs associated with the airtight layer if building from new. The simplicity of projected seasonal saving assumes the same external conditions throughout the whole heating season. A more complex hour by hour analysis is unlikely to provide a significantly larger saving.

3.3 Particulate Matter

Figure 5 shows the results of hourly internal PM₁₀ measures over a seven-day period of analysis to show key trends. The levels clearly fall and rise in both houses at times that coincide with the heating and humidification of the spaces. At the start of the period the levels are close together, but the results also show the Airtight room values dropping well below those of the Control room but then regaining levels later.

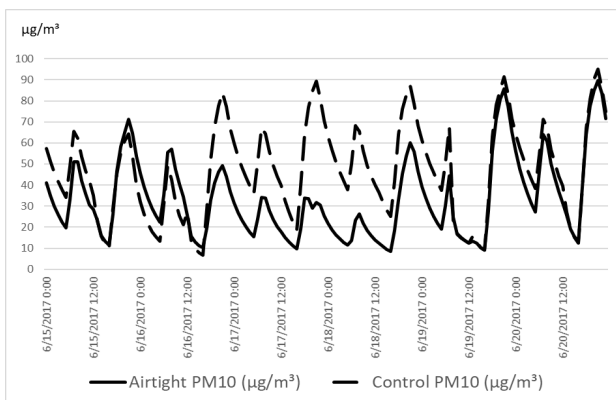


Figure 5: PM₁₀ values in Control and Airtight rooms

Figure 6 shows the variation in the Control house plotted

against internal thermal and hygroscopic measures. Temperatures, dew points and RH levels can be seen to rise as expected during periods of active heating and humidification (shown in grey). The increases in the Control room PM₁₀ levels appear to be roughly proportional to the duration of the simulated occupancy.

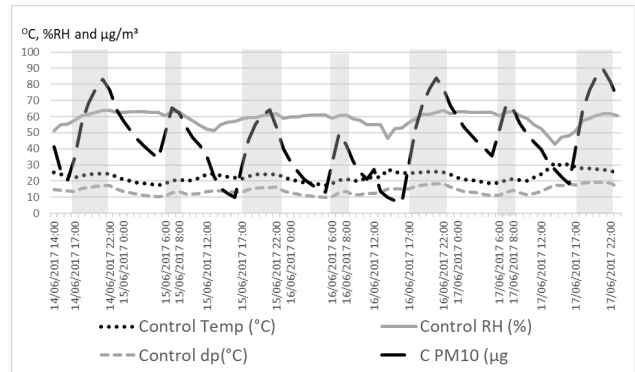


Figure 6: PM₁₀ Control room

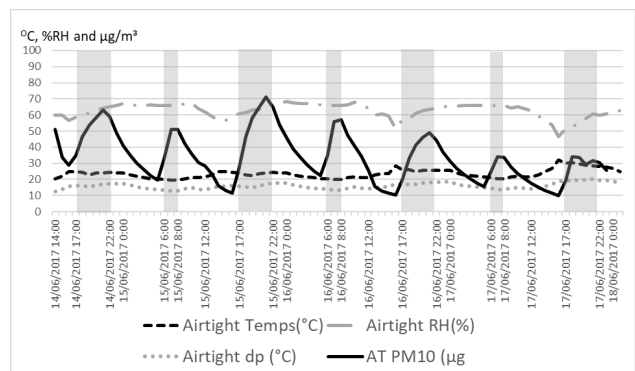


Figure 7: PM₁₀ Airtight room

Figure 7 shows a similar rise and fall in the Airtight room but with peaks that drop steadily over the period. Figure 5 shows that over the following days the peaks rebuild to levels similar to the Control room. The diurnal variations are caused by particles that have settled on surfaces, resulting in low readings, are re-suspended from surfaces by increased air movement from buoyancy currents created by heating from the manikins, space heaters and humidifiers. When these interventions turn off, the PM deposits back on room surfaces. The difference between PM₁₀ readings in each room show no strong connection with the expected impact of airtightness of the spaces. The differences are small for periods and then increase. Particulates generated internally do not appear to be exhausted to outside via infiltration mechanisms. Hernandez et al. (2017) showed that external PM₁₀ levels over an eight-week period in winter follow a similar

pattern with peaks in the morning and evening. These coincided with morning traffic and evening use of wood burning fires. However typical peak and average levels were much lower than those observed in Figure 5. The peak for external winter PM₁₀ level only reached 74.7 µg/m³ once over the entire monitoring period with typical peaks between 15 and 25 µg/m³. Wallis et al. (2019b.) monitored internal PM₁₀ levels in the unoccupied unfurnished rooms. They found the Control room also to have internal levels higher than the Airtight room, but that overall levels were significantly lower than external levels at the same time. The unoccupied levels were much lower than the levels measured with the simulated occupancy. The increase in levels measured over those measured externally and without simulated occupancy gives confidence that these levels shown in Figures 6 and 7 are due to the simulated occupancy interventions.

Acceptable Levels

Both rooms spend time over the maximum limit of 50 µg/m³ recommended by the World Health Organisation WHO (2006). Table 5 indicates that the average for the airtight house is lower and spends significantly less time over these levels. This is contrary to intuitive expectation that the Airtight room would retain any particulates more completely than the Control room.

Table 5: Acceptable limit exceedance

	Control	Airtight
Average µg/m ³	45	33
No. > 50 µg/m ³	34	14
% > 50 µg/m ³	41%	17%

3.4 TVOC's

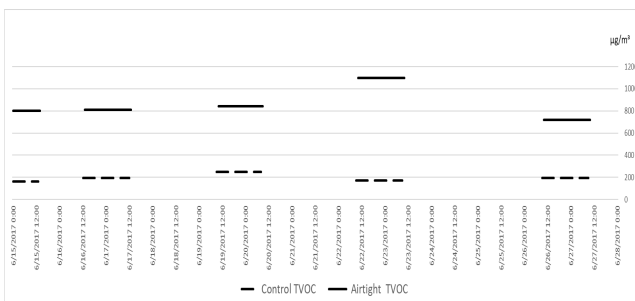


Figure 8: TVOC levels on the Control and Airtight house

Figure 8 shows the collection of TVOC levels over a 24hour

period, on intermittent days. The TVOC's levels build up over the 24-hour period, but as the method does not capture hourly measures, the final measure is shown as constant throughout the day for clarity. The values in the Airtight room are consistently and significantly higher than those in the Control with a maximum difference of 300%. With the exception of readings over one period when the Airtight room reading increases significantly, TVOC's rise and fall consistently in both the rooms.

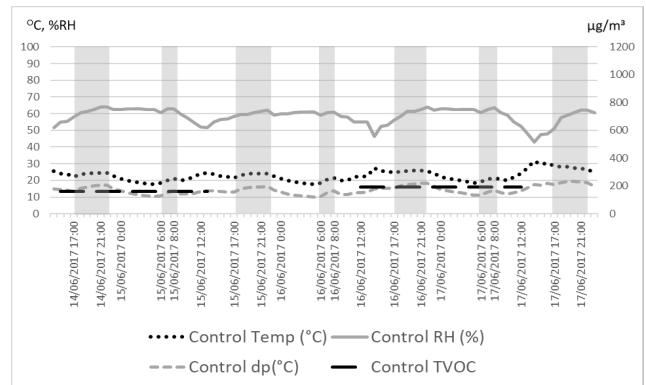


Figure 9: Periodic TVOC levels in the Control Room

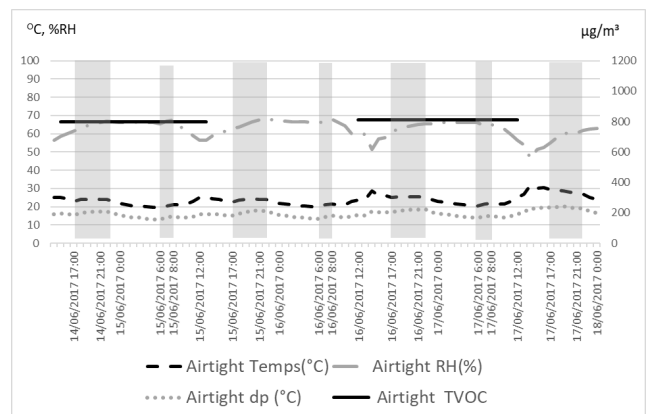


Figure 10: Periodic TVOC levels in the Airtight Room

Figure 9 and 10 show there is no obvious connection between the TVOC levels and internal temperatures, dew points or RH's in either the Control or the Airtight room. The Airtight readings are much higher during similar internal conditions. The highest TVOC level shown in Figure 8 occurs in the Airtight room at a time when diurnal variations were low as a result of low solar gain and high steady RH levels, but the TVOC increase is disproportionately larger than the increase in RH or the decrease in air temperature and dew point. There was no obvious new source of TVOC in the Airtight room or building as a whole so the increase on this particular day

is unexplained. At other times the variations of TVOC levels are very small, irrespective of changes in comfort measures between days. The TVOC collection methodology prevents comparison of the parameter with the diurnal heating and humidification of the spaces. The elevation of TVOC readings in the Airtight space fits with the principle that the airtight structure contains the contaminants better than the Control Room.

Acceptable Levels

There are no New Zealand guidelines for acceptable levels of TVOC's. Pluschke (1999) summarised that in Finland 600 $\mu\text{g}/\text{m}^3$ is quoted in the building code with 200 $\mu\text{g}/\text{m}^3$ as a level where 90% of the occupants will be satisfied. In Germany a target level is 300 $\mu\text{g}/\text{m}^3$ and in the USA 200 $\mu\text{g}/\text{m}^3$. With any of these standards the Control house is well below and the Airtight house well above.

4 Conclusion

4.1 Dry Bulb, Dew Point and Relative Humidity

In terms of occupant comfort measures, the Airtight room showed very little benefit when compared to the Control house in the unheated state. Simulated occupancy increased the benefit slightly but again occupants are only likely to sense a difference in the very coldest conditions which occurred between the hours of 2.00am to 5.00am, when most occupants would be sleeping. Monitoring of the electricity consumed by the 1500W finned heaters would have provided additional insight into the impact of the airtight structure. Simple calculations indicate that the energy and financial implications would also be small. Extrapolations of the room data to the whole house and for a whole season risk over estimation of the impacts. However, the benefits are small but tangible. Using the monitored data for the bedrooms and other spaces in the house would make a reliable base with which to ratify a full computer simulation. This would enable full seasonal benefits for the complete house to be reliably predicted which would in turn enable a valid prediction of the full financial benefits that might then be used to gauge the full life cycle benefits of airtightness. This simulation once ratified could then be applied to locations with more extreme winter and summer conditions to build guidance for nationwide practice.

4.2 Particulate Matter

Simulated occupancy clearly created conditions in both

houses that elevated PM_{10} readings above recommended levels for significant amounts of time. Increasing airtightness had an unexpected positive effect on these readings for short periods in the testing period and at times this reversed to a small negative effect, compared to the Control room. Reasons for this reversal are unclear but difference in readings between rooms are much larger than the margins of accuracy for the sensing equipment. An explanation maybe that significant variation in the PM can be created by identical furnishings and environmental interventions. Additionally the PM may be re suspended quite differently by very similar occupancy effects. The particulates generated by the simulated occupancy do not seem to be exhausted to outside via infiltration mechanisms. In light of the trend for new homes to become more airtight but under ventilated and the observation that acceptable limits are exceeded for significant amounts of time the interaction between PM_{10} values and airtightness warrants more detailed examination.

4.3 TVOC

The control house is significantly less airtight than many houses currently being constructed, and the Airtight house is more so. Locally there was no strong connection between internal TVOC's and the external climate. Measures in the two rooms straddle published acceptable international guidelines with the Airtight room exceeding the highest levels permissible in the northern hemisphere throughout the period of monitoring. More research needs to be undertaken to develop a reliable target for air change rates either natural or mechanical that will enable the achievement of acceptable TVOC levels.

4.4 Friend or Foe?

Airtightness appears to be both friend and foe in the houses being examined. A clear foe with regard to TVOC's and an inconsistent friend when considering PM, thermal and hygroscopic comfort. Whilst the differences of the airtightness of the full-scale buildings were measured, there could have been other differences between the individual rooms being investigated. With airtightness being included in the review of New Zealand building regulations, there are strong indications that reduced infiltration on its own is not beneficial to all measures of internal environmental quality. Some level of active, controlled ventilation will have a minimal negative effect of comfort and energy but a likely positive effect on IAQ

measures. This lack of clarity combined with the trends of increasing airtightness on new build homes in NZ points to a need for significant further research with the view to influence future building regulation that can balance the needs of occupant comfort and health.

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Fuel Poverty Awareness: A Preliminary Study of New Zealand Tenants

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ABSTRACT

Fuel poverty is an issue that has been documented to affect many low-income households in New Zealand. Many studies have shown the effects of fuel poverty to include health and mortality issues during winter periods in the country. To eradicate fuel poverty, sufficient information should be provided to not only decision makers but those directly affected – low-income earners. This study is aimed at investigating the level of awareness of low-income earners to fuel poverty and its effect on their health and comfort. A two-stage survey was carried out on tenants in low-income tenants within Auckland city. This survey involved a questionnaire survey of tenants and physical observation of tenants' households in Auckland City, New Zealand. The results show that there is insufficient awareness of fuel poverty amongst tenants. Also, the majority (80%) do not seek advice on fuel poverty and the associated effects. The results further showed that there is still evidence of fuel poverty in these households. The implication of this study calls for more efforts to be made by the appropriate authorities to inform the public, in particular, those affected, about fuel poverty. This pilot study was carried out on a small population of low-income earners. More studies are required across the country for the results to be generalised.

Keywords: Fuel poverty, Low-income, New Zealand, Tenants

1 Introduction

Fuel poverty can be defined as the inability to afford adequate warmth at home (Lewis, 1982). While this classic definition has been criticized (Waddams et al., 2012) as not capturing fuel poverty in totality and modified to suit the current state of arts (Lloyd, 2006; O'Sullivan et al., 2015), it remains the easiest explanation over the years. The significance of fuel poverty stems from its impact, directly and indirectly (Shaw 2004), on the household and their overall wellbeing. It affects not just the physical health but social, emotional and psychological stability of the individual. Studies have shown various effects of fuel poverty to include health hazards such as respiratory and skin problems (Rankine, 2005, Dear & McMichael, 2011), depression (Harrington et al., 2005; Liddell & Morris, 2010, Lawson et al., 2015) and even deaths (Howden-Chapman et al., 2012; Davie et al., 2007). New Zealand has been noted among developed countries to have the second highest rate of asthma (Taptiklis & Phipps, 2017) as one out of four children is prone to asthma.

Tackling fuel poverty in households relies on the ability to mitigate three major factors – household income, thermal performance of the dwelling and the price of energy required to keep the dwelling warm. These factors are interdependent and determine whether a household is fuel poor or not. The thermal performance of a house represents its ability to retain much-needed heat to keep the indoor environment warm without any additional heating system. It is dependent on some features including the building design and materials (walls, floors and roofs). While the World Health Organisation (WHO) requires a house to maintain an acceptable standard of 18°C indoor temperature to be considered warm (MBIE, 2018), Lloyd (2006) suggests a heating regime level of 21°C in the main living area and 18°C in other occupied rooms. However, in 2006, only 9% of a documented 386 dwellings in New Zealand met the WHO standard for indoor temperature (Isaac et al., 2006) and in 2015, about 4500 people surveyed believed that their houses were too cold (Statistics New Zealand, 2015).

It can be said that fuel poverty affects mostly low-income

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earners (Moore, 2012; Isaac et al., 2010, O'Sullivan et al., 2015). This is mainly related to living in poorly insulated houses that require more energy to heat up and the high cost of energy. Energy bills potentially take about 16% of the earnings of low-income earners (Power, 2005). In fact; according to Phipps, (2017), fuel prices in New Zealand rise faster than occupants' income. Isaac et al., (2006) found that only about a third of households in the lowest income quintile achieved an average living room-evening-winter temperature of above 16°C. This demography represents a large percentage of the New Zealand population. As noted by Howden-Chapman et al., (2012), it is estimated that around a quarter of households in New Zealand suffer from fuel poverty to some degree. Occupants of low- income houses spend three times more than average on energy bills relative to income (Wilkinson et al., 2001).

In New Zealand, low-income earners are those who have an annual income of less than 60% of the national median income (\$48,800 a year or \$23.50 per hour in 2016) after housing costs (Statistics New Zealand, 2017). A majority of those that fall into this category are residential housing tenants comprising many of students, immigrants and low-income workers. Studies have shown a link between this group of the population and fuel poverty. For instance, Isaac et al., (2006) observed that dwellings that achieved an average living room temperature of less than 16°C, were more likely occupied by tenants rather than actual homeowners. The BRANZ 2015 House Condition Survey of almost 600 houses showed that rental properties were twice as likely to smell damp than owner-occupied houses and nearly three times as likely to feel damp (White & Jones, 2017). According to Howden-Chapman et al., (2012), those on low incomes are more likely to rent and rental properties are predominantly older housing stock. Buckett et al., (2012) noted that almost twice the amount of tenant-occupied houses were found to be in poor condition, meaning they need attention in the next three months. In 2015, Statistics New Zealand found a significant relationship between colder dwellings and tenant occupiers (Figure 1).

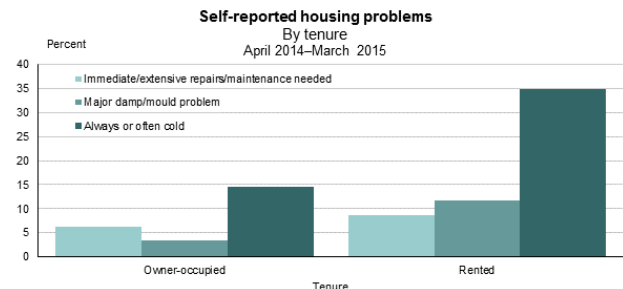


Fig 1: Housing problems per Tenure in New Zealand Homes (Stats NZ, 2015)

The NZ government has attempted to tackle fuel poverty in various ways. An example is The Household Energy End-use Project (HEEP) which was established in 1995, to monitor energy use and indoor environmental quality in NZ houses for ten years¹. Based on the findings of HEEP and other studies within the country, various strategies have been introduced. Example, the New Zealand Standard for installing insulation (NZS 4246:2016) was established to guide the correct installation of insulation products to achieve the intended thermal performance in residential houses. Also, insulation statements are now required, effective from July 2019, on all tenancy contracts, wherein the landlord must disclose whether there is insulation in the rental home, where it is, what type and what condition it is in so that tenants can make an informed decision (Tenancy Services, 2017). Furthermore, the government has initiated a programme called “The Warm Up New Zealand: Healthy Homes” which offers 55% insulation subsidies for low-income homeowners and landlords with low-income tenants in homes built before 2000 (Smart Energy Solutions, 2018). While these are good initiatives, it is important that tenants have a good understanding of fuel poverty and its effects for these initiatives to be effective. Lloyd (2006) pointed out that the New Zealand government has not done enough to provide those affected by fuel poverty with information, specifically on the relevant health issues. While the study above was carried out over a decade ago, there has not been any follow-up study to ascertain whether the public’s awareness of fuel poverty has improved. Hence, the public may still be naïve to the dangers associated with being fuel poor. This study provides quantitative proof of current public awareness of the fuel poverty. Also, despite the intervention strategies employed by the government, there may still be

¹ More on HEEP can be found at <https://www.branz.co.nz/heap>.

significant fuel poverty in low-income households. Hence, this study asks the question:

1. Are tenants aware of fuel poverty and its effects?
2. Are tenants of rented low-income households still fuel poor?

This study provides more information on fuel poverty and its effects. It was aimed at ascertaining whether tenants are still affected by fuel poverty and further establish whether that there is currently, significant evidence of fuel poverty in low-income homes. To answer the questions asked and achieve the aim of this study, a field investigation is conducted on house tenants in Auckland city, New Zealand. The significance of this study is that it is focused on a current urgent issue in the country – fuel poverty. As indicated by Howden-Chapman et al., (2012), fuel poverty is a significant contributor to New Zealand’s high winter mortality rate and hospitalisation. It is hoped that the findings of this study will be informative to decision makers and assist in developing appropriate strategies towards the total eradication of fuel poverty from the country.

2 Data collection and results

This study was carried out in Auckland, New Zealand. This city was chosen as it is the business hub of the country (Rasheed et al., 2017) and has a significant number of tenants. Two stages of survey were carried out. Firstly, an online questionnaire survey targeting 50 tenants across Auckland city was undertaken to establish the awareness of tenants on fuel poverty and its effects. This number of response survey is representative of tenants in Auckland city. Conducting an online survey assisted in avoiding researcher’s bias (Kothari 2004) – common limitation of questionnaire surveys. This was carried out through surveymonkey.com. Secondly, a field survey was carried out on 50 rented houses using a paper-based questionnaire and pictorial observation of the evidence of fuel poverty. Questionnaires have been shown to be an appropriate tool to retrieve occupants’ perception of their environments (Hodges et al., 2016, Rasheed & Byrd, 2018).

A random sampling technique was adopted (Kelley et al., 2003) and a target of 50 participants was set for each stage of the study as a subset of tenants in Auckland city (Sekaran & Bougie, 2009). This number is deemed accepted. The data collected was statistically analysed using simple descriptive analysis methods. The findings are presented and discussed in the following sections.

2.1 Stage 1 - Online survey of tenants’ awareness to fuel poverty

The total of 50 responses from the online survey received were deemed appropriate for analysis. The remaining respondents did not fit into the selection criteria for this survey. The selection criteria were:

- a. The living status of the participant (tenant or house owner),
- b. The annual income and
- c. The age of participants.

It was important that the participants are current tenants with an annual household income of below \$49,999 (Statistics New Zealand, 2017) and aged above 18 years (adults). Out of the 50 responses, 66% are females while 60% are 25 years and above. Majority of the respondents occupied houses that were over 20 years old and all of them had an income below \$49,999 (Table 1).

Table 1: Background information on online survey

	respondents	
	<i>Respondents’ background information</i>	
<i>Sex</i>	Females (66%)	Male (34%)
<i>Respondents’ age</i>	18 – 24 years (60%)	25 years and above (40%)
<i>Age of house occupied</i>	Above 20 years (68%)	20 years and below (32%)
<i>Income</i>	\$0 - \$24,999 (54%)	\$25,000 - \$49,999 (46%)

Awareness of fuel poverty

To establish the awareness of respondents to fuel poverty, they were asked to indicate how familiar they are with the concept of fuel poverty. As shown in the figure below, about 72% indicated that they are not familiar with the concept of fuel poverty. Those who were familiar with fuel poverty (57%) identified the internet as their main source of information.

For the question on familiarity with the health effects of fuel poverty, about 57% indicated that they were familiar with the associated health issues of fuel poverty. The nature of health issues identified were majorly physical (94.74%), followed by psychological (42.11%) and social (31.58%). However, only 33% of the participants who indicated familiarity with fuel poverty and associated health issues were confident of the strategies to tackle fuel poverty.

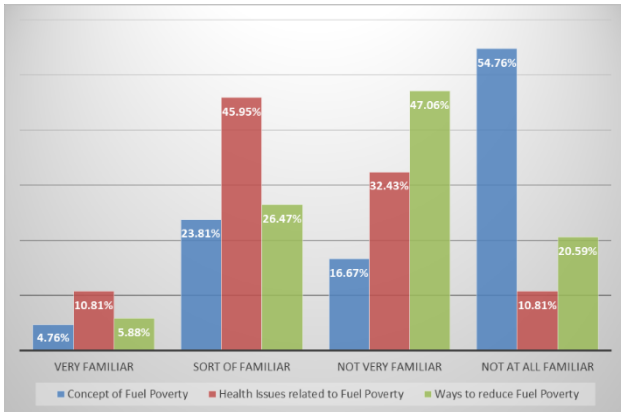


Figure 2: Awareness on Fuel poverty and associated health issues

Information on Tackling Fuel Poverty

As shown in the figure below, a significant 79.41% of the participants noted that they had not sought any advice on how to tackle fuel poverty in their houses. Most of the participants had no reason why they haven't sought advice (23%); others stated that finance was a reason while some felt they had no need for the advice (19%). The rest of the participants were unaware of where to seek advice from, unaware that fuel poverty exists or unaware that advice is available.

Finally, those who had sought advice on fuel poverty were asked whether they had acted on this advice, and if they had, what strategies have been employed. It was interesting to observe that about 83% of participants had not acted on the advice they received. For the 17% who indicated that they had acted on the advice given, the strategies employed included installation of curtains to reduce heat loss, using more energy efficient heaters and using heaters at smarter periods.

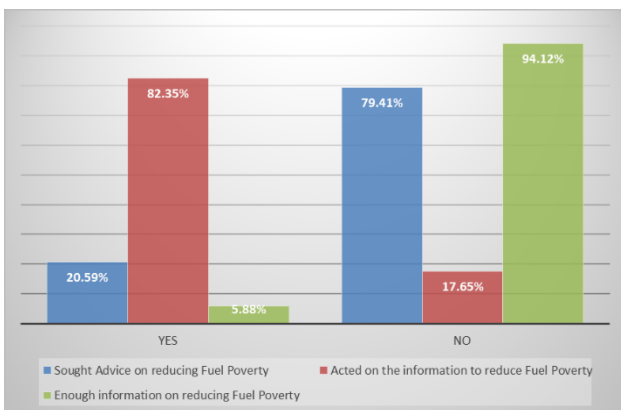


Figure 3: Tackling Fuel Poverty

2.2 Stage 2 - field survey of rented low-income households

To establish the existence of fuel poverty and its effects, a household is expected to have poor thermal performance, and experience associated health symptoms and financial constraints to keeping the home warm when required (Lloyd, 2006; Fellegi & Fülöp, 2012). As such, this field survey was carried out to assess the existence of these factors amongst the occupants of rented apartments (tenants). These set of participants were selected as they are made of up low-income earners (Isaac et al, 2006). The participants were located in Auckland city and were selected through emails and personal requests. Majority of the participants in the 50 apartments surveyed have resided in their current houses for more than one year (76%). These houses have mostly 4 or more occupants (62%) per household including infants, adult and the elderly.

Table 2: Background Information on participants

Participants background information		
Residence tenure	More than one year (76%)	Less than one year (24%)
Occupants per household	2 and 3 occupants (38%)	4 or more occupants (62%)

Thermal performance in low-income homes

The participants were asked questions about the thermal performance of their homes.

Firstly, the participants were questioned on their familiarity with common evidence of the existence of poor thermal performance in houses– condensation, leaking roof, mold growth and dampness in their houses (Shannon et al., 2003; Howden-Chapman, 2004, Canterbury District Health Board, 2012). Most of the participants agreed that they experience leaking roofs, mold growth and dampness in their houses (Figure 4).

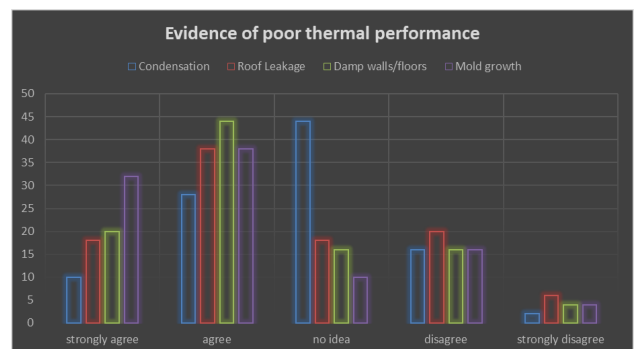


Figure 4: Evidence of poor thermal performance

To verify their responses, the participants were asked to

show evidence of presence of mold growth, condensation, roof leakage or damp walls/floors in their households. The following pictures represent the evidences of observed poor thermal performance in these rental households.



Figure 5: Indication of mold growth and dampness on walls/floor found in some of the participants' households

Associated health symptoms

The participants were asked to identify health symptoms they have experienced living in their houses. Majority of the participants stated running nose (22%), sore throat (17%) and sneezing (19%) as the most common symptoms they experience in their homes. These were followed by blocked nose (9%), depression (8%) and coughing (8%).

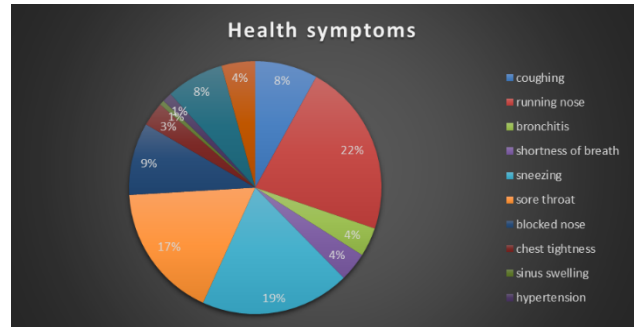


Figure 6: Health symptoms experienced by participants

Evidence of Fuel poverty – Fuel affordability

The participants were asked questions that indicated inability to provide required warmth in their homes. The tables below (table 3) show the responses of the participants to the questions asked.

Firstly, the participants were asked the question “in the past 12 months, have you put up with feeling cold to save on heating expenses?” The majority (58%) of the participants in both types of residents answered “Yes” to this question.

Next, the participants were asked how often it is difficult to afford the fuel expenses in their homes. Thirty percent (30%) of the participants answered “never” while 24% answered, “occasionally”. Twelve percent (12%) answered “quite often” while 34% answered, “very often”.

The final question asked about the level of financial stress experienced by the participants after paying their energy bills. Most of the participants indicated that they somewhat felt (28%) and moderately (36%) feel financially stressed after paying their energy bills.

Table 3: Experience of fuel poverty amongst participants

Financial issues	Response				
	Yes	No			
Putting up with cold to save on heating expenses	Yes (58%)	No (42%)			
Difficulty in affording the fuel expenses in their homes	Never (30%)	Occasionally (24%)	Quite Often (12%)	Very often (34%)	
Level of financial stress experienced after paying their energy bills?	None (16%)	Slightly (14%)	Some what (28%)	Moderate (36%)	High (6%)

3 Discussion

The results of this study suggest that while there are ongoing efforts to tackle fuel poverty, there is still limited public awareness of its existence and measures available towards its eradication. The results also indicate that majority of the people affected by fuel poverty do not know what it means to be fuel poor, are not confidentially sure of the associated health issues and how to tackle or mitigate fuel poverty in their homes. It was also noted that 60% of the participants are 18 -24 years old. This signifies a troubling risk if young adults are ignorant of an issue that has a huge impact on the economic health of the country. Rankine (2005) noted that the young and the elderly are more vulnerable when it comes to physical health effects caused by fuel poverty. The implication is that this proves that sufficient efforts have not been directed towards increasing public awareness of fuel poverty. Another implication is that public ignorance can hinder or slow down the various efforts by the government to curb fuel poverty. The findings supports Lloyd's (2006) suggestion that the government needs to do more to make the public aware of fuel poverty and its effects. It is not enough to have information available on the internet; public jingles on media are required as this will assist in sending the message home.

It was also shown that some of the respondents have not sought advice on how to deal with fuel poverty because they do not know that advice on fuel poverty exists, where to get advice or think it requires money to get advice. This could be related to the fact that there is low public awareness on the issue – *a problem unknown cannot be solved*. The public should be informed of various ways of controlling the indoor temperature since it influences thermal comfort as experienced by the occupants (O'Sullivan et al., 2015). Avenues for advice as well as more information should be made more available and reachable to the public through the media, relevant tenancy documents and other avenues.

The stage 2 survey on tenants indicates that all of the participants surveyed can be termed to be fuel poor (see section 2.2). The results showed that most of the occupants experienced mold growth, leakage of roofs, condensation and damp wall/floor in their houses. The participants also acknowledged experiencing health symptoms in their houses. Some health symptoms were common amongst the tenants such as sneezing, running nose, depression and sore throat. This finding supports already existing research on the health effects of fuel

poverty (Shannon et al., 2003). It is however interesting to note that these symptoms still exist despite over a decade research on its existence and prevalence in the country. It also indicates that the authorities have not done enough to tackle this issue. According to Howden-Chapman (2012), one in four New Zealand households may still be experiencing fuel poverty.

Furthermore, this study showed that most of the participants have had to put up with feeling cold to save on heating expenses (58%). A probable reason could be low-income tenants may find it difficult to afford heating appliances and/or do not want to deal with high electric bills as a result of frequent use of heating appliances. As observed by White & Jones (2017), rental households have less access to more cost-effective heating appliances (heat pumps, wood burners and flued gas heaters) than owner-occupiers. The authors added that rental households were more reliant on portable heaters (unflued gas heaters), which are typically more expensive to run, less effective for heating larger living spaces and are known for their risks to occupant health. This could also explain the health symptoms identified by the participants of this study.

It is interesting to note that a significant percent (54%) do not always find it difficult to afford the fuel expenses in their homes. A plausible reason could be that the tenants have become used to the practice of paying for fuel and always factor it in as a reoccurring expense. Also, as tenants, energy bills may be part of the tenancy agreement and have to be paid to the landlord or the energy providers to retain the tenancy. This also could explain why the participants indicated that they experience financial stress after paying their energy bills. To answer the questions set for this study, we can deduce that most tenants are unaware of fuel poverty and its effects; and they are still fuel poor despite the efforts made by the authorities to tackle fuel poverty. That said, we acknowledge that this study has been conducted a small sample of the wider New Zealand population. It would be highly beneficial for this study to be replicated in other cities in the country to ascertain whether the results found would be similar and thus, generalizable.

4 CONCLUSION

The need to tackle and possibly eradicate fuel poverty in New Zealand cannot be overstated. The effects of fuel poverty on health and thus economy of the country make it an issue that should be prioritised. The study described

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in this paper further proves that fuel poverty is still prevalent in households despite government's effort to deal with it. The reason could be related to the ignorance of the most affected –tenants. Hence, it is recommended that more efforts should be channelled towards increasing the awareness for the public to fuel poverty. A nationwide educational campaign on fuel poverty should be launched targeted at not just low-income tenants or households but all New Zealanders, covering all areas of fuel poverty such as how to identify if your household suffers from it, what the associated health effects are, and what steps can be taken to reduce or remove the effects. Also, instruments to help improve the thermal performance of homes such as heaters, curtains, insulation, or perhaps double glazing, could be offered by the government to those who are most financially crippled for a subsidized amount. This would allow people to help themselves, without being put off because of high costs. This study has investigated a limited number of the population. As such, its findings cannot be generalised across the country. More studies across the country should be carried out to ascertain public awareness and familiarity with fuel poverty.

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Energy Retrofitting: Value Case for Costs and Savings

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ABSTRACT

Energy retrofitting upgrades existing buildings towards achieving energy efficiency thus has the potential of addressing contemporary issues such as global warming and greenhouse gas emissions. However, many building owners are reluctant to invest in energy retrofits due to the contradictory views associated with initial costs and saving potentials of these projects. One logical solution to accelerate the energy retrofitting is through disseminating knowledge on actual cost implications and saving potentials of energy retrofits among building owners. This study reviews existing literature on costs and savings of energy retrofitting and identifies the best set of energy retrofits to apply in existing buildings. Fourteen studies were subjected to review and the different energy retrofits which were incorporated into various buildings were identified. The findings indicated that while it is established that energy retrofits provide numerous savings in energy consumptions, carbon dioxide emission, cooling load, and associated operating costs, the optimal benefits depend on the type of retrofits carried out. For instance, studies showed that energy-efficient lighting retrofits are important retrofit measures for any kind of buildings, whereas solar collectors and Photo Voltaic cells, Low-E double glazing, heat recovery, wall insulation, HVAC systems, and air filtration are not financially optimal due to their incremental costs and long payback period. These setbacks could be addressed with suitable subsidies on retrofits with high energy savings and lower incremental costs. The study findings are useful in decision making by building owners as they seek to implement energy retrofits while considering economic savings and other sustainability considerations.

Keywords: Costs, Energy Retrofits, Savings, Sustainability

1 Introduction

The impact of the built environment on Greenhouse Gas (GHG) emissions and natural resource depletion is staggering. Buildings consume about 36% of global energy and produce 40% of GHG emissions (International Energy Agency [IEA] and the United Nations Environment Programme [UNEP], 2018). Consequently, the existing built environment will have a very high responsibility in dealing with global issues. Therefore, energy efficiency has become a prime concern in the built environment. Energy retrofitting is defined as any type of upgrade at an existing building that is wholly or partially occupied to enhance the energy performance of buildings to achieve energy reduction targets (Fasna & Gunatilake, 2019). Previous studies have highlighted that the building owners

and occupiers are interested in potential energy cost savings of retrofits in existing buildings (Ma et al., 2012; Newsham et al., 2009). A study by Fluhrer et al. (2010) highlighted 38% of reduction in energy use through retrofits such as insulated reflective barriers, daylighting, energy-efficient lighting and plugs, chiller plant retrofit and Variable Air Volume (VAV). Furthermore, energy retrofits reduce the operation costs and contribute savings during the life-cycle, which subsequently reduces the Whole Life-Cycle Cost (WLCC) of the building (Aktas & Ozorhon 2015).

However, Davies and Osmani (2011) found that building owners are unwilling to pay for retrofits due to the high initial cost. According to McDonald et al. (2008), any improvements to existing space require capital expenditure. In fact, Rehm and Ade (2013) found that

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retrofits such as the installation of high-performance cladding systems and the use of energy-efficient mechanical equipment are very expensive. Moreover, Kasivisvanathan et al. (2012) stated that the industries are unenthusiastic about energy retrofits due to the long payback periods.

On the other hand, Zhai et al. (2014) argued that the owners and occupiers are willing to invest in energy retrofitting due to reduced construction costs compared to new construction. Similarly, most organisations are motivated to invest in energy-efficient retrofitting due to lower operation costs and high returns on the investment (McGraw-Hill Construction 2009). As per Bond (2010), renewable energy projects provide a high return on major investments within a short payback period.

Even though, the case studies being conducted on energy retrofits revealed that those reduce the operation costs and contribute savings during the life-cycle and subsequently reduce the WLCC of the building, nevertheless contradictory views exist in terms of the cost implications and potential paybacks of energy retrofits. Moreover, the previous studies were challenged by determining the most cost-effective retrofit technologies

to apply for a project amongst the retrofit options readily available. Still, there is a lack of evidence on the cost and savings associated with the individual retrofits. In order to fulfill the current research gap, there is a need for a review of the existing literature on energy retrofitting. For instance, the review study conducted by Jagarajan et al. (2017) identified the different types of energy retrofits, while Hong et al. (2019) further divides retrofits mix into major types of retrofits such as building envelope and insulation, lighting, Heating Ventilation and Air Conditioning (HVAC), renewable energy, metering and sensors, and energy-efficient equipment and proposed a global assessment of the individual retrofit measures and their associated cost and savings. Further, Ma et al. (2012) reviewed the energy retrofits and the associated energy savings and recommended further investigation to facilitate cost-effective building retrofits. Hence, this review study intends to fill this gap by identifying cost implications and potential savings of energy retrofitting, cost-effective energy retrofits for buildings and highlighting the economic drivers and challenges of energy retrofitting.

Table 1: Energy Retrofits specified in LEED V4 for Existing Buildings: O+M version

Feature	Energy Criteria	Intent	Retrofits
Energy and Atmosphere (EA)	Optimize energy efficiency performance	Achieve higher levels of operating energy performance	<ul style="list-style-type: none"> • Use of energy meters on major mechanical systems and sub-metering for all systems • Energy-efficient lighting/plugs • Use of time-scheduled control of lighting • Ceiling and wall insulation • Window replacement and upgrading • Cladding replacing and insulations • Improvement of heating, preheat upgrade • Chiller plant retrofit • Cooling tower replacement • Floor insulation • Heating controls, heat recovery, Heating system equipment retrofits • Implement energy-efficient equipment and appliances • Boiler efficiency improvement • Low-e double glazing • Foundation insulation
	Advanced Energy Metering	Energy management and tracking building and system-level energy use	<ul style="list-style-type: none"> • Install building energy meters • Building automation/management systems
	Renewable Energy and Carbon Offsets	Use of local and grid-source renewable energy technologies and carbon mitigation projects	<ul style="list-style-type: none"> • Adoption of renewable energy; geothermal, wind, biomass and biogas technologies • Solar collectors and PV cells
	Enhanced refrigerant management	Reduce ozone depletion and minimize climate change	<ul style="list-style-type: none"> • HVAC and refrigerant replacement equipment with reduced refrigerant charge and increased equipment life • Use fire-suppression systems that do not contain Hydrochlorofluorocarbons (HCFCs) or halons

1.1 Different Types of Energy Retrofits

Different energy retrofits can be incorporated into existing buildings as suggested in worldwide sustainable rating systems. Sustainable rating systems such as Leadership in Energy and Environmental Design (LEED, 1998), Comprehensive Assessment System for Building Environmental Efficiency (CASBEE, 2001), Hong Kong Building Environmental Assessment Method (HK-BEAM, 1996), GBTool (1998), and Green Globes (2005) were designed to rate the sustainable performance of existing buildings at the operation and maintenance stage. These rating systems indicate various energy retrofits for the sustainability achievement of existing buildings.

Moreover, Fowler and Rauch (2006), Nguyen and Altan (2011), and Say and Wood (2008) highlighted LEED is the dominant and most widely used rating system around the world. To date, LEED encompasses more than 94,000 LEED building projects over 165 countries and territories (USGBC, 2019). LEED is widely acknowledged and of recognizable standard for sustainable development despite most of the countries have established a body of environmental certification and developed a national assessment system for sustainability (Smith et al., 2006).

typical energy retrofits as specified in LEED V4 for Existing Buildings: O+M version are shown in Table 1.

2 Methods

The aim of this paper is to review the available research studies to determine the cost-effective energy retrofit technologies that could be applied to existing buildings. Three objectives were directly related to this research aim:

- Objective 1: to identify cost implications and potential savings of energy retrofitting
- Objective 2: to identify cost-effective energy retrofits for buildings
- Objective 3: to highlight the drivers and challenges of energy retrofitting

Relevant studies published on the cost and savings of energy retrofits are obtained by searching in computerized databases such as Scopus and Web of Science which have access to indexed and relevant publications. Other databases and "Google Scholar" are also used to include other relevant studies that might not be indexed in the first two databases. Journal articles, conference papers, and thesis reports are identified by using the above-mentioned databases.

Table 2: Methodological Overview of Reviewed Studies

Source	Building Type	Country	Methods	Source Type
Si (2017)	University	UK	A single case, simple energy calculations, and payback analysis	Ph.D. Thesis
Li et al. (2017)	Industrial factory	China	Site measurements and simple energy calculations	Procedia Engineering
Ciampi et al. (2015)	Historical building	Italy	Simulation using a dynamic simulation software: TRNSYS	Energy Procedia
Abdallah et al. (2014)	Public building	US	A single case, energy simulation, and payback analysis	Construction Research Congress
Nabinger and Persily (2011)	A manufactured home (unoccupied)	US	On-site measurement	Energy and Buildings
Ascione et al. (2011)	A historical building hosting presidential office and some classrooms	Italy	The numerical model calibrated by experimental data	Energy and Buildings
Zhang et al. (2011)	Hotel, residential, office	China	Case studies and interviews	Building and Environment
Santamouris et al. (2007)	School	Greece	Simulation modelling	Energy
Stovall et al. (2007)	Residential	US	Energy modelling	Proceedings of ASHRAE THERM X
Verbeeck and Hens (2005)	Residential	Belgium	Simulation modelling	Energy and Buildings
Mahlia et al. (2005)	Residential	Malaysia	Simple energy calculations	Energy and Buildings
Doherty et al. (2004)	University	UK	Experimental investigation	Applied Thermal Engineering
Stefano (2000)	University	Australia	Simple energy calculations with Net Present Value (NPV) and payback	Energy
Cohen et al. (1991)	Residential	USA	Actual measured energy and cost data	

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An extensive search is conducted using keywords such as "Green retrofit", "Sustainable retrofit", "Energy retrofit", "Retrofit", "Retrofitting". The publications are identified and filtered in two stages. In the first stage, two hundred and eleven (211) publications were cumulatively generated as search results. In the review stage, most relevant publications were sorted out by eliminating irrelevant and duplicate publications, considering the studies which address cost implications and saving potentials of energy retrofits. In the second stage, the publications from the first stage were thoroughly reviewed and fourteen (14) of them aligning with the above criteria were used for the review study. The methodological overview of these fourteen (14) studies in terms of the type of buildings, regional context of studies, and retrofit assessment methods are shown in Table 2.

3 Analysis and Discussion of Review Findings

3.1 Cost Implications, Potential Savings of Energy Retrofits

Often, building owners face difficulties in identifying and implementing an optimal set of energy retrofits that can improve the energy efficiency of their buildings while minimizing the required cost and receiving optimal operational savings. Therefore, the key studies on energy retrofits in different contexts are reviewed and major outputs in terms of cost implications: initial investment costs of retrofits, additional costs and cost savings compared to replaced items, payback period; and potential savings: energy saving, Carbon Dioxide (CO₂) emission reduction, and cooling load reduction of individual energy retrofit items are summarised in Table 3. As shown in Table 3, an experimental study which reflects the energy and environmental performances of the green roof systems with and without simulations by Santamouris et al. (2007) found that the energy-saving due to reduction of the cooling load of the green roof system was between 15–49%. The same authors estimated the cooling load reductions due to insulated building with the green roof is 6–33%.

Stefano (2000) reported the potential of saving electricity and electricity-related carbon dioxide emissions at Melbourne University by modeling the energy consumption of four energy efficient lighting technologies: electronic ballasts, T8 magnetic ballasts, T8 electronic ballasts, and T5 electronic ballasts as alternatives to replace 1.2 m fluorescent lighting fixtures which would result in energy savings of 13.9%, 20.5%,

24.4%, and 64.9%, respectively.

Another study, Mahlia et al. (2005) highlighted significant savings of energy and cost of \$37 to \$111 million by replacing incandescent lamps with compact fluorescent lamps. Recently, Si (2017) calculated energy saving, investment cost and payback of lighting retrofits of a University building in the UK. Three energy-efficient lighting retrofits were considered such as 30W halogen lamps, T5 lamps, and lighting timers, amongst 30w halogen lamps, provide a substantial saving of energy by 1800 kWh for an investment cost of £298 and the initial investment cost could be recovered within 0.8 years. However, implementing T5 lamps provide a little saving (378 kWh) for a high investment cost of £440 which requires 8 years to payback.

Further, Si (2017) indicated integrating a Building Management System (BMS) provides an annual energy saving of 18,413 kWh for an investment of £3,000 which could be payback within 2.4 years and installing secondary glazing on all single glazed windows provides annual energy-saving 20,160 kWh which would pay back the investment cost of £11,200 within 16 years.

Cohen et al. (1991) analysed the energy savings and cost-effectiveness of individual retrofit options which could be applied in residential buildings based on collected data on metered energy consumption and actual installation costs. Stovall et al. (2007) performed an experimental study on wall retrofit options such as replacing the cladding, adding insulation under the cladding; and multiple sealing methods that can be used when installing replacement windows in well-built or loosely built rough openings. The results obtained through the experiments were subsequently applied to an energy model and estimated energy impacts derived by the whole-house. Accordingly, the annual utility cost savings of houses equal to 10% in terms of most of the selected wall retrofit options. Another study, Zhang et al. (2011) demonstrated the incremental costs of applying floor insulation ranges between 30-100 ¥/m².

Energy efficient retrofit of historical buildings was studied by Ascione et al. (2011), thereby, come up with a multi-criteria approach that can be employed in a numerical energy model.

The authors were further able to simulate the energy performance effectiveness and economic feasibility of several energy refurbishments of historical buildings. The results showed that wall insulation, heat recovery, and double-glazing system with low-emissive coating involve

investment cost around €18,600, €17,000, and €76,000 and save 2%, 5%, and 12% of annual energy respectively.

Doherty et al. (2004) conducted an experimental investigation on implementing a ground source heat

Table 3: Cost and Saving Effects of Energy Retrofits

Energy Retrofits/Technologies	Cost Implications				Potential Savings			Sources
	Investment cost	Cost saving	PB (years)	Additional cost	Energy	CO2 emission	Cooling load	
Green/Vegetated roof	—	—	—	—	—	—	15-49%	Santamouris et al. (2007)
High albedo and vegetated roof	—	—	—	—	—	—	6-33%	Santamouris et al. (2007)
Electronic ballasts over 1.2m fluorescent lamps	—	—	—	—	13.9%	13.9%	—	Stefano (2000)
T8 magnetic ballasts over 1.2m fluorescent lamps	—	—	—	—	20.5%	20.5%	—	
T8 electronic ballasts over 1.2m fluorescent lamps	—	—	—	—	24.4%	24.4%	—	
T5 electronic ballasts over 1.2m fluorescent lamps	—	—	—	—	64.9%	64.9%	—	
Replacement of incandescent bulbs by 25%, 50% and 75% of Compact fluorescent lamp (CFL)	—	\$37, \$74 & \$111 million	—	—	—	—	—	Mahlia et al. (2005)
T8 lamps replacement with T5 lamps	£440	—	8	—	378 kWh	—	—	Si (2017)
Replacing 50W halogen spotlights with 30W halogen lamps	£298	—	0.8	—	1800 kWh	—	—	
Efficient interior lighting	\$1042	\$1539	0.72	—	—	—	—	Abdallah et al. (2014)
Use of time-scheduled control of lighting	£240	—	1.2	—	1620 kWh	—	—	Si (2017)
Wall insulation	€18,600	—	—	—	2%	—	—	Ascione et al. (2011)
Window replacement and upgrading	—	>\$15/GJ	—	—	2-5%	—	—	Cohen et al. (1991)
Cladding replacing and insulations	—	10%	—	—	—	—	—	Stovall et al. (2007)
Improvement of heating, preheat upgrade	—	<\$2.70/GJ	—	—	19-34 GJ	—	—	Cohen et al. (1991)
Floor insulation	—	—	—	30-100 ¥/m ²	—	—	—	Zhang, et al. (2011)
Heat recovery	€17,000	—	—	—	5%	—	—	Ascione et al. (2011)
Ground source heat pump compared to electrical heating	—	—	0.25	—	—	11.3 tons	—	Doherty et al. (2004)
Energy efficient HVAC system	\$14,900	\$4,974	3.18	—	—	—	—	Abdallah et al. (2014)
Boiler efficiency improvement	—	74%	0.64	—	64.3%	—	—	Ciampi et al. (2015)
Low-e double glazing	€76,000	—	—	—	12%	—	—	Ascione et al. (2011)
	£11,200	—	16	—	20,160 kWh	—	—	Si (2017)
Building management system	£3,000	—	2.4	—	18,413 kWh	—	—	Si (2017)
Solar collectors and	—	—	—	75% of	25%	—	—	Verbeeck and

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PV cells	—	—	—	NPV	—	2-6%	16.8 tons	—	Hens (2005)
CO2 sensors	—	—	—	—	—	60%	—	—	Li et al. (2017)
Motion sensors	\$540	\$430	1.45	—	—	—	—	—	Abdallah et al. (2014)
Air filtration, air sealing of ventilation system	€7600	—	—	—	—	11%	11%	—	Ascione et al. (2011)
	—	—	—	—	—	10%	—	—	Nabinger and Persily (2011)

pump in a University building. The predicted CO2 savings for the system are 11.3 tons per annum and the payback period for the system is 0.25 years compared to electrical heating. Another simulation study was done by Ciampi et al. (2015) on a historical building in Italy, highlighted that the use of a natural gas-fired condensing boiler saves 64.3% of energy, reduce operating cost by 74.0% and the simple payback equals 0.64 years.

Abdallah et al. (2014) developed an optimization model for selecting sustainability measures to minimize building operational costs for existing buildings within an available upgrade budget. This study highlighted energy efficient measures such as Light-emitting Diode (LED) and fluorescent lighting, and HVAC systems minimise building operational costs. The payback periods highlighted for lighting and HVAC systems are 0.72 and 3.18 years respectively.

In terms of renewable energy, Verbeeck and Hens (2005) discussed the economic viability of different retrofit measures using the NPV method and concluded that solar collectors and PV cells reduce the total primary energy consumption by 25%, however, this retrofit option is not financially optimal due to the increase of the total net present value by 75%. Similarly, Li et al. (2017) estimated that the solar thermal system and the PV together can produce 2~6% of the total energy consumption and the CO2 emissions reduced by 16.8 tons per year.

Further, Li et al. (2017) estimated the energy-saving due to CO2 sensors was 25.99kWh/m², nearly 60% of the predicted usage. Moreover, Ascione et al. (2011) and Nabinger and Persily (2011) investigated the impacts of air tightening retrofits such as installing house wrap over the exterior walls; sealing leakage sites in the living space floor; tightening the insulated belly layer; sealing leaks in the air distribution system. The results showed that for the two studies, the energy consumption rate for heating and cooling was reduced by 11% and 10% respectively.

3.2 Cost-effective Energy Retrofits for Buildings

Most energy retrofits identified above ensure the reduction of energy consumption and CO2 emission. The

studies above showed that appropriate technologies selection of retrofit is very important in energy retrofits to achieve maximum sustainable performance. Amongst the selected energy retrofits, energy-efficient lighting retrofits are important retrofit measures for any kind of buildings, whereas solar collectors and PV cells, Low-E double glazing, heat recovery, wall insulation, HVAC systems, and air filtration are not financially optimal due to the incremental costs and long payback periods. However, the current study recommends suitable subsidy energy retrofits such as lighting controllers, BMS, boiler efficiency improvement, motion sensors, window replacement and upgrading, cladding replacing and insulations, improvement of heating, and preheat upgrade which have lower incremental costs and high energy savings to overcome these setbacks when selecting optimal retrofit mix along with high-cost energy retrofit measures.

Moreover, most of these reviewed studies were carried out based on numerical simulations instead of reporting actual cost implications and potential savings due to the implementation of the energy retrofits. Only a few studies such as Abdallah et al. (2014), Ciampi et al. (2015), Doherty et al. (2004) and Si (2017) have conducted analysis accounts for NPV and payback period. More research and application work with practical case studies on energy retrofits in different building types is essentially needed. This can help to increase the level of confidence of building owners to retrofit their buildings for better sustainable performance.

3.3 Economic Drivers and Challenges of energy retrofitting

This section reviews the economic drivers; the reasons for energy retrofitting and the main economic challenges that were encountered during both initial and operation stages of the energy retrofits.

Economic Drivers

The owners or occupiers of existing buildings may have varying drivers whether a building should be retrofitted and confusions about time and the way of implementing the retrofit. For example, Fuerst and McAllister (2011)

explained that high rent, occupancy rate, and tax reduction motivate the owners to implement retrofit projects. Further, Gucyeter and Gunaydin (2012) pointed out that the owners may be driven because of reputation enhancement. On the other hand, the occupiers are interested in energy cost savings. Even though the owners invest in energy efficiency retrofit, the occupiers receive the most direct benefits of energy cost savings (Ma et al., 2012; Newsham et al., 2009). Similarly, low rent and productivity are other drivers that motivate the occupiers to implement the retrofit (Menassa & Baer, 2014).

Moreover, for both owners and occupiers, the main motivation for energy retrofitting is low operation costs, followed by a high return on the energy investment, higher asset values, improved tenant satisfaction, and competitive advantage (McGraw-Hill Construction, 2009). The study conducted by Aktas and Ozorhon (2015) found that the main driver for energy retrofitting is the company's corporate responsibility on sustainably lead the market with the intention of increasing environmental awareness in society and employee satisfaction. This finding is like what has been reported in Hakkinen and Belloni (2011), that increasing environmental awareness would eventually improve the company's corporate image. Furthermore, these authors observed a client-driven approach and employee satisfaction are other reasons for energy retrofitting existing buildings.

From a stakeholder perspective, a drastic reduction in GHG emissions is vital in order to mitigate global warming and climate change. Therefore, the duty-bound to look at the methods of emissions reduction from existing buildings drives the energy retrofitting (Wilkinson et al., 2009). Further, the retrofitting of existing buildings reduces energy use worldwide (Bullen, 2007). Indeed, policymakers have acknowledged the need for more retrofitting projects in the company's vision and environmental policy of the client to achieve sustainability in the built environment (Wilkinson et al., 2009).

Economic Challenges

The stakeholders must be taking actions to reduce emissions of the existing buildings to drastically reduce GHG emanations globally (Wilkinson et al., 2009). However, even with the subsequent growing concerns of the stakeholders over sustainability aspects, still, energy retrofitting is not winning its place at the forefront due to the challenges exist (Pedini & Ashuri, 2010). According to Wilkinson (2012), the previous researches have shown that the building stakeholders' perspective to execute

retrofitting projects depend on the challenges that exist and most of the time they are reluctant to agree with retrofitting. The high initial cost exists as the main challenge when retrofitting existing buildings with sustainability features, therefore, the first costs for any improvements to existing space require capital expenditure than it is required for a new green space construction (McDonald & Ivery Gagne, 2008).

A study by Pedini and Ashuri (2010) revealed that wrong perception regarding costs due to lack of knowledge and experience lead to decisions not to implement energy retrofit. Moreover, the finance plans are usually unstructured to track Life-Cycle Cost (LCC) for a given project and the associated longer-term gains are difficult to record. Hence, the high initial capital cost, lack of knowledge on LCC, and insufficient funding are those factors affecting retrofit projects financially.

The shift in government priorities, such as removing tax incentives and subsidies are other barriers to existing building retrofitting and sustainability implementation (Azizi et al., 2010). As a result, lack of financial incentives, loss of financial incentives, uneven and difficult to obtain tax and regulatory incentives, uncertain expiration dates of incentives, and lower involvement of government and private sectors affect the stakeholders' involvement in the implementation of retrofit projects in existing buildings.

As per Reza et al. (2011), the awareness of green and sustainability is a key requirement to attract investors from building industries as well as to the overall population. When the owners and investors do not have access to enough information, they will not realize that sustainable designs are the best course of action to pursue. Unaware of the cost and benefits of green building, retrofitting and sustainable construction have primarily affected stakeholders from implementing retrofit projects.

4 Conclusion

Although there is a considerable amount of publications on energy retrofits available in the major research databases, review studies focus on the existing body of knowledge on cost and savings of energy retrofits is still lacking. To this end, this paper presents a review of various energy retrofits as classified in the dominant sustainable rating system: LEED V4 for Existing Buildings: O+M green rating system. Further, the paper includes the cost implications and potential savings of energy retrofits.

Reviewed studies demonstrated that the sustainable performance of existing buildings can be improved greatly

if the energy retrofit measures are selected and implemented properly. Findings from the review show that the energy retrofits provide savings mainly in energy and associated operating costs. Energy-efficient lighting retrofits are identified as important in most of the previous studies and these retrofit measures are suitable for any kind of buildings, whereas solar collectors and PV cells, Low-E double glazing, heat recovery, wall insulation, HVAC systems, and air filtration are not financially optimal due to the incremental costs and long payback periods. The current study recommends suitable subsidy energy retrofits such as lighting controllers, BMS, and boiler efficiency improvement which have high energy savings and lower incremental costs, to overcome these setbacks. However, few of the selected studies considered for the current review were based on numerical simulations. Therefore, there could be an inconsistency in actual and predicted energy savings of retrofit measures implemented in real buildings. To overcome this limitation, there is a need for more research with practical scenarios and actual data to increase the level of accuracy in potential energy retrofits' savings.

The reduced WLCC is the major economic driver that motivates the owners and occupiers to invest in energy retrofits, followed by rising energy costs. In fact, energy efficiency retrofits reduce the cost of energy and the operation costs, which subsequently contribute to the reduction of the WLCC of the building. Moreover, high return on major investment within a short payback period such as renewable energy projects also motivates the investors to go for retrofitting. Energy retrofitting enhances building value, thus increases the property value and the owners will be able to earn high rental. Additionally, the energy retrofitted existing buildings have high resale value, less construction cost compared to new construction, less depreciation in rent and price reduced insurance cost and have a greater chance of lease renewal. Due to those aspects, the owners and occupiers are willing to invest in energy retrofitting.

Therefore, this review would enable building owners and decision-makers to identify and implement energy retrofits that can maximize the sustainability of their buildings while minimizing the required cost. However, the review of the literature provided in the current study is limited to several selected papers and does not account for the regional context for individual retrofits. This critical review will be further expanded in evaluating individual energy retrofits and energy retrofits mixes which provide

the most cost savings during the building life-cycle for various regional contexts.

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Actual Energy-related Occupant Behaviours Collected in Surveys and Quantified through Building Simulations

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ABSTRACT

Two buildings from Western Sydney University, in Sydney Australia, were used as case study for this research. Firstly, 100 questionnaire surveys were performed to the occupants of a green-rated and a non-rated building in order to collect occupants' interactions with heating, cooling, lighting, plug loads, shading and windows opening. Then, the results from the surveys were quantified by means of dynamic simulations. These simulations were performed to calibrated models, according to actual energy data, from the two buildings mentioned previously. In order to be able to be comparable, the buildings had to have similar characteristics, such as; floor area, types of activities, schedules, primary energy resources used in the main systems, among others. Finally, with the simulation results it was possible to obtain the actual occupants' actions and behaviours in the two buildings, collected in the surveys. Results show that occupants from the non-rated building are more proactive in terms of energy efficiency than the ones in the green building. Furthermore, heating, lighting and plug loads are the impacting end uses due to occupants' behaviours in the non-rated building, while in the green building occupants have influence in lighting, heating and cooling. Moreover, due to the fact that most of the main systems, in the green building, are being controlled by a centralized management system, occupants' behaviours have less impact in the overall energy use.

Keywords: Energy use, occupant behaviour, surveys, dynamic building simulation, green building, university building

1 Introduction

According to the International Energy Agency (IEA), occupants play an important role in the use of energy in buildings. The "Program in Energy in Buildings and Communities", was created to address the use of energy in buildings, under Annex 53 with the incorporation of architectural engineering, computer modeling and simulation, building, social and behavioural sciences; and occupant behaviour impacts the overall energy use (Yoshino, Hong, & Nord, 2017). Moreover, occupant behaviour in buildings was defined under Annex 66 in order to address the main gap among predicted and operational energy in buildings (Yan et al., 2017). Occupants' behaviours are complex and unpredictable, and therefore contribute to a discrepancy among predicted energy, during the design stage of a building, and the actual energy measured during its operational stage (D'Oca, Hong, & Langevin, 2018; Hong, D'Oca, Turner, & Taylor-Lange, 2015; Hong, Sun, Chen, Taylor-

Lange, & Yan, 2016; Hong, Taylor-Lange, D'Oca, Yan, & Corgnati, 2016; Yoshino et al., 2017). Energy-related occupant behaviour translates the interaction of occupants passively due to the type of activity performed, their presence and movement, and actively by their interaction with switching on and off plug loads and lighting, air conditioning set-points, opening or closing blinds, as well as windows and/or doors (Yan et al., 2017). Past researches, highlighted that occupants interactions with the building features and systems may increase the overall energy use in at least 50% (Khashe et al., 2015; Stazi, Naspi, & D'Orazio, 2017). Moreover, occupant behaviour is varied and multifaceted; as an example, due to different backgrounds, motivations, demography, social-psychological aspects and diversity; and therefore additional research related to occupant behaviour is needed, in order to address its complexity more in depth (T. Hong et al., 2016). Furthermore, the driving factors associated with occupant behaviour, according to the IEA, may be related with; the perception of comfort (Baker &

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Standeven, 1997; Dong & Andrews, 2009; Emery & Gartland, 1991; Hoes, Hensen, Loomans, de Vries, & Bourgeois, 2009; Langevin, Wen, & Gurian, 2016; McCartney & Nicol, 2002; Roetzel, Tsangrassoulis, Dietrich, & Busching, 2010; Turner, 2006; Zeiler, Vissers, Maaijen, & Boxem, 2014), individual expectations (Burrows, Johnson, & Johnson, 2013), age (Kavousian, Rajagopal, & Fischer, 2013; Nisiforou, Poullis, & Charalambides, 2012), gender (Nisiforou et al., 2012), values (Burrows et al., 2013), social interactions (Bartram, Rodgers, & Muise, 2010), climate (Branco, Lachal, Gallinelli, & Weber, 2004; Masoso & Grobler, 2010; Steemers & Yun, 2009), activity type (Mahdavi, 2011), accessibility to control building features (Arens, 2010; Azar & Menassa, 2012; Fabi, Andersen, & Corgnati, 2013; Mahdavi, 2011; Mahdavi, Mohammadi, Kabir, & Lambava, 2008; Maniccia, Rutledge, Rea, & Morrow, 1999; Nicol, 2001), time (de Wilde, 2014; Mahdavi, 2011; Polinder et al., 2013; Stokes, Rylatt, & Lomas, 2004), among others. Therefore, the IEA grouped these factors according to psychological, contextual, social and physiological factors, as well as environmental parameters, time-related actions, and other additional arbitrary factors (Stazi et al., 2017).

Surveys started to be used as guidelines to report physical, social and psychological factors, and may be incorporated in the evaluation of energy efficiency (Hong, Yan, D'Oca, & Chen, 2017). Thermal comfort and adaptive control are commonly addressed by means of a questionnaire survey, where occupants' levels of comfort and satisfaction are addressed, preventing extra use of energy (J. F. Nicol, 2002). Therefore, surveys can be a good indicator to evaluate behavioural patterns regarding energy, and data generated from surveys may even be used in simulation programs as input variable for occupant behaviours (Andersen, Toftum, Andersen, & Olesen, 2009; Barthelmes et al., 2018; Feng, Yan, Wang, & Sun, 2016) (Crosbie & Baker, 2010; Ek & Söderholm, 2010). Furthermore, there is also additional need, in order to translate behavioural occupancy with reliability, for models that may be able to simulate actual occupant actions and behaviours, with accuracy, as well as enhanced quality of collected data and monitoring system (T. Hong et al., 2016; Yan et al., 2015). Finally, past literature indicates that green office buildings can use additional levels of energy when compared to conventional office buildings with the exact function and size. However, occupants are more tolerant and energy

efficiently proactive in green buildings, as well as when they have control over the building systems and features (Khashe et al., 2015; Leaman & Bordass, 2007) (J. F. Nicol, 2002).

This paper investigates the actual impact in the overall energy performance of a green-rated and a non-rated building, in Sydney Australia, due to behaviours and actions of occupants. The study incorporates results from surveys supplied to occupants from these buildings.

2 Research Methodology

A non-rated building from 1989 and a green building certified in 2016 according to the Green Star Australian certification system as a 6 Star building (GBCA, 2013), were used as case study to evaluate their energy-related occupants behaviours. To be classified as a green, the building had to comply with requirements in terms of land use and ecology, management, emissions, energy, indoor environmental quality (IEQ), water, materials and transport. The building has a photovoltaic system with 374 modules that produces 134 MWh of electricity per annum.

The buildings are comparable due to have similar characteristics in terms of type of construction, occupancy rates, floor area, activity type, primary energy source and annual intensity rates. Therefore, due to their similarities, it is possible to conclude what are the main differences among a green-rated and a non-rated building. The main characteristics of the two buildings are presented in Figure 1 and Table 1.

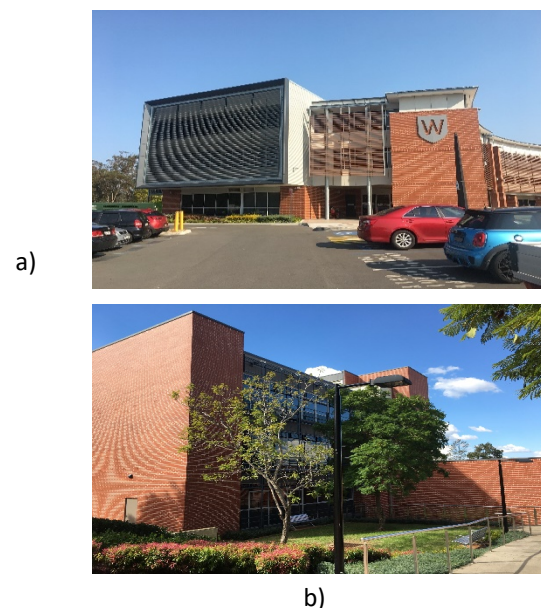


Figure 1: a) Green-rated building; b) Non-rated building

Table 1: Characteristics of the two buildings

	Green-rated building	Non-rated building
Conditioned area (m ²)	5181	4667
Unconditioned area (m ²)	515	576
Total floor area (m ²)	5696	5242
Annual energy intensity (kWh/m ²)	187.22	190.45
Average occupancy intensity (W/m ²)*	0.16	0.11
Average light intensity (W/m ²)	6.07	10.85
Average plug loads intensity (W/m ²)	16.04	23.15
Main activities	Offices, laboratories, class/computer rooms and circulations	
Primary energy for hot water and cooling	Electricity	
Primary energy for heating	Natural gas	

* Per conditioned area

Occupant behaviour was studied by means of dynamic building simulations, using the software DesingBuilder as a 3D interface to EnergyPlus (Version 8.3.0) (DoE, 2016). Then, results from questionnaire surveys, related with occupant’s interactions with lighting, HVAC, shading, among others; were used as input variables in the simulations. Finally, the actual use of energy allocated to occupant behaviour was calculated as output from the dynamic simulations, according to what was suggest in past literature (Andersen et al., 2009; Barthelmes et al., 2018; Feng et al., 2016).

2.1 Calibration and validation

The models from the two buildings were calibrated and validated according to actual annual energy consumptions, monitored through the central management system from Western Sydney University. Consequently, the models calibrated are a reliable representation from the reality and, therefore, it is

² Includes classrooms

² According to surveys, occupants only activated the shading system due to glare in 68% of the rooms with

possible to quantify the actual behaviours related with the use of energy, collected in the surveys.

2.2 Occupant behaviours

The adaptive control behaviours related with use of plug loads, lighting, shading, windows opening and air conditioning, were collected in surveys. Consequently, results from the surveys were transformed into probabilities in order to be used as input variables to the simulation process. Therefore, the actual energy uses due to the actions and behaviours of occupants can be determined through simulation. The probabilities of occurrence of a specific action are presented in Table 2.

Table 2: Occupants’ actions collected in surveys

System	Actions	Green building	Non-rated building
		P(A) _{GB}	P(A) _{EB}
Plug loads	Switch off plug loads Offices at end of the day	0.58	0.78
	Switch off plug loads Labs at end of the day ²	0.38	0.49
	Switch off plug loads Circulations at end of the day	0.53	0.74
	Switch off plug loads General at end of the day	0.53	0.74
	Switch off plug loads Offices during daytime	0.38	0.48
	Switch off plug loads Labs during daytime ¹	0.20	0.36
Windows	Open/close windows during daytime when hot/cold	0.51	0.36
Shading ³	Close shading due to glare	0.31	0.31
Light	Reduction due to glare and visual discomfort	0.50	0.38
	Switch off lights at the end of the day	0.50	0.61
	Switch off lights during daytime	0.30	0.43
HVAC ⁴	Adjust thermostat	0.11	0.18

shading in the non-rated building and 61% of the rooms with shading in the green building

⁴ The percentage of occupants interacting with the air conditioning system is low due to the fact that this system is mainly managed by the management system.

	when cold		
	Adjust thermostat when hot	0.09	0.23

The probabilities were determined according to the following equation.

$$P(A) = \sum_{i=1}^n P(A/E_i) \Leftrightarrow P(E_i) \text{ (Eq. 3)}$$

The buildings chosen for this research were two buildings from Western Sydney University with similar characteristics, as shown in Table 1: a non-rated building and a green-rated building. The non-rated building has four levels above the ground and a total area of 5242 m2. Its orientation is from West to Este and has some neighbourhood buildings that provide shading during the day, as well as architectural features.

The green building is oriented from North to South, with an area of 5696 m2 and three levels above the ground. Similarly to the non-rated buildings, it has neighbourhood buildings that provide shading during the day, as well as architectural features that shade internal rooms. Figure 2 represent the outside view from both models.

3 Models characteristics

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a)



b)

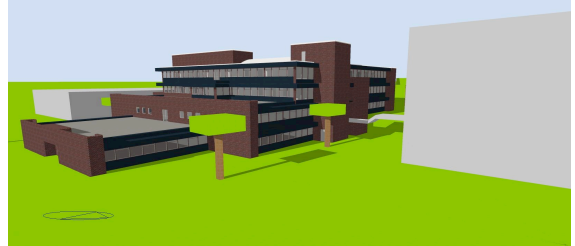


Figure 2: a) Green-rated building model; b) Non-rated building model

3.1 Construction, shading and schedules

Energy audits (Level 1) (ASHRAE, 2004) were performed to collect data related with; type of construction, measurements, distances, neighbourhood buildings, shading systems and validate the “as build” plans, supplied by the Office of Estate and Commercial, Western Sydney University, Australia. Internal shading was assumed according to the actual shading systems present in the buildings.

U-values varied from 1.23 to 5.40 W/m2-K, in both buildings. Due to the fact that some data related with the building envelope and glazing was inaccessible, in the non-rated building, assumptions were made having as support the National Construction Code of Australia (NCC) (ABCB, 2016) and ASHRAE standards (ASHRAE, 2007, 2009).

Buildings operate from 6:30am to 8pm and schedules were according to the actual ones. When information was omitted, data was assumed according to Green Star (GBCA, 2015).

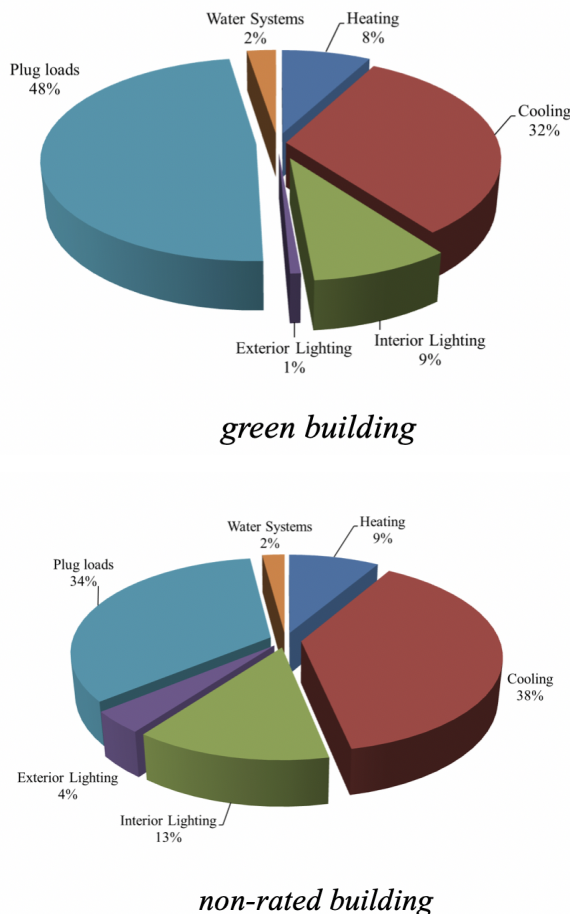
3.2 Thermal zones, internal loads, air conditioning and hot water systems

The green building was divided in 32 thermal zones, while the non-rated building was divided in 52. Both buildings have the exact same type of activities due to the fact that they are university buildings. These activities are: offices, computer labs, workshop areas, meeting rooms, server

Only a few rooms have individual units such as Splits or Multisplits

rooms, laboratories, circulations, storage and technical areas.

Figure 3: Energy distribution per end use due to occupant behaviour



Actual density rates for occupancy, lighting and plug loads, as well as schedules, type of activities, air conditioning systems and additional technical data were collected in energy audits and site visits performed to the buildings. The majority of data was according to the “as build information”. Both buildings have similar operation schedules for HVAC system, that operates from 8am to 6pm and set-point temperatures are: 23oC for summer and 22oC for winter. Nevertheless, in the green building the set-points may vary; from 19 oC to 23 oC in summer and from 18 oC to 24 oC in winter. The primary energy source to produce hot water and cooling is electricity, and natural gas for heating.

Heating and cooling in common areas is supplied by radiant slabs in the green building and both buildings have several air handling units to maintain the indoor air quality

according to the Australian requirements (Australia, 2016).

4 Results

Actual results of the actual distribution of energy per end use in the buildings are represented in Figure 3. It is possible to see that in the green building plug loads are the highest energy intensity use (48%), followed by cooling (32%). In the non-rated building cooling represents 38% of the total energy use, followed by plug loads with 34%. However, the energy intensity from plug loads is higher in the non-rated building (23.15 W/m2) when compared to the green one (16.04 W/m2). Therefore, it would be expectable that the percentage of plug loads, as an end use, would be higher in the green building, and these buildings are university buildings with similar schedules. Consequently, it is possible to assume that cooling, heating and lighting systems installed in the green building are additionally efficient than the ones installed in the non-rated building.

5 Discussions and conclusion

Results have shown that lighting, heating and cooling are the end uses impacted in the green building due to occupants’ behaviours, while in the non-rated building occupants have effect in heating, lighting and plug loads. Therefore, this study shows that the combined impacts of actual occupant’s behaviours in the non-rated building decrease the energy associated with plug loads and lighting 59% and 35% more than the occupants from the green building, respectively. However, occupants from the green building will reduce the use of cooling within a 26% range and increase heating less 34%, comparing with non-rating building.

The annual indicators for energy, GHG emissions and costs for the green building, due to occupant behaviour, are: 35kWh/m2, 32kgCO2-eq/m2 and 184 AUS Dollar/m2, respectively. Likewise, the annual indicators for energy, GHG emissions and costs for the non-rated building, due to occupant behaviour, are respectively: 47kWh/m2, 43kgCO2-eq/m2 and 244AUS Dollar/m2. Consequently, results show that the impact in the overall energy use related with actions and behaviours from occupants, in the green building, is 25% less significant than in the non-rated building. Therefore, is possible to conclude that occupants from the non-rated building have a higher direct impact in the overall energy use of the building. As the majority of the systems in a green building are

controlled automatically, it would be expectable that the impacts of occupants in the overall energy use would be less impacting than the ones in a non-rated building. Therefore, this fact confirms that a green building is already an optimised version of a building, and therefore occupants will have less impact in the overall energy use.

6 Acknowledgement

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Papercrete for Higher Thermal Efficiency in New Zealand Timber-framed Buildings

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ABSTRACT

Heat loss through the building envelope is a major issue in timber-framed residential buildings. Papercrete would be a solution to this “cold housing” problem, as it has good insulating properties depending on its composition and would also be a sustainable solution to the cold housing problem in New Zealand. The appropriateness of Papercrete as an insulated building system in timber-framed buildings is largely unknown. This research investigates the suitability of Papercrete in decreasing heat loss in timber-framed buildings and intends to fill the gap in the New Zealand construction industry regarding Papercrete as a way of reducing heat loss in timber-framed buildings. The insulation properties of Papercrete were identified using past research studies. They were then compared with the current New Zealand Building Code (NZBC) requirements. Mainly a qualitative approach was employed in terms of document analysis. The appropriateness of Papercrete for New Zealand residential buildings was presented in terms of its insulation properties and compliances to current NZBC requirements. It is hoped that the findings of this study would contribute to future research on the use of Papercrete as an alternative building system to reduce heat loss in New Zealand residential buildings.

Keywords: Papercrete, Thermal efficiency, Timber-framed buildings

1 Introduction

The recommended minimum indoor temperature in New Zealand residential buildings is 18 °C. However, most New Zealand houses have an indoor temperature of about 16 °C (Science Media Center, 2008). The traditional methods of insulating houses might not be the most effective solution to the cold house issue in New Zealand. Therefore, new materials that have higher thermal efficiency rates should be researched and used. For example, new building materials such as Papercrete can be taken into consideration if it satisfies the New Zealand building code requirements and contributes to better thermal and energy efficiency in buildings. Apart from that, new materials that have lower energy consumption also benefits environmental sustainability.

Papercrete products usually have a similar appearance to standard concrete with a higher degree of sustainability than concrete. Papercrete consists of paper/sawdust, concrete, sand, clay and other components. There are various mixtures of Papercrete available on the global

market. The properties of Papercrete largely depend on its composition. The properties of a specific type of Papercrete are shown below in Table 1.

Table 1: Properties of dry papercrete

Property	Values
Weight	47 GSM
Thickness	0.06 mm
Moisture content	7.5%
Bursting strength	168 kPa
Tearing resistance	12.6 kPa
Tensile strength	113 kg

Note: The information in Table 1 was retrieved from Properties of Papercrete Concrete: Building Material by Yogesh, Shermale and Varm (2017).

The Compressive strength of papercrete is presented in Table 2.

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Table 2: Compressive strength of papercrete

Papercrete type	Compressive strength (MPa)		
	7 days	14 days	21 days
Sun-dried	1.025	1.25	1.65
Water-cured		1.10	1.40

Note: The information in Table 2 was retrieved from Papercrete Bricks: An Alternative Sustainable Building Material by Delcasse et al. (2017).

The Figure 1 and Figure 2 shows Papercrete products and buildings made of them.



Fig 1: Papercrete block (Lily Ann Fouts, 2016)



Fig 2: Papercrete house (Wood House Group, 2019)

In general, Papercrete is well-known for good sound and thermal insulating properties. It is also light-weighted

compared to concrete. It is made of recycled paper or leftover sawdust.

The aim of this research is to propose “papercrete” as an alternative internal and external wall material in order to decrease heat loss in New Zealand residential buildings. There are two main objectives in this study: to analyze the suitability of Papercrete in decreasing heat loss and to compare Papercrete construction with the current standard practice of timber buildings. The following three research questions were established to achieve the objective set in this study.

1. What are the properties of papercrete?
2. How do papercrete properties correspond to NZBC requirements?
3. How does papercrete construction, including buildability, cost, transport and logistics and sustainability aspects, compare with the current standard practice of timber building construction?

The scope of the research mainly encompasses the field covering the physical properties of papercrete. In addition, information regarding papercrete in New Zealand and other countries is provided along with the sustainability aspect.

2 Literature review

The use of insulation aims to retain heat and sound and keep buildings dry. It is widely used across New Zealand and is considered as a standard building practice. Insulation materials are often placed between the wall frame and cladding and can be used in external and internal walls. There are two main types of insulation; thermal and acoustic. Usually, these two types are combined and used. A new amendment has been made to the New Zealand Residential Tenancies Act, which states that landlords must inform future tenants about insulation in the property (Tenancy Services, n.d.). In addition to this change, new requirements for insulation will come into effect from 1 July 2021. New requirements are addressed to landlords, who did not insulate their property in 2016. The amendment declares that “all rental properties will need to have insulation which meets the 2008 Building Code, or (for existing ceiling insulation) have a minimum thickness of at least 120 mm” (Tenancy Services, n.d.). New Zealand homes are known for being cold houses because the temperature inside is lower than the standard requirements. The main reason for this issue is poor insulation.

Another crucial aspect of insulation is the health and

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safety regulations regarding its installation. Therefore, insulation plays one of the central roles in the health and safety aspects of home occupants. From another perspective, construction workers who are involved in the installation of insulation must be protected according to the New Zealand Health and Safety Act 2015. Insulation must be installed in accordance with New Zealand Standard (NZS) 4246:2016 that covers energy efficiency and installing bulk thermal insulation in residential buildings. A poorly insulated building is not likely to retain heat inside the house and can lead to severe health damage to the occupants. The World Health Organization (WHO) (2018) says that low indoor temperatures can provoke respiratory and cardiovascular morbidity. The WHO further emphasises that the steady indoor temperature for countries with a cold climate should be 18°C. This value is also considered the recommended indoor temperature in New Zealand houses (BRANZ, 2015). It has been found that the number of people aged 65 years and over living in insulated houses that had been hospitalized with circulatory illness was significantly lower than those in the same age category living in uninsulated houses (World Health Organization, 2018). This implies the significance of the use of proper insulation materials in New Zealand residential buildings.

Thermal insulation in New Zealand buildings should not be an issue nowadays. One of the first problems that occurred due to poor insulation was reported in the 1940s. Isaacs (2007) writes that significant parts such as the ceilings and walls of over 50% of new buildings were covered with mould. Therefore, it was recommended to provide better insulation and air circulation in buildings with poor insulation properties. Since then, local companies began manufacturing fiberglass insulation in the early 1960s. Prior to this, imported insulants were used. The first region which made insulating houses mandatory was Waimairi when in 1971, local authorities implemented thermal insulation by law (Isaacs, 2007). It should be acknowledged that, in order to increase the quality of house insulation, NZS 4218 has been improving over the past few years. However, the standards have been targeting minimum insulation levels which may not be sufficient. This aspect may also have contributed to New Zealand's cold housing problem.

The aforementioned concerns regarding poor insulations in New Zealand buildings urge the need for research on this topic. Therefore, alternative insulation materials were considered in this study. There are various insulation

materials (e.g. fibreglass, cellulose, sheep wool, synthetics and mineral wool, polyester, wool/polyester blend, polystyrene and macerated paper) which are currently in use (BRANZ, 2017). Most of these materials are made of recycled substances. For example, fibreglass predominantly consists of 40%-60% recycled glass (Energy Department, n.d.).

As discussed before, insulation can be installed in different parts of a building, for example, external and internal walls as well as the ceiling. According to BRANZ (2007), 42-45% of heat loss in houses occurs through openings. Other than that, 13-14% of heat loss occurs through the roof, 11-13% through the walls, 12-15% through the floor and 10-17% through air leakages. Therefore, sufficient attention must be directed towards improving heat retention of those vulnerable parts of the building envelope. Regarding openings, there are many solutions currently available on the market. Widely known double glazed plastic windows are one of the best current options to control heat loss. However, this does not preclude insulating walls. As an alternative solution to the materials mentioned above, Papercrete is proposed for insulating external and internal walls.

Papercrete is an innovative building material made of various substances such as cellulose, sand, sawdust, fly ash, glass fibre and cement. Papercrete properties depend on the proportion of these substances. Among various research papers on the topic of properties of papercrete, the publication "Properties of Papercrete Concrete: Building Material" by Shermale and Varma (2017) explains this in a concise and precise format focusing on the different options of papercrete. Most commonly, Papercrete is produced in the form of block or brick, the necessary components of which are cellulose and water. This article focuses on a specimen sized 100x100x100 mm with a curing period of 28 days. In this study, the highest compressive strength of a Papercrete specimen was 5.0 MPa with a composition of paper: cement: sand: fibre glass in a proportion of 1:1:3:1%. This was used to compare the concrete's compressive strength requirement for residential buildings which is 28 MPa and higher for commercial construction (Jamal, 2017). However, compressive strength may vary depending on the type of wall. Compressive strength of the material is higher for loadbearing walls than alternative walls. According to Shermale and Varma (2017), papercrete block/brick of 5.0 MPa can be used for non-loadbearing walls. Papercrete with a higher portion of cement has

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higher compressive strength which enables the use of loadbearing walls.

Another valuable mechanical property of Papercrete is water resistance. The water resistance level is crucial in the New Zealand climate, which is humid, especially in the winter. This property depends on the content of the paper in brick/block. When the paper content increases, the water absorption rate rises dramatically (Selvaraj et al., 2015). Therefore, a waterproofing coating must be applied. The waterproof coating is usually used in the form of sheets covering Papercrete blocks/bricks.

Papercrete is more ductile in comparison with pure concrete. Tensile strength of Papercrete increases when the paper content is increased. Tensile strength is an essential aspect for the regions with high seismic activity such as New Zealand, particularly in earthquake sensitive areas. Splitting tensile strength (fsp) of Papercrete varies from 0.79 MPa to 3.17 MPa. The flexural tensile strength of Papercrete lies between 4.36 MPa and 10.84 MPa (Selvaraj et al., 2015). Splitting and flexural tensile strength can have different values to those stated above, due to the changing ratio of the components that directly affect the tensile strength.

Fire resistance is another crucial aspect to be analysed in the New Zealand building environment. There are a number of regulations under the Health and Safety Act 2015, which have been established to minimize the occurrence of hazards which may lead to fire risks. Therefore, it is suggested to use flame-resistant materials in construction. As mentioned earlier, Papercrete may consist of a large share of paper, cellulose or recycled paper-like substance. Paper is a highly flammable material. Papercrete becomes a material which is highly flammable if it contains a significant portion of the paper. However, Papercrete with a high content of the paper is not suitable for construction in New Zealand. As observed by Anandaraju et al. (2015) in an experimental investigation, Papercrete bricks made of well-composed substances did not burn during 5 minutes of a fire resistance test however it was mentioned that they would burn down to ashes after several hours. In any case, the Fire Resistance Level (FRL) of the material must be known before its installation to the structure. It is worth mentioning that there is no formal ratio of composition materials for the design of papercrete.

Papercrete is also a lightweight material compared to concrete. Therefore, it does not contribute to a high dead load as in conventional concrete based materials.

Papercrete can be considered as an environmentally friendly construction material compared to concrete. Papercrete is partly composed of paper, sawdust, sand, clay and water. These substances are considered to be sustainable for the environment. Moreover, recycled paper and sawdust leftovers can be utilized for Papercrete bricks/blocks. In accordance with data presented in Chung et al. (n.d.) the frequency of paper recycling is about 60%-80% in many countries. Much of this recourse can be used in the construction industry. However, the construction industry tends to be considered as one of the highest waste-generating industries. It produces approximately 15% of the waste.

Overall, based on the analyzed articles, it is evident that Papercrete possesses essential qualities to be successful as an alternative insulating material in New Zealand. The research gap of this study emerges from the lack of studies conducted on reducing heat loss in New Zealand houses. Besides, there is a lack of alternative materials available as thermally efficient building materials. Therefore, Papercrete is proposed for internal and external walls in New Zealand residential buildings.

3 Research methods

This research has mainly a qualitative focus. However, statistical data and data on mechanical properties are also included in the research, composing of quantitative aspects. Along with that, there are several documents analysed such as recent publications in construction and engineering-oriented journals, New Zealand regulations and standards and relevant research papers. Figure 3 below demonstrates the research process followed in this study.

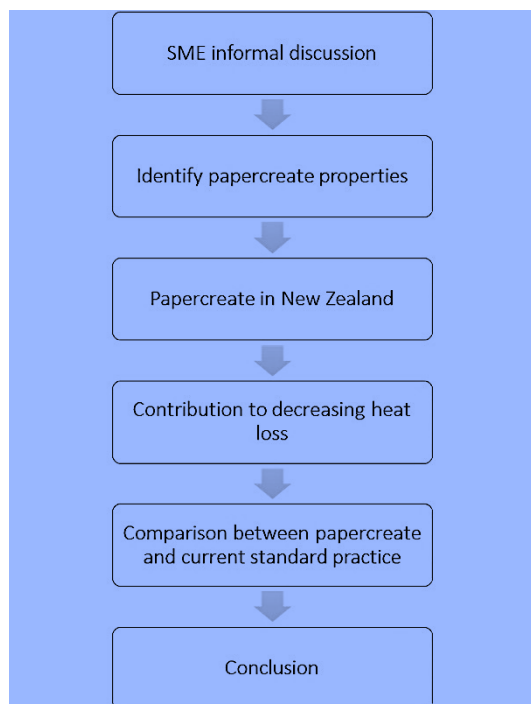


Fig 3: The research process

To begin with, a Subject Matter Expert (SME) in Papercrete industry was informally interviewed. Afterwards, the properties of the Papercrete suitable for the New Zealand built environment were identified. The physical properties of Papercrete are unchangeable, and they have been defined in earlier studies. Therefore, the physical properties were retrieved from previously conducted studies and research articles. Next, there is a description of the popularity of Papercrete in New Zealand. Lastly, the NZBC and BRANZ publications were taken as referencing materials to compare papercrete's compliances to NZBC. There are three main types of documents that have been analysed in this study, including New Zealand standards and regulations, relevant journal articles and conference papers.

4 Data collection and analysis

In this study, primarily secondary data was used. There were 19 articles selected and analyzed in this study, which were then divided into clusters of information. These are mechanical properties of papercrete, sustainability aspect, legal compliances and others. The research articles were used to compare different studies and find the most optimal information suited for this research. It should be mentioned that the legal documents (NZBC compliances) were the foundation of answering the research questions of this study.

In addition, a SME informal discussion was conducted to support the secondary data analysis results. The SME interview was conducted with a person who has been involved in the construction industry in Russia for 43 years. The SME has excellent knowledge in Papercrete with a strong construction engineering background. Currently, the SME interviewee is working as a CEO of a quality assurance company in the Eastern part of Russia. SME was asked to provide answers for some questions related to this study, and a summary of the responses are presented in the below sections.

This construction material is popular with replacing conventional materials that have been used in construction for decades in Russia. Papercrete, at this stage, cannot take the place of traditional materials mainly because of its specific characteristics and price. The SME said that Russia is not a "green country", and people do not have this mentality to save the environment by paying a little bit more for sustainable products such as Papercrete.

The content of Papercrete can be different depending for what construction purpose it is used. The most common Papercrete content produces the following characteristics: density 400-850 kg/m³, thermal conductivity 0.07-0.17 W/m K.

According to the SME interviewed, Papercrete blocks can be technically used for both internal and external walls. For example, Papercrete blocks of size 500mm x 300mm x 200mm are usually utilized in external walls, and 600mm x 300mm x 120mm blocks are used for internal walls. The SME shared that the average market price of a Papercrete block in Russia is 4400 RUB/m³ (~108 NZD/m³). The SME said that Papercrete blocks were introduced in the Russian market a few decades ago. Papercrete is usually compared to materials like concrete blocks, bricks and timber blocks. However, there is currently no exactly similar material to Papercrete in the construction market in Russia.

The answers provided by SME gave sufficient information on the application of Papercrete in Russia. Referring to SME pricing information, the price for Papercrete in New Zealand can be anticipated by comparing prices to the Russian market. The SME informal discussion provided a good addition to understand the value of Papercrete in Russia. Since there is a small number of studies conducted on Papercrete material, SME opinions were very helpful in this study.

The SME interview revealed that Papercrete could be considered as a material for both internal and external

walls, depending on paper to concrete content. Papercrete is a relatively common material in some countries like Russia and perceived to be a "green" material compared to its alternatives such as concrete. Unlike other green building materials, Papercrete is not costly compared to concrete.

5 Findings and discussion

5.1 The properties of Papercrete

The study found that Papercrete indicated its R-value as 2.0 to 3.0 per inch (Shermale & Varma, 2015). For Papercrete block consisting of paper fibres, sound and heat insulating properties are defined as excellent (Shermale & Varma, 2015). Papercrete is an excellent thermal insulating material (Safin et al.). Tensile strength was shown at a maximum of 28.3 and minimum of 0.195 to 0.052MPa, which is very low (Shermale & Varma, 2015). The standard average tensile strength of a Papercrete block is 0.7-1.0MPa (Yaskevich, n.d.). Another study showed that the average compressive strength was defined as 34MPa at 60 days strength with the following material composition (in kg): waste paper 50, water 450-85, cement 950, sand 1000 and SP 50 (Yun et al., 2011). However, it was declared in another research that the average compressive strength of the Papercrete cube lays between a minimum of 1.12MPa and maximum of 2.36MPa (Shermale & Varma, 2015).

Papercrete, in which paper is replaced by sawdust, is considered to be suitable for loadbearing walls with 4 storey or higher buildings (Safin et al., n.d.). Water absorption is high in Papercrete blocks. One research defines this value as 45.2% (Stenina, 2015). Fire-resistance rating is lower than concrete due to the highly flammable component in Papercrete, which is cellulose or sawdust. Fire resistance of sawdust elements vary from 0.75 to 1.5 hours (Yaskevich, n.d.). Also, Papercrete is a light material. One study showed that 1m² of a wall erected of Papercrete is 8 times lighter than the same wall made of bricks (Yaskevich, n.d.). In terms of health and safety aspects, Papercrete does not consist of asbestos which is a prohibited construction material in New Zealand. Main components of Papercrete blocks are organic (cellulose, sawdust, sand) except cement. This combination of composite elements are not considered to be harmful to humans' health and can be used for construction purposes. Papercrete is believed to be composed of "breathable" materials, meaning that it gets the moisture out. Overall, Papercrete is light, environmentally friendly,

cost-effective, healthy and consists of breathable material as compared with pure concrete.

5.2 Papercrete properties corresponding to NZBC requirements

The New Zealand Building Code does not mention Papercrete material as a prohibited material or if it can be utilized in the construction industry. Therefore, it is difficult to come up with a decision if, in the future, Papercrete will be approved to be used or not. In accordance with clauses E2 and E3 of the Building Regulations 1992, moisture must not penetrate the living space causing fungal growth and impacting the health of inhabitants. Moisture absorption is the key issue of

Timber construction	Papercrete construction
Material cost ~\$351/m ³	Material cost ~\$108/m ³
Thermal conductivity 0.10-0.38 W/mK	Thermal conductivity 0.08-0.17 W/mK
Fire resistance Poor	Fire resistance Good
Ease of use Poor	Ease of use Good
Material efficiency Good	Material efficiency Excellent

Fig 4: Papercrete - timber comparison (Yaskevich, n.d.)

Papercrete properties. Even though Papercrete tends to transfer moisture from the house to the outside, it also has a tendency to accumulate moisture. Thus, Papercrete must not be used in places with high moisture content. For example, it can be used for internal wall insulation and external walls, but Papercrete must be covered with high water resistant materials such as cladding. Moreover, Papercrete should not be used in bathrooms. However, in terms of fire resistance, Papercrete is recommended to be painted with fire restraining paint in order to improve fire resistance which can reduce the likelihood of quick ignition of the material. Papercrete is an insulation material which must comply with clause H1 of Building

Regulations 1992. This clause states energy efficiency provisions and requires construction materials to retain heat inside the house, in order to decrease the utilization of energy. Typical R-values for thermal insulation is 1.8 (Smarter Homes, n.d.). This R-value is accepted by the Building Code. Papercrete has high R-value; thus, it is considered to be suitable for this purpose. According to BRANZ, the minimum thickness of insulation material should be maintained. Papercrete can be made in different levels of thickness. Therefore, it complies with BRANZ minimum thickness requirements. BRANZ states a minimum density of insulation material of 9.8 kg/m³, while the average density of sawdust (Papercrete component) is 500-850 kg/m³ (Yaskevich, n.d.). If including cement to Papercrete mixture, the overall density will increase to approximately 1800 kg/m³. The sound insulating properties of Papercrete cannot be questioned under New Zealand regulations since the sound absorption of Papercrete is rated as excellent and has a sound absorption diapason of 126-2000 Herz (Yaskevich, n.d.). To conclude, Papercrete can be compared to concrete, as many properties are similar. Therefore, Papercrete is likely to be approved for construction utilization in similar regions where concrete construction is carried out. However, Papercrete can also be used in higher seismic zones because of greater tensile strength as compared to concrete.

5.3 Comparing papercrete construction with the current standard practice of timber-buildings (buildability, cost, transport and logistics and sustainability aspects)

Papercrete construction is not widespread in New Zealand but has good buildability. Papercrete is material that can be shaped differently, providing wide varieties to a client. Nevertheless, this material can only be used for small to medium construction depending on the mixture of Papercrete itself. If Papercrete is used in blocks, it is considered fast and comparatively easy at erecting a structure. Data on the cost of Papercrete in New Zealand is absent. However, the components of Papercrete are not expensive. For example, in Russia, the price of Papercrete is 4400 RUB/1 m³ (~108 NZD/1 m³) (source: SME informal discussion). Moreover, the price of concrete blocks is 5000 RUB/1 m³ (~123 NZD/1 m³) (source: SME informal discussion). Transport and logistics can be simplified by locating the production of Papercrete in New Zealand, and components of Papercrete are available on the New

Zealand market. There are some countries which have already set up papercrete production, such as China, Russia and the USA. Depending on proposed prices by exporters, exporting Papercrete might cost less than producing it locally. Currently, Radiata Pine is the most popular timber for construction in New Zealand, and this material is produced locally. Papercrete is considered to be a sustainable material (Sheth & Joshi, 2015). Current New Zealand standard practice encourages using sustainable building materials. The most popular type of residential construction in New Zealand is timber-framed buildings, and it will be relevant to make a comparison between timber construction and papercrete. Figure 4 shows the comparison between current construction practice related to timber materials with the perspective of Papercrete construction. Information provided in Figure 3 is relevant to Russia. However, these prices could potentially be extrapolated to the New Zealand market as well.

5.4 Summary of findings

This study has found that Papercrete is suitable for load-bearing walls, enabling use in external walls of buildings. However, it is not recommended to use Papercrete in external walls without a weatherproof cover. We acknowledge that Papercrete blocks might not be suitable for extremely high wind zones in New Zealand due to its lightweight nature. Papercrete has both excellent thermal and sound insulating properties compared to existing insulating materials available in the New Zealand market. Due to the general absence of information about papercrete in the NZBC, concrete was considered as the closest material to Papercrete.

The degree of weathertightness of Papercrete is weaker than pure concrete. Thus, a combination of concrete and papercrete can be used in the zones with severe weather conditions. For example, high content of moisture tends to accumulate in the base of the foundation. Therefore, concrete blocks should be used at the base, followed by Papercrete blocks in the wall. Undoubtedly, Papercrete is an innovative construction material for New Zealand. Therefore, it is recommended to test the material in the New Zealand environment. Moreover, Papercrete's properties can be altered in accordance with its required use. For instance, the compressive strength of Papercrete can be improved by adding more concrete components. This is a great advantage of Papercrete, which enables it to be modified depending on the NZBC requirements and the client's needs.

As was discussed previously, the degree of buildability of Papercrete is similar to concrete blocks. According to the SME who was interviewed, the price of Papercrete in New Zealand can be less than NZD150 per 1m³. The main components of Papercrete are taken from plants. After demolition, Papercrete can be recycled by dividing organic and non-organic parts, which can then be used to make new Papercrete blocks. Papercrete is more flexible than concrete. Thus, it might be ideal for utilization in high seismic zones. As papercrete is compatible with New Zealand timber-framed buildings, it can be an excellent alternative material to the existing insulating materials in combination with double glazed windows.

6 Conclusion and recommendations

This research is primarily aimed at proposing Papercrete as an alternative internal and external wall material in order to decrease heat loss in New Zealand residential buildings. The findings showed that Papercrete could be considered as an alternative way of reducing heat loss in New Zealand residential buildings. Papercrete has many advantages, one of which is a combination of construction and insulation material in one material.

Papercrete blends in various characteristics that allow being used in internal and external walls. The main disadvantage of Papercrete is that it can only be used in external walls in conjunction with double glazed windows to minimise significant heat losses through the building envelope. Papercrete's weathertightness can be increased by applying a humidity-resistant coating. Papercrete is a "flexible" material that allows using in load-bearing or non-load-bearing walls. Papercrete's material composition can be adjusted depending on the climate zone it is intended to use. For example, it can consist of more concrete in humid areas. More paper/sawdust can be added to Papercrete in dry zones. Likewise, the environmental sustainability of this material can be controlled, adjusted and customized.

It is suggested that the New Zealand construction industry should work towards either manufacturing or importing Papercrete as a great insulation material for residential buildings. Further, we recommend that Papercrete can be used in external walls in conjunction with double glazing of openings to achieve significant heat loss improvement. In comparison with the current standard practice, Papercrete is considered to be an innovative material and can relate to concrete due to its similar properties as concrete. The current New Zealand Building Code does

not have information about Papercrete material. Therefore, it has been compared to concrete and found to be suitable to be used in the New Zealand climate. Further experimental research should be conducted on improving the weathertightness of Papercrete and to adjust the Papercrete composition to suit the New Zealand environment.

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Constraints in the Supply Chain of Prefabricated Elements used for Housing Construction in New Zealand

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ABSTRACT

The term prefabrication is becoming a trending topic in the New Zealand housing construction industry due to its benefits. However, the adoption rate of prefabrication is relatively low in New Zealand due to many challenges, including a lack of integration in the supply chain. Even though prefabrication has been studied in the areas of the supply chain and lean manufacturing, there have been very few concerning the constraints in integrating the supply chain in prefabrication. Therefore, this paper aims to explore the barriers and enablers for supply chain integration in modular elements manufacturing processes.

The paper is based on the analysis of twelve semi-structured interviews among prefab experts, selected through purposive sampling technique as it facilitates capturing participants, appropriate to the study based on the researcher's own knowledge and opinion. Content analysis is used to analyze the gathered data.

Ad-hoc relationships, poor planning and scheduling, transportation of volumetric modules, and information sharing are identified by the participants as major challenges in the manufacturing processes of modular elements used to build housing. Industry and government need to focus on supply chains in prefabricated module manufacturing and rectify these constraints to improve the housing construction sector in New Zealand.

Keywords: Housing, Prefabrication, Modular prefabrication, Supply chain, New Zealand

1 Introduction

Affordability, sustainability and productivity issues in the New Zealand residential construction industry have created a move towards prefabrication driven by its benefits (PrefabNZ, 2014). The notion of prefabrication has the potential to enhance industry performance with the improvements in environment, health and safety, value for money, profitability, predictability and productivity (Bildsten, 2011; Chiang, Chan, & Lok, 2006; Pasquire & Gibb, 2002; Tam, Tam, Zeng, & Ng, 2007; Tatum, Vanegas, & Williams, 1987). Even though prefabrication has been identified as a potential solution for the New Zealand residential construction sector, the usage level is still low (Page, 2014; PrefabNZ, 2014). At present on average 64% of the revenue comes from prefabrication with the usage of 11% and 37% for non-residential buildings and residential buildings respectively (Prefab, 2018). The study further emphasized the current production of modular elements and whole building as 57% and 77%

respectively and among the modular element manufacturing, panels and pods mark the highest production capacity (79% and 71% respectively) (Prefab, 2018).

The lower level usage of prefabrication is triggered by the bespoke nature of building construction, lack of skill and experience, and the implications of logistics, site operations, the supply chain and procurement (Shahzad, 2016). Similarly, extensive project planning from an early stage, lack of coordination and communication, and transportation constraints are found to be other barriers to uptake of prefabrication in housing construction (PrefabNZ, 2014). In addition to those, market failures have also influenced the wider take up of prefabrication in the New Zealand construction sector (BRANZ, 2013). The prefabrication construction sector needs to address the above challenges if it is to compete effectively and efficiently with traditional on-site construction projects (Pan & Goodier, 2012, Doran & Giannakis, 2011). Supply chain management has been

identified as one of the areas to be improved to achieve the benefits of prefabrication (PrefabNZ, 2014; Stroebele & Kiessling, 2017).

The application of supply chain management to the construction industry requires a huge effort (Vrijhoef, Koskela, & Howell, 2001). It involves developing vertical integration in the whole process of design and production focusing on boosting opportunities to add value while diminishing the total cost (Akintoye, McIntosh, & Fitzgerald, 2000). As this application requires a significant shift in the mindset of the participants towards collaboration, teamwork and mutual benefits (Awad, 2010), it is hardly surprising that only a few advanced applications have been reported in the construction industry. This paper, therefore, focuses on identifying barriers and challenges for supply chain integration in prefabricated element manufacturing.

The paper begins with a background idea of prefabrication and supply chain management and continues with the methodology used in analyzing gathered data. The main findings are presented as nine barrier-enabler couples, explained with the help of the data. The implications are discussed at the end.

2 Methodology

For this paper, 12 semi-structured interviews were conducted with the aim of identifying barriers and enablers for the manufacturing process of prefabricated elements that are used in house construction. Generally, in New Zealand, whole building manufacturing is not popular. For this research, therefore, modular elements manufacturing is considered. The distribution of the interviewees according to their designation and experience is shown in Table 1. The twelve semi-structured face to face interviews were carried out among prefab industry experts and they were selected based on a purposive sampling technique as it facilitates capturing participants, appropriate to the study based on the researcher’s own knowledge and opinion (Saunders, Lewis, & Thornhill, 2009). Participants were selected considering their current position and experience in the manufacturing process of prefabricated house building elements. People who do not have experience and knowledge in the manufacturing process of prefabricated house building elements were excluded from the interviews. Participants were mainly asked about the barriers in the manufacturing process of prefabricated elements and enablers to overcome the highlighted barriers.

Table 1: Demographic data of participants

ID	Role	Relevance to the NZ residential construction industry	Experience
P-01	Managing Director	Manufacturing ceiling battens and roofing battens, steel frames, steel trusses, and steel floor joists	14.5 Years
P-02	Associate Director	Working as a designer/project architect in industrial, commercial, residential and institutional sectors	11 Years
P-03	Managing Director	Design, manufacture and build modular houses	25 Years

P-04	Consultant	Environmental sustainability of the residential built environment	10 Years
P-05	Managing Director	Develop affordable modular houses	15 Years
P-06	Director	Develop modular house elements	7 Years
P-07	Chief executive	Residential development	13 Years
P-08	Director	Design, manufacture and build modular houses	8 Years
P-09	Director	Development of modular construction	3 Years
P-10	Technical Manager	Development and education of mass timber market for residential construction	5 Years
P-11	Production Manager and Director	Residential development	7 Years
P-12	Operational Manager	Timber manufacturing for residential construction	14 Years

The gathered data were analyzed with the aim of identifying barriers and enablers. The analysis method was mainly content-driven. As this paper represents issues in the supply chain and suggestions to improve the supply chain, the thematic content analysis is the best approach to identify the common themes across the data sets (Fellows & Liu 2015; Saunders, Lewis & Thornhill 2009). At first, barriers and enablers were identified through the interview transcripts. Next, these barriers were categorized under managerial, relationship and technical. And finally, the barriers were linked with enablers as mentioned by the

interviewees and reflected against previous research in this paper.

3 Findings

Based on the outcomes from the interviews, there are numerous internal barriers involved with the supply chain integration in modular elements' manufacturing process and each barrier was coupled with the well-matched enabler. Mainly, internal barriers are categorized under relationship, technical and managerial. Apart from the above, interviewees further indicated the other external barriers which affect the supply chain in prefabricated elements.

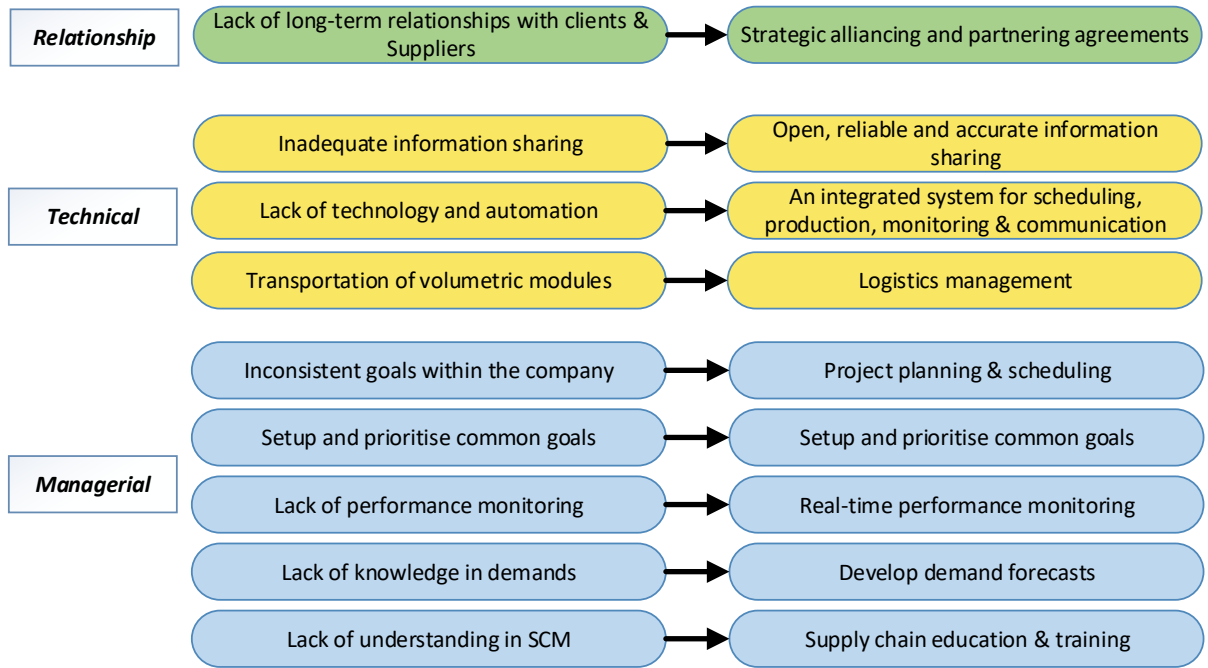


Figure 1: Barriers and enablers for SCI in modular elements manufacturing

3.1 Relationship barriers

Lack of long-term relationships with suppliers & clients- Partnering and alliancing

In New Zealand, most of the construction projects are formed with a temporary set-up team and the project team is discharged at the end of the project (Masood, Lim, & Gonzalez, 2016). In a similar way, manufacturing projects adhere to project basis business relationship agreements between clients and suppliers rather than entering into long term contracts. 10 out of 12 participants highlighted the issue-lack of long-term partnerships with clients and suppliers. This is emphasized by the following statement comment from a participant.

“We don’t have any agreements with the suppliers, we selected them based on our past experience and sometimes by quotations. But we will move into that near future– (P-08)”

As a result of this temporary formations, conflicts are inevitable due to lack of trustworthiness between clients and suppliers and on the other hand, a waste of time and effort in the tendering process for selecting suppliers. In contrast to project-based agreements, long term relationships

always facilitate healthy coordination among the parties and resulting quality outputs with time and cost savings.

Interviewees, therefore, suggested managing long-term relationships with suppliers and clients as it facilitates a better platform to perform without delays and disruptions. Strategic partnering and alliancing are proper means to establish long-term relationships (Meng, Sun, & Jones, 2011; Saad, Jones, & James, 2002).

3.2 Technical barriers

Lack of information sharing- Reliable information sharing system

Communication among the participants plays an integral role in delivering any project successfully within preplanned timeframes, quality, and budget. In light of this, it is highly emphasized the need for a standardized and effective communication scheme throughout the construction process of prefabricated buildings. However, in New Zealand, modular manufacturing companies are not using any standardized information-sharing systems to share information openly. E-mails, phone calls, face to face talks, meetings are used to communicate

and share information. This reflects the following statement made by a participant.

“We share information through informal ways like word of mouth or emails- (P-03)”

Information should be readily available to all the stakeholders and companies in the supply chain and the business processes should be structured in a way so as to allow full use of this information. Modern IT applications provide better sources to share information along whole the supply chain and avoid delays and disruptions in the process. Accessibility, reliability, and accuracy of information become rewarding to all the stakeholders in their decision making. All the participants identified this as a major barrier and suggested to have a standardized information system to overcome the problem.

Lack of technology and automation- An integrated system for scheduling, production, monitoring & communication

The paucity of technology involvement and reluctance to innovation are common phenomena in the New Zealand construction industry. Therefore, the process of prefabrication requires accurate and reliable information and more automated machinery. Modern technologies facilitate effective means of handling updates and changes in the manufacturing process and indicate real-time performances. The use of extensive modern IT tools and automated machinery provides solutions for information and data exchange and performance and efficiency problems in the industry (Lessing, 2015). However, modern information usage and communication technologies in the New Zealand construction industry appears to be at a very low level. This reflects the following comment made by a participant.

“Technological barriers in 3D scanning, modeling and 3D dimensioning and that sort of things are quite new in New Zealand. So it's going to take a few years to use those together – (P-03)”

However, It was noted that few companies (2 out of 12 participants endorsed) use technologies like

Building Information Modelling (BIM) for their productions.

Therefore, companies need to invest more in IT tools and automated machinery to avoid less innovative nature in the industry.

Transportation of modules -Logistic management

Transportation of modules is another key criteria to consider in the prefabricated housing construction. Most of the components of the house are manufactured in a factory and then, deliver of those into the site with greater attention. As New Zealand's landscape is hilly and transportation of heavy modules across the country is quite a challenge, and thereby, transportation incurs a significant cost. This is emphasized by the following statement.

“New Zealand's geography means that we are inevitably going to have a large transport component-(P-10)”

“In New Zealand, the land is very heavy and skinny. Therefore, transportation is difficult, and it takes a significant amount of money to transport heavy modules- (P-03).”

Even though, proper logistics management enables to mitigate the difficulties arising from the transportation of prefabricated elements such as avoid idling time and storage problems. The significance of logistics management is emphasized by the following statement.

“A transportation plan could help to coordinate the delivery process across New Zealand – (P-10)

3.2 Managerial barriers

Inadequate project planning- Planning and scheduling

As noted, the lack of project planning and scheduling seems to be a major internal barrier in modular elements manufacturing processes. Compared to traditional construction, prefabrication requires a proper management system from start to end to avoid delays and to achieve customer satisfaction. Jonsson (2014); Kamali and Hewage (2016) and Jaillon and Poon

(2008) also discussed the importance of having a proper project planning system for prefabrication construction. Early design freeze and less flexibility for changes in prefabrication, improve the requirement of a proper plan with schedules to eliminate complications (Jaillon & Poon, 2008). However, in New Zealand, most of the prefab manufacturing companies are not using proper project planning tools to schedule their work. 11 participants highlighted this issue as it has created delays and cost overruns in their manufacturing processes. It is clearly reflected from the following response by a participant.

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

Thorough planning on the entire process covering proper documentation and ownership of each function is required in the early stages of the process. Further, extra attention and close scrutiny on design, planning, and scheduling of each activity to avoid changes, errors and defects in the execution. The significance of scheduling is well identified from the participant’s comment below.

“Production scheduling is a really important aspect to avoid delays in the process, However, In New Zealand, most of the companies are not stick to their plans – (P-04)”

Inconsistent goals within the company-Setup prioritize common goals

Goal setting is an important component of a business to gain competitive advantages through achieving targets and improving performance. Prefab manufacturing companies in New Zealand, do not seem to be interested in setting up short-term and long-term goals. Based on the findings 8 out of 12 participants emphasized this issue in the interviews. Stakeholders of the supply chain process of prefabrication are having their own goals for career development rather than having common goals. Different perspectives of the participants of the process and inconsistent goals

within the company create poor collaboration and coordination issues. This ultimately results in cost and time overruns and poor quality work.

Inadequate performance measurement systems - A systematic performance measurement system

Prefabrication is about improving efficiency in the construction. Performance measurements and evaluations are required to develop the processes. Real-time performance measurements are beneficial for product development, efficiency improvements and decision making. However, performance measurement and follow-ups in the manufacturing process are not properly conducted within the factories. In New Zealand, most of the manufacturing companies are operated with less automation. Most of the companies are operated on a project to project basis and try to achieve a particular project within the time frame. According to the interviews, all the participants emphasized the advantage of having a performance monitoring system.

A systematic performance measurement system and a real-time analysis are required to analyze and continuously improve the production process. Real-time performance measures facilitate evaluations of the performance and thereby, it can be used for decision making and future expansions. This reflects the following comment made by a participant.

“Real-time performance monitoring will facilitate improvements to the continuous production line- (P-05)”

Lack of clear direction and guidance-proper management and coordination

Lack of clear directions and guidance through the process creates conflicts and ultimately impact on production. 7 out of 12 participants highlighted this issue and they encouraged to have a proper management system throughout the manufacturing process. In manufacturing, clear direction and guidance are required specifically for the machine operators and for other workers for day to day operations.

Lack of knowledge in consumer demand- Demand forecasting

A clear idea of the market demand and its trends is necessary to ensure that the companies are getting sufficient work for survival and growth within the industry. Market investigations and surveys are needed to forecast consumer demand and demand trends in the market. However, among the interviewees, only one company had a database for customer demand evaluation, and most of the other participants pointed out it as a barrier.

Lack of understanding of SCM- Training and education

As noted, prefab manufacturing companies are not using manufacturing concepts to improve their efficiency. Some of the participants of the interviews are aware of Lean Principles and using it to minimize the waste. However, the concept of supply chain management is not used in most of the companies.

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

4 Conclusion

This paper has identified 9 barriers and corresponding enablers for supply chain integration in modular elements manufacturing processes. Based on the findings, ad-hoc relationships, poor planning, and scheduling, lack of effective and efficient ways to share information seems to be major barriers in the supply chain process. Therefore, the industry needs to focus more on these barriers with the corresponding suggestions to overcome these in order to improve the efficiency of the production. Moreover, industry and government need to invest in adopting modern technology and automation to improve the efficiency and integration of the production process of modular elements used to build houses.

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The Factors Constraining the Adoption of Prefabrication in the New Zealand Residential Construction Sector: Contractors' Perspective

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ABSTRACT

The advantages of prefabrication are reflected through a significant increase in productivity and performance in the construction sector. As a result, off-site manufacturing technology has had a profound impact on New Zealand's construction industry. Building contractors are considered as one of the main beneficiaries of this process. There are a large number of reports from existing research projects which have focused on the benefits of prefabrication. Only a few studies have looked at why contractors hesitate to apply prefabrication techniques which are reflected in low levels of productivity in the construction sector. This study aims to understand the reasons why residential construction contractors hesitate to use prefabricated construction systems and materials. A comprehensive literature review followed by a document analysis was performed as part of the qualitative research method used in this study. The findings of this study will be presented as a matrix with the significance of each constraint. This study paid greater attention to the contractors to highlight the benefits of prefabrication in the New Zealand residential construction sector.

Keywords: Prefabrication, Constraining factors, Contractor, New Zealand

1 Introduction

1.1 Background

The world's population has dramatically increased the demand for houses around the world. As a result, new home buyers are looking for fast and durable construction solutions. Therefore, there is a strong need for the development of prefabricated buildings that would bring fast and durable building techniques. Prior research has shown that many countries including the UK, USA and Australia have already developed sophisticated prefabricated-based building systems (Azman et al., 2010; Blismas & Wakefield, 2007; Goodier & Gibb, 2007; Prefab NZ, 2018). Similarly, in New Zealand, the government has started to promote an intensive housing model with the transformation and upgrading of New Zealand's economic and social development. Notably, the acceleration of an urbanization strategy driven by the influx of a large overseas population, the housing demand in New Zealand has significantly increased (Grimes & Holmes, 2010). Therefore, there is a pressing need to innovate the traditional construction model by promoting and supporting prefabricated buildings. For a long time, the construction industry in New Zealand has been characterised by low productivity, poor construction quality, and reluctance to adopt new technologies, which

has slowed down the development of the construction industry (Scofield et al., 2009a). At the same time, the profit margins of the construction projects have reduced. However, the expectations of the clients/customers have increased. The recent development of prefabrication and assembly technology has brought more advantages in construction cost, time, and quality for New Zealand construction projects (Finnie, Ali & Park, 2018). However, Becker (2005) points out that there were development obstacles in the application of prefabrication technology in New Zealand's construction industry.

The implementation of prefabrication is more applicable to medium and largescale projects with its cost advantage. The benefits of prefabrication-based construction include eco-friendliness, financial savings, higher flexibility in construction techniques, consistent quality, short construction time span and increased levels of health and safety for all stakeholders in the supply chain. Within the supply chain, building contractors are one of the key stakeholders who could massively benefit from the use of prefabrication (Tam et al., 2007). However, it is evident that most contractors do not use prefabrication techniques, reflecting low productivity in the construction industry (Goodier & Gibb, 2007).

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1.2 Research aim and objectives

The purpose of this study is to identify the reasons why residential construction contractors hesitate to apply prefabrication techniques and to analyze the above factors restricting the application of prefabrication techniques. The findings would be useful for construction practitioners in terms of understanding the main problems that hinder the growth of prefabrication, thereby giving prefabrication more of a significant impact on New Zealand's construction industry. The following research objective was established under the research aim of this study:

1. To identify and describe the factors that restrict the use of prefabrication by New Zealand contractors in the residential construction sector.

It is noted that the objectives of this study are limited to the residential construction sector in New Zealand. Also, this study is based on research articles that address the issues in the New Zealand construction industry.

2 Literature review

This section provides an in-depth analysis of several concepts and related issues of prefabrication. In particular, it discusses the key topics related to off-site construction, including a definition of prefabrication, the benefits of prefabrication, comparison between prefabrication strategy and traditional building methods, development of off-site production in New Zealand construction industry, and the key issues associated with prefabrication.

2.1 Prefabrication

The Modular Building Institute (MBI) (2010a) defines the concept of prefabrication as the process of production and assembling major building components at remote off-site locations for subsequent installation at the construction site. In the actual construction process, prefabrication is the construction mode that performs most of the work in the factory with higher quality and efficiency while ensuring safety, then is later transported to the construction site (Durdyev & Ismail, 2018).

Prefabrication can be understood as the main structural component associated with a building that is manufactured in an off-site environment, shipped to the site and assembled (MBI, 2010a). As structural components are not manufactured on-site, off-site prefabrication is different from traditional construction methods (Arif and Egbu, 2010; Azman et al. 2010; Pan et

al., 2007). Prefabrication technology has many advantages such as shortening the construction period, improving project quality, reducing costs, improving the construction site environment, reducing construction risks and increasing productivity (Lu, 2009; Lusby-Taylor et al., 2004). This technology is used in a wide range of applications, not only for the construction of houses and multi-story buildings but also for road and bridge construction projects (Ngowi et al., 2005). Mbachu (2009) argues that prefabrication technology is a prerequisite for driving large-scale mechanized and automated construction processes in many countries. Many construction industry practitioners believe that prefabrication technology is the future of the construction industry (Hampson and Brandon, 2004; Tam et al., 2007). Although prefabrication is less used in the construction industry in New Zealand, the industry is still in the process of adopting it.

2.2 The benefits of prefabrication

Even though prefabrication is not currently the most advanced building technology, the advantages of this technology have been widely recognized. The advantages include cost reduction, improved building quality, environmental friendliness and its contribution to sustainability. In summary, Gibb and Isack (2003) cite the benefits of off-site construction, as follows:

1. Off-site production can perform early seismic tests on building structural components to understand the seismic capacity of buildings in advance, thereby reducing design defects and ensuring building quality.
2. Since the manufacturing phase is completed at the factory, the construction environment, and quality can be well controlled, which is why the quality of off-site manufactured building components is better.
3. Prefabrication can complete the manufacture of major structural components in the factory in advance, shortening the project duration.
4. Prefabrication has less on-site processing of materials, reduces environmental pollution, reduces resource consumption, and makes the construction site more tidy and orderly.
5. There is no on-site prefabrication process, the number of materials and equipment appearing on the site is reduced, and the construction site can be better managed.
6. The project construction efficiency, project quality, and construction safety guarantees have been

effectively improved, resulting in lower construction costs.

2.3 Comparing prefabrication and traditional construction methods

Goodier and Gibb (2007) point out that, in the project design phase, the starting point for determining whether to use prefabrication or traditional construction is usually the cost of installation, not the value of the project over its entire life cycle. However, compared with the conventional construction method, the use of prefabrication significantly improves the speed of construction. In addition, prefabrication is a more environmentally friendly construction technique. Baret and Weidmann (2007) claim that prefabrication has significant advantages in terms of resource consumption and greenhouse gas emissions as opposed to traditional construction methods. MBI (2010a) compares the benefits of prefabrication with traditional construction methods, provided below:

1. In prefabrication, the structural components are manufactured in the factory, which saves the material loss and environmental pollution caused by the site construction and reduces the generation of construction waste.
2. Prefabricated components are assembled on-site compared to traditional on-site construction methods, saving much labour, and improving construction efficiency.
3. Building structural components can be directly transported to the site for installation after the factory is manufactured. No additional scaffolding is required during installation, which saves costs and reduces safety hazards.
4. Prefabricated components are mass-produced through industrial production, which can effectively reduce the high cost of using different shaped components in construction projects.
5. Prefabricated components are standardized in the factory, meaning that external factors are limited and the quality is higher than on-site manufacturing. This can effectively improve the quality of the project.

2.4 Prefabrication in New Zealand construction industry

The New Zealand construction industry primarily involves on-site construction methods. Therefore, it is characterised by low productivity (Scofield et al., 2009a). Even though off-site manufacturing methods have not been well developed and applied in New Zealand construction (especially in residential development), this

concept is well-known within the industry. The application of prefabricated buildings in New Zealand dates back to the early 19th century, starting with the import of panel housing components from the United Kingdom and the United States (Scofield et al., 2009b). As the availability and access to technology in New Zealand is relatively low, many contractors are reluctant to try new construction methods with high risks. Moreover, the development of off-site manufacturing technology, industrialization levels and coordination of technology are insufficient among construction practitioners in New Zealand (Noktehdan, Shahbazzpour, & Wilkinson, 2015). Similarly, many factors (see Figure 1) have led to the slow development of prefabricated buildings in New Zealand. Since New Zealand construction regulations also emphasize construction efficiency, adapting more prefabrication systems would unquestionably bring huge benefits to the future construction market.



Fig 1: Challenges in a prefabrication (Prefab NZ, 2019)

Prior research has shown that prefabrication technology has begun to be used in government projects. For example, the KiwiBuild project, which proposed to build 100,000 housing units launched an open tender on 6 September 2018 to use prefabricated technology to accelerate the availability of affordable housing. According to Prefab NZ (2019), under the same material standards, prefabricated houses can be built at a cost savings of 15% over conventional construction. This new form of construction coincides with current mainstream construction demands.

Through the years that it was not accepted by the market, prefabricated technology has been led by the New Zealand government. Government intervention is a turning point in the prefabrication field. One of the leading construction companies in New Zealand has developed a prefabrication product factory (New Zealand

Herald, 2019). These prefabricated products are expected to supply to the government agencies who are part of the Kiwi Build project.

2.5 Challenges with building prefabrication systems

Despite the many benefits of prefabrication, there are still numerous constraints to implementing prefabrication in New Zealand construction projects. As the production capacity of New Zealand manufacturing factories is limited, it is challenging to increase prefabricated building components. Subsequently, prefabricated building parts are very costly.

Another challenge in prefabrication is its high logistic cost. For example, when prefabricated buildings components are installed on-site, they need to be lifted by cranes. Due to the lack of technology and sufficiently powerful cranes in New Zealand, the crane logistics cost significantly challenges prefabrication applications (Shahzad, 2011).

The process of manufacturing and procurement of prefabricated building components also has a high lead in time (Goodier & Gibb, 2005). In addition, there are only a few alternatives to prefabrication building components offered by manufactures (Arif & Egbu, 2010). These factors have contributed to the slow development of prefabrication in New Zealand residential buildings.

Although New Zealand's local promotion of modular buildings and prefabricated buildings is vast, implemented projects and modular systems suitable for large-scale development are minimal, especially for medium and high-rise modular construction projects. China International Marine Containers Group (CIMC) Modular Building Systems (2016) has worked on several modular construction projects in the United Kingdom and Australia. Currently, the first modular construction project of CIMC Modular and New Zealand's local builders is close to mass production and will be shipped to New Zealand soon. More than two years after entering New Zealand, CIMC Modular believes that current New Zealand modular buildings are still in the early stages of cultivation, especially in regard to overseas module suppliers. According to CIMC Modular Systems (2016) from local governments to end users, the extent of local acceptance and recognition of modular buildings is still relatively low. Compared with Australia and the United Kingdom, CIMC Modular believes that New Zealand's approval process is more complicated and takes longer. Secondly, there is a shortage of construction professionals. CIMC Modular Systems (2016) points out that the multi-domain

collaborative content involved in modular buildings is entirely different from traditional construction methods. In modular building projects, all the different consultants, construction teams, and modular supply teams need to work together to ensure an efficient and economical design of the module and realize the industrial manufacturing of the factory.

Implementation of modular construction in New Zealand is challenging as there are relatively few engineering consulting firms in New Zealand who are familiar with specific modular building systems, including architectural design consultants, structural consultants, fire consultants (including fire engineers), energy efficiency consultants, sound insulation consultants, and mechanical, electrical and public health consultants (Shahzad, 2011; Prefab NZ, 2018). Similarly, Scofield et al. (2009) claimed that the lack of knowledge of prefabricated building technology by professionals providing consulting services could be the biggest challenge in bringing modular construction to New Zealand.

In addition to the problem of a small talent pool within the industry, no bank mortgage policy embraces prefabricated houses. PrefabNZ (2018) says that banks have a direct system to assess the loan risk of on-site construction, but if the home is produced in advance at the factory, they need an additional assessment mechanism. At present, financial institutions have doubts about loans, which are all related to risks.

In summary, this section has reviewed existing literature and reports on issues related to prefabrication. We found that past literature has not sufficiently focused on the constraints of adopting prefabrication from a contractor's perspective. Therefore, this study will identify and describe the factors that restrict the use of prefabrication by New Zealand contractors in the residential construction sector.

3 The research design

This research gathered information from existing research articles and reports published by subject matter experts in the New Zealand construction industry. The research articles and reports focus on factors that influence the development of prefabrication in the New Zealand construction. A qualitative analysis was conducted based on the research articles collected. The key factors limiting the use of prefabrication were drawn from the data analysis.

4 Research findings

Based on the summary of the existing studies on prefabrication in the New Zealand construction industry, the key constraints for residential contractors adopting prefabrication technologies were identified.

Table 1: The key constraints

Rank	Constraint	Supportive citations
1	High capital cost	Blismas and Wakefield (2007) Gibb and Isack (2003) Haas et al. (2000) Jaillon and Poon (2010) Jaillon and Poon (2010) Noktehdan, Shahbazzpour and Wilkinson (2015) Phillipson (2003) Shahzad, Mbachu and Domingo (2014) The Cooperative Research Centre (CRC) (2007b)
2	Lack of skills and knowledge	Bell (2009) Goodier and Gibb (2007) Noktehdan, Shahbazzpour and Wilkinson (2015) Shahzad (2011)
3	Inadequate processing and planning	CRC (2007b) Goodier and Gibb (2007) Jaillon and Poon (2010) Kelly (2009) Love and Irani (2004) Murray et al. (2003) Poon (2010) Rivard (2000) Scofield et al. (2009a) Vanegas et al. (2002)
4	Inherent industry and market culture	Alridge et al. (2002) Craig et al. (2006) Mbachu and Nkado (2007)
5	Poor logistics and field operation methods	CRC (2007b) Shahzad (2016) Shahzad and Mbachu (2013)
6	Tight regulations and code requirements	Page and Norman (2014) Shahzad (2011) Shahzad, Mbachu and Domingo (2015)
7	Lack of supply chain and procurement innovation	Durdyev and Mbachu (2011) Finnie, Ali and Park (2018) Scofield et al. (2009) Tam et al. (2007)

The following sections will discuss the constraints identified above.

4.1 High capital cost

Contractors in the construction industry generally consider prefabricated projects to be more costly than conventional construction due to price, value, and productivity considerations (Blismas and Wakefield, 2007;

The Cooperative Research Centre for Construction Innovation (CRC), 2007b; Phillipson, 2003). Similarly, Gibb and Isack (2003) argued that prefabrication construction is more expensive than the traditional field construction method. Mainly, the higher cost of prefabrication-based construction methods is related to the high cost of steel moulds used in prefabrication, rather than the regular timber made formwork used in the field (Jaillon and Poon, 2010). In addition, the CRC (2007b) reports that design costs in prefabrication are higher than that of on-site construction. However, Haas et al. (2000) argue that under special conditions, the cost of prefabricated projects could be less than traditional construction projects. Particularly, considering the lifecycle cost and using standardization and reusing processes, the high capital cost of prefabrication can be minimised (Haas et al. 2000; Jaillon and Poon, 2010).

4.2 Lack of skills and knowledge

The New Zealand construction industry has a limited capacity to disseminate and accept new technologies (Noktehdan, Shahbazzpour, & Wilkinson, 2015). The main reason for this is that education and training in the construction industry are relatively traditional, and the promotion of new technologies is not favourable. Goodier and Gibb (2007) believe that in order to expand the application of prefabrication technology, it is necessary to train industry practitioners. Also, there is a lack of information and guidance on prefabrication techniques. As a solution, Bell (2009) points out that increasing publicity is an effective way to develop and disseminate new technologies. The emergence and development of new technologies will inevitably lead to the vacancy of skilled talents required to develop and operate prefabrication in the industry (Bell, 2009). The lack of such trained personnel has led contractors to be reluctant to adopt prefabrication techniques.

4.3 Inadequate planning and processing

The main differences between prefabrication and the traditional on-site building models include design, production, transportation and construction aspects (Durdyev & Ismail, 2019). Out of those aspects, transportation and construction are significantly different, reflecting architectural design standardisation, factorisation of part production, site construction and assembly, integration of architectural decoration, and

construction process informatisation in prefabrication. As a result, the designing of prefabricated buildings needs to be carried out in the early stage. Also, manufacturing prefabricated building components requires a long time span. In order to not delay the installation of components, the design and manufacturing should be well planned and carried out in advance. It should be noted that prefabricated buildings have more precise requirements for design, fabrication, and installation.

Kelly (2009) explains that prefabrication projects usually take longer because of the need for a final design before the commencement of installation and construction. In order to successfully complete a prefabricated building project, extensive coordination is required among clients, designers, builders, and installers. This shows that prefabrication-based projects need a lot of time and capital in the early project stage.

The construction industry believes that the main reason that impedes the development of prefabrication technology is that the production and manufacturing of building components require lengthy processing and planning (CRC, 2007b). Goodier and Gibb (2007) also point out that long lead times are a crucial constraint for prefabrication projects, especially for contractors, who need to know precisely when planning starts.

Rivard (2000) claims that computers should be used as an auxiliary tool in the design and construction stages to solve the problem of construction efficiency. However, small and medium-sized construction companies in New Zealand rarely use information technology instead of focusing on traditional construction methods. As a result, the lack of application of information technology is a problem hindering the development of prefabrication related processes (Love & Irani, 2004; CRC, 2007b).

Inadequate processing and planning bring uncertainty to building contractors. CRC (2007 b) and Jaillon and Poon (2010) cite the uncertainty at the design stage as a factor contributing to the slow development of prefabrication technology.

The installation stage of prefabricated components manufactured in the factory should match the interface at the construction site. Vanegas et al. (2002) emphasise that the mismatch of interfaces leads to illegal installation by contractors. When the prefabricated components are inadequately planned and processed by the manufacturers, they may not be accurately installed on-site, leading to large-scale problems. Therefore, it is clear that one of the key constraints that prevent contractors

from entering prefabrication-based projects relates to planning and processing prefabrication of building components.

4.4 Inherent industry and market culture

As discussed before, small and medium-sized construction companies in New Zealand commonly use traditional construction methods that are non-technology driven. This has substantially slowed down the development and dissemination of prefabrication technology. Alridge et al. (2002) argue that stakeholders in the construction industry who are reluctant to try new technologies and new ways of thinking have primarily hampered the technological development of the construction industry. Furthermore, contractors are more assured and used to traditional construction methods (Durdyev & Ismail, 2019). The organisational processes in the construction industry are varied and complicated, requiring multiple types of work to cooperate with new technologies such as prefabrication. Mbachu and Nkado (2007) provide a similar view that new changes make the construction processes more complicated. Therefore, adding new changes to traditional contractor's mindset makes it difficult to bring prefabrication into practice.

4.5 Poor logistics and field operation methods

The transportation component is the main challenge in applications of prefabrication (CRC, 2007b). The New Zealand economic market is small, resulting in high labour and machinery costs, and the need to use large transport equipment from the factory to deliver to the site, which increases freight costs. Additionally, the current real estate development in Auckland requires high density, and the size of the site is limited, which makes it unbearable for large transport equipment and cranes to function in this limited space (Shahzad, 2011). There are also a limited number of large transport equipment and crane operators in New Zealand that cannot meet the current market demand (New Zealand Herald, 2017). Therefore, the implementation of prefabrication becomes challenging due to poor logistics and field operation methods used in New Zealand.

4.6 Tight regulations and code requirements

The New Zealand Building Code (NZBC) and building regulations (e.g. district plans) are primarily concerned with the health and safety of people and buildings. It has been discussed that tight regulations affect the

implementation of innovative building techniques such as prefabrication (Page & Norman, 2014; Scofield et al., 2009; MBI, 2010). As mentioned above, the use of large cranes to move prefabricated building elements often bring health and safety issues. This strongly discourages building contractors to apply prefabrication technology in New Zealand (Shahzad, 2011).

4.7 Lack of supply chain and procurement innovation

The supply chain operation processes have an essential impact on the construction industry. Tam et al. (2007) argue that the construction and operation of prefabrication require significant levels of innovation in resources and technical support. However, Scofield et al. (2009) argue that prefabrication lacks resources and technical assistance in New Zealand and has insufficient production potential due to a lack of innovation in the supply chain. This brings significant challenges to contractors who want to use prefabricated building systems. Overseas imports that are required for prefabrication applications are procured through traditional purchasing systems (Finnie, Ali & Park, 2018). Therefore, the lack of innovation in procumbent methods used in construction makes constraints for contractors to adopt prefabrication in their projects.

5 Conclusion and recommendations

5.1 Conclusion

The primary purpose of this study was to understand the reasons why residential construction contractors hesitate to apply off-site manufacturing techniques. The study found seven key constraining factors; high capital cost, lack of skills and knowledge, inadequate process and planning, inherent industry and market culture, poor logistics and field operation methods, tight regulations and lack of supply chain and procurement innovation.

Due to the relatively small size of the New Zealand construction industry and low demand in the market, the upfront input cost of using prefabrication is higher than the traditional building model.

The construction industry in New Zealand does not sufficiently promote upskilling and new technologies. Therefore, the industry needs to be elevated with new skills and knowledge so that prefabrication can be implemented. As the level of technology is still low, the project planning and processes seem poor, resulting in difficulties in bringing prefabrication processes to be in place.

The key parties in the construction industry still pursue a traditional mindset. They are reluctant to use new technologies such as prefabrication. The industry is still behind in terms of technology and skills, which results in poor logistics and field operation methods, restricting the adoption of prefabrication techniques.

The tight regulations and code of practices that have been established based on traditional construction models also make it is difficult to implement fast erection of building elements using prefabrication. The lack of innovation across the supply chain brings challenges for implementing prefabrication, which requires highly efficient processes such as integrated building solutions, BIM and 3D printing.

5.2 Recommendations

This study has shown that there are significant constraints that hinder building contractors adopting prefabrication in New Zealand residential construction. This shows the need for in-depth research to understand better the aforementioned constraints, which would also help the smooth and fast application and development of prefabrication technology. Even though the main direction of this study is for residential construction, the applicability of prefabrication techniques in commercial building projects should also be prioritised. For example, the risk assessment and analysis in commercial prefabrication needs attention. The government plays a major role in reducing the tax of prefabrication products and bringing more contractors on board. The industry needs to work together with the government to promote, upskill and train building contractors to apply prefabrication in construction projects. This would bring fast, cost-effective and high-quality project outcomes in the New Zealand residential construction sector.

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Nature of New Zealand Construction Industry: An Exploratory Analysis of Performance Hindering Challenges

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ABSTRACT

Over time, due to increased competition in construction industry worldwide, researchers have tried to understand the determinants of construction firms performance. Literature suggests that contingency-based approach is increasingly studied to explain performance related issues for construction firms. An in-depth understanding of the construction industry is therefore essential, in particular, how businesses within the industry perform and how they combine to shape the growth and development of the national economy. A review of the literature suggests that in New Zealand, there are peculiar internal and external firm related challenges that limit the performance of the construction businesses. An in-depth literature review has been conducted and the data from other sources including from industry reports, government documents and industry surveys has been reviewed to understand these problems. A few rich interviews with subject matter experts have assisted in the collation of perspectives on potential solutions. The research proposes various possible solutions for government, the construction industry and for individual construction firms that will enhance the performance of the industry as whole.

Keywords: Construction firm performance; Contingency approach; New Zealand construction industry; Risks; Risk-sharing

1 Introduction

The construction industry is of crucial importance to the economy of any country. It contributes directly and indirectly to various other sectors for example, the manufacturing sector, service sectors and provides various employment opportunities in a country. Therefore, it can be ascertained that a growing physical infrastructure including roads, commercial buildings, residential units, factories, ports and other monumental projects can be a sign of the growing economy of a country. The literature suggests that the output from construction industries averages around 3-8 % of national GDP for most of the countries worldwide (Arditi & Mochtar, 2000). Data from the United Nations Economic Commission for Europe (UNECE) shows a spread of contribution by construction companies to national GDP in Europe from 2-10 % for the year 2018 (UNECE, 2019). Hence a good or bad performing construction sector can directly affect the socioeconomic development of a country. Construction firm performance can be understood as the measurement of efficiency and

effectiveness of different mechanism adopted to meet the stated objectives of the firms (Neely, 1998). This research therefore conceptualizes 'construction firm performance' as measurement of efficiency and effectiveness of different mechanism adopted to meet the stated objectives of the firms. Some of the possible objectives of construction firms can be high quality of end products, enhanced profit margins and satisfied customers among others (Kagioglou et al., 2001).

Over time, due to increased competition in construction industry worldwide, researchers have tried to understand the determinants of construction firm's performance in uncertain business environments. (Cheah et al., 2004; Xue et al., 2010; Ye et al., 2009). Based on an extensive review of the literature, Deng and Smyth (2013) concluded that contingency-based approach is being studied increasingly to understand the complex performance issues in the construction industry. The Contingency theory proposes that for enhanced performance, there should be a fit between several internal and external firm factors like resources, capabilities and business environment.

The reports by PWC (2016) and Page and Norman (2014)

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noted that, in New Zealand, the construction industry has a significant effect on the overall economy, more so than any other industry. It is estimated that around 4.6 % and 8 % of GDP in year 2013 and 2015, respectively, was contributed by the construction industry to the New Zealand economy. However, New Zealand's construction industry is also a highly volatile industry and in the last 20 years, the construction sector has shown both a double-digit growth and decline, which is the sign of a highly volatile nature that of an industry and a similar phenomenon is not observed in other sectors of economy (PWC, 2016).

Considering the enormous value of New Zealand's construction industry, there is a need to understand the reasons for its high volatility and the various risks that are involved in the construction business in the country. Hence, improvement in the performance of this sector offers a range of benefits to different stakeholders. For individual firms, this means better profitability for owners and more earning opportunities for the work force, and for end users this means a decrease in construction costs, a better quality in terms of the end product, fewer project delays and more value for money. Recently, a large number of high-profile construction firms have gone bankrupt, which has had a negative effect upon overall industry (Edmund, 2018). It is therefore pertinent to explore the problems that the industry is currently facing. This research aims to identify the critical issues the construction industry in New Zealand currently faces and to explore possible way forward. The scope of this research is to identify issues that pertain to the whole construction industry. In this research the firm and project level issues have not been discussed in-depth.

2 Methodology

In order to understand the problems in New Zealand's construction industry, the research was conducted in two phases. In the first phase, an in-depth literature review was conducted using the search engines of 'Scopus' and 'Google Scholar'. The search for the literature was carried out by using the relevant titles and keywords in the search engines. In order to gain more relevant literature in the New Zealand context, different filters, such as, 'subject area' (business, engineering, management), 'document type' and 'keyword', were used in the Scopus search engine. Afterwards, abstracts were scanned to select relevant papers. Various researchers have followed this approach in the construction management literature

(Hong & W.M. Chan, 2014; Ke et al., 2009). A few of the keywords used were, "New Zealand construction industry", "New Zealand construction industry problems", "New Zealand construction industry risks", "construction business risks" and so forth. Although, a few relevant research papers were selected, little success was achieved in finding literature relevant to New Zealand's construction context. Therefore, various Government documents, publications from the Building Research Association of New Zealand (BRANZ), construction industry reports, various construction industry related surveys, construction magazines and newspaper articles were reviewed to understand the specific industry problems. This step enabled the researcher to identify the main problem areas that the construction industry is currently facing.

After developing a preliminary scope of the problem areas, semi structured, face to face interviews were conducted to collect an open-ended response around the identified problem areas in detail. A total of five interviews were conducted with industry experts who are currently working in New Zealand construction industry and had an experience of 15-20 years in New Zealand, at various decision-making roles in their respective firms. The profile of the interview respondents is shown in **Error! Reference source not found.** below. The data gathered from the interviews was analyzed using 'thematic analysis' approach. This method is useful for identifying and describing the patterns in the qualitative data (Braun & Clarke, 2006). The data gathered from the interviews was transcribed and thematically coded using NVivo. Therefore, enabling to classify the interview data into common themes from which relevant information can be gained around the research questions. The identified themes were then associated with the problem areas that were highlighted in the first step.

Table 1: Interview respondents' profile

Interviewee	Role	Years of experience
A	CEO	20
B	CEO	20
C	Principle quantity surveyor	15
D	Project manager	20
E	Project manager	15

3 Findings and discussion

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The finding from literature review and interview discussions identified certain internal and external factors influencing construction firm's performance in New Zealand. The identified internal firm factors identified are risk identification and pricing, labor productivity, narrow profit margins. The external business environment factor is labor and skill shortage, traditional procurement approaches, regulatory costs and economies of scale. In order to confirm or refute the highlighted issues, the interviewees were asked about the question related to each highlighted problem area. The findings are discussed in detail below:

3.1 Internal Firm Factors:

Risk identification and pricing:

The construction business inherently involves more risk due to the involvement of many parties, i.e., designers, consultants, engineers, contractors, suppliers and so forth (El-Sayegh, 2008). An unhealthy risk allocation is where the stakeholders who are most able to control the risk do not bear the consequences of this risk. Instead, the risk is transferred to some other stakeholder, who may not be in a best position to mitigate the risk. Generally, most of the risk is transferred to the contractor (Cheung et al., 2003). However, the ability of a stakeholder which is taking the risk, to actually manage that risk affects the overall project performance (Roumboutsos & Anagnostopoulos, 2008). New Zealand's construction industry is also dealing with the problem of the unfair risk allocation to the different parties during the execution of the project (Mbachu & Taylor, 2014). The (PWC, 2016) report notes that, in New Zealand's construction industry, there is a trend to pass most of the risk to the supplier/contractor through highly complex contracts (sometimes additional variations of over 100 pages to the standard contract), which leads to the increase in the overall cost of the construction. Sometime high-profile firms have failed for the same reason. Carillion in the UK and RCR Tomlinson in Australia are two recent examples (AECOM, 2019).

Commenting on the question, that how serious the issue of unfair risk allocation, was affecting the performance of construction firms, all the interviewees agreed that risk management deserves significant attention by all the stakeholders as it was hindering the performance of industry as a whole. From discussions it also came to notice that during tendering process, inadequate documents are usually provided by the clients, where it is difficult to completely understand the risks that are

involved in the contract. Only a highly skilled team at the contracting firm can foresee such risks and lookout for any clauses which may be detrimental to the firm during the project execution stage. From discussion, it also emerged that most of the contractors were taking an unfair amount of the risks with little understanding of risks. In some cases, only a few problems during project execution exposed them to risks they were unable to mitigate which led them to bankruptcy. The interviewees suggested that, before undertaking a contract, the contractors should properly workout the risks and price them accordingly. Additionally, the clients should try to provide adequate drawings and other relevant documentation so that the scope of the work and the risks involved are clearly understood by all of the stakeholders. Similarly, the industry and government can investigate the use of the "Proportionate liability approach", that is frequently used in Australia as a possible alternative to 'Joint and several liability rule'. According to this approach, the liability for the loss is divided among the stakeholders as per their share of responsibility (McNair, 2016).

Labor productivity

Official statistics suggests that the productivity in New Zealand's construction industry has not improved considerably over time. The report (Page & Norman, 2014) notes that the traditional measure of productivity including labor, capital and multi factor productivity (MFP) has not improved, compared to the demand in the sector. This essentially means that little progress has been made related to worker skill improvement, application of better processes and efficient use of capital. Most of the rise in productivity is due to more labor units (worked hours) compared to the value added to each hour.

The interview respondents were asked to comment on current productivity levels in the industry and the possible solution to it, the respondents argued that, in order to improve labor productivity, it should be monitored continuously during the execution of the project and any instances of low productivity from usual practice should be investigated immediately. More innovative approaches to construction, such as, the use of pre-fabrication and 3D printing should be looked into to improve the productivity of the industry. Similarly, a need to invest in training and in the up skilling of the workforce, was also discussed by a few of the respondents. The (PWC, 2016) report notes that, too many small players in the industry also hinders the productivity, thus more collaborative working should

be promoted.

Narrow profit margins

The construction firms in New Zealand are facing the pressure of reduced profit margins (Edmund, 2018). Gross margins have reduced across sectors while worker's wages have been increased (Page & Norman, 2014). The financial report by Australia and New Zealand Banking Group, estimated the profit after tax to be around 2 % for year 2017 for construction firms in New Zealand, which is quite low (ANZ, 2017). In comparison construction companies in Australia are making around 4 % profit after tax (Balatbat et al., 2010). Similarly, a large number of small firms were not making any profit at all in New Zealand (Curtis & Page, 2014). This is quite alarming and a possible predictor of bankruptcy for several firms currently operating in New Zealand. Many high-profile companies such as Ebert and Mainzeal have gone into receivership recently (Edmund, 2018).

The interview respondents were asked to comment of financial performance of construction firms in New Zealand. All of the respondents agreed that most of the firms were not making healthy profits due to several reasons. Some of these reasons were preference of the client on lowest price, poor project management practices by contractors, and their inability to understand the risks involved. Similarly, it was also argued by interviewees that many small and medium sized firms were not monitoring their cash flows and other financial indicators and hence were losing money without realizing it. Also, some contractors especially small sized companies were not properly pricing their work efforts and hence are finding it difficult to survive for longer duration. Commenting on possible solutions, some respondents were of the view that contractors should make around 5 % of profit after tax in order to grow and sustain the business. In addition, the companies should do extensive review of risks involved and price those risk accordingly. Similarly, financial aspects should also be monitored regularly, and good project management practices should be adopted to ensure long term survivability of the business.

3.2 External business environment factors:

Labor and skill shortage

Results from a number of industrial surveys, highlight the issue of the unavailability of skilled labor as one of the main problems hindering the performance of the construction industry. Skill shortage is more pronounced

for the design function and other technical skills (PWC, 2016). The (AECOM, 2019) survey notes that , 43 % industrial practitioners identified the skill shortage as the biggest industry challenge, while 69 % of industrial professionals identified it as the main issue for industry in the Civil Contractors New Zealand (CCNZ) survey (CCNZ & Teletrac Navman, 2017). The research report by BRANZ, also highlighted the inability of the industry to attract people with the required level of skills for the construction industry, as one of main hindrances affecting its performance. This is probably based on the fact that there is less job security in the construction sector due to the boom-bust cycle that is one of the usual characteristics of this industry. The same report, however, also observed that, staff retention (an important parameter for skill development) was not adequately monitored by the majority of the firms (Page & Norman, 2014).

When the interviewees were asked to give their opinions about labor and skill shortage in New Zealand construction industry, the respondents were of the opinion that small population of the country and huge demand for infrastructure were reasons for the shortage of skilled labor. The shortage of skilled labour can have an impact on overall firm performance from tendering to the project execution stage. Similarly, sometimes there is also the issue of the inability to pass drug tests by personnel who are currently available for work. Commenting on the possible solutions three interviewees held the opinion that employers should go to different countries where adequate skilled labor supply is available and hire employees directly for short and long term or on a project basis based on the model of the construction industry in the gulf states, for example in the United Arab Emirates (UAE), Qatar and so forth. However, such approaches often lead to language barriers. Therefore, in such instances, a supervisor fluent in English and in the primary language of the labour force, should be appointed where possible. Other interviewees opined that small improvements in the workplace setting, such as, the availability of coffee/tea and steps, for example occasional get togethers for employees, can boost the morale and enhance the commitment to stay with a firm/industry, which generally leads to skill enhancement. The (PWC, 2016), report also notes that government and industry should work in collaboration by investing jointly for the purpose of upskilling and training the skilled labour force. Also, initiatives could be devised to attract the relevant skilled workforce, such as, project managers from other

sectors, for example from manufacturing and so on. Another possible solution could be to relax immigration policies to attract more skilled construction professionals. The same view was shared by industrial professionals during the CCNZ survey (CCNZ & Teletrac Navman, 2017).

Traditional procurement approaches

The traditional procurement method in construction involves the preparation of the design documents by the client and then various bidders are invited to bid for the project, based on a lump sum contract amount. The bidder with the lowest quoted price is awarded the project. This approach is known as Design-bid-build approach (DBB) (Eriksson, 2008). However, this approach often does not lead to the best results in terms of quality, time and the whole life cycle cost for the project (Cheung et al., 2003).

The (AECOM, 2019) report argues that the preference for the traditional procurement practices, for example the lowest cost tender bidding, is a significant problem in New Zealand's construction industry. There seems to be too much of a preference on the lowest price contracting method, without proper consideration of the quality or the life cycle costs. A trust deficit is also prevalent among the client and the contractor. The report also estimates that around NZ \$50 million per year, is lost due to poor procurement practices and potentially NZ \$525 million in cost savings can be achieved over a period of 15 years up to 2030, by using other innovative procurement approaches, such as, design-build procurement methods (DB).

The government sector is one of the biggest clients for the construction industry. However, in order to manage the risk, the government tends to go for the traditional DBB mode of procurement, whereby the contract is awarded to the lowest bidder. However, this is not always the best approach to contracting as is evident from the research (Eriksson & Westerberg, 2011; Pesämaa et al., 2009). Due to the separation of the design and build function, during DBB procurement methods there is a separation of the contractor and design team, which limits the valuable input in terms of the construction management and project execution details (Ruparathna & Hewage, 2015). This is especially relevant during a big project, where sometime the designer is unable to understand the practical implications of the project.

Then there is also an issue of using nonstandard contracting practices i.e., custom/ tailored contracts

which have additional variations. For example, the Standard Conditions of Contract for Building and Civil Engineering (NZS 3910) is well understood by all industry stakeholders, however any variation that is added leads to uncertainty since such variations can be interpreted in different ways by different stakeholders which may lead to a litigation process and hinder standardization and mass production. This shows that procurement practices have not matured enough in the industry especially for government procurement (PWC, 2016).

In order to gain more insight around the problem, the interview respondents were asked about their satisfaction with the procurement approaches currently prevailing in the industry in terms of delivering the value for money. The interview respondents unanimously agreed that procurement practices prevalent in industry were not optimal and should be changed. During the discussions around the issue it also came to notice that sometimes the contractors are underbidding intentionally in anticipation that they would cover the costs with additional work which usually happens during the execution of project and then charge a high premium for those additional works. Therefore, clients should look out for such practices and should consider other aspects as well before the award of contract such as previous experience of a contractor, satisfied customers and so forth in addition to price. Two interview respondents also opined that the innovative procurement approaches such as Design-build method (DB) and Target cost contracting (TCC), could be a viable alternative to DBB method of procurement for construction firms operating in New Zealand. The target cost contracting (TCC) approach with gain-share/pain-share arrangements, could be followed for big projects, which has been successful in other countries (Chan et al., 2010) while literature points to a number of benefits of Design-build (DB) procurement method. (Ilori & Talukhaba, 2017; Ruparathna & Hewage, 2015). Industry professionals also feel that the use of standardized contractual documents should be promoted. In addition, it was agreed by all of the interviewees that alliancing /partnership/ public private partnerships are the best ways to achieve value for money. 90 % of the respondents also agreed that partnership approaches are a better alternative to achieve value for money in the (AECOM, 2019) survey.

Regulatory costs

Regulation and Compliance costs are also perceived as

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one of the major challenges confronting the industry (AECOM, 2019). Accordingly, 31 % respondents considered these costs as one of the major issues, while 42 % considered increasing regulatory compliance costs as one of the main issues for the construction industry (CCNZ & Teletrac Navman, 2017). Furthermore, these regulation costs are also considered to be one of the reasons for the high construction costs in New Zealand (AECOM, 2019; ANZ, 2017; Page & Norman, 2014). Usually the regulations are imposed by the government for the betterment of the general public and to manage the business risks for the different stakeholders. For example, the government may implement some laws to promote health and safety practices, ensuring safety for those working in a particular industry or for general public. However, the quality of such regulations can hinder or support the overall performance of industry. The (PWC, 2016) report notes that industry stakeholders opine that the government should perform a detailed cost-benefit analysis, before imposing a new regulation, in order to assess its suitability. In addition, regular evaluations should be carried out in order to assess the impact of a regulation, and improvements should be made where needed.

An example of such a scenario could be the analysis of “retention regulations”, imposed in 2017, which were intended to reduce losses for the various stakeholders in the case of a firm failure. However, (PWC 2016) report estimates that the new regulation costs to be around NZ \$30 million per annum for the industry. This is a significant cost, even more than the total risk it intends to address. The additional costs are ultimately transferred around the entire supply chain, thus increasing the cost of the end product and shrinking the profit margins. Similarly, Health and safety regulations, although of the utmost importance to ensure safe workplaces, have also been criticized for having high compliance costs and confusion around their proper implementation (PWC, 2016). In New Zealand, an approval for any type of construction needs to be obtained by building consent authorities (BCAs). This approval process by building consent authorities also needs improvement. The current issues involve delayed approval times, variations in procedures among the various BCAs at the different locations in New Zealand and varying consenting costs (PWC, 2016).

When the interview respondents were asked to give their opinions around the quality of rules and regulation for construction industry, the interviewees argued that building codes and health and safety regulations were

necessary for a functional building industry. Some interview respondents also felt that it was the responsibility of the construction companies to understand the regulations and how they will affect their business to avoid any unfavorable circumstances. The setting up of special courts to resolve construction related disputes such as, in the UK construction industry was also proposed by some of these experts. The interview respondents also opined that BCAs needed more resourcing in order to improve its functioning. The (PWC, 2016) report proposed a similar solution that for better functioning BCAs, more standardized processes across all the BCAs should be implemented, which will help create a more efficient consenting process and a consistent interpretation of the building code.

Economies of scale

The concept of the economies of scale imply that as the operational and production capacity of an organization increases, its efficiency increases (Ambrose et al., 2005). From the perspective of construction this means that as the volume of the construction work increases, a construction firm is able to deliver better quality products at a reduced price.

The (PWC, 2016) report notes that due to the isolated geographic location and the small population, large scale development is often a challenge in New Zealand’s construction industry, and thus there is a difficulty in achieving economies of scale. In Australia, the workforce is 7.3 times larger than in New Zealand, enabling it to achieve much better economies of scale. This is especially true for the residential sector, where there is a huge demand, however there are fewer large-scale development opportunities. In comparison, Australia has large brown field development opportunities, while few such opportunities are available in New Zealand. In addition, government procurement policies are also viewed as sub optimal by industrial players, for example Housing New Zealand Corporation, usually divides the large projects in small packages, (possibly to reduce risk), causing a hindrance to achieve economies of scale, which can help in reducing the overall construction costs.

When interview respondents were asked to comment on possible solution to the economies of scale, they were of the opinion that problem with economies of scale will continue to affect the overall industry for some years in the future, as the issue is also related to the low population and the corresponding demand for the

infrastructure. A few respondents suggested that the problem could be addressed to some extent by taking advantage of global supply chains for example, by ordering pre-fabricated components or modular buildings from countries where they are available at a cheaper price and hence the advantage of the economies of scale of other countries can be achieved in New Zealand. Some expert also suggested that government can address the problem by initiating a large-scale projects package, instead of dividing large projects, into smaller multiple projects. Such large-scale development opportunities will also attract many international players. (PWC, 2016).

4 Conclusion

The current study is exploratory in nature, conducted to understand various problems that the New Zealand construction industry is currently facing. The findings from the literature review and in-depth interviews with industry experts revealed certain internal and external factors. The identified internal factors pertain to firm management issues like risk identification and pricing, labor productivity and narrow profit margins. These firm specific factors have a negative impact on long term survivability in business. The external relevant factors are those which are related to business environment in which such firms are operating. They include labor and skill shortage, traditional procurement approaches, regulatory costs and economies of scale. These external factors make it difficult for construction firms to operate with healthy profit margins and make the product of the industry (built environment) expensive. Several possible actions for government, the construction industry and individual construction firms were discussed. Among others, few of such possible solutions like providing large scale development opportunities to industry players, a review of the building regulations and understanding and pricing of risk by the contractors was discussed.

However, this was an exploratory study and more in-depth research will be conducted by the researchers in next phase to assess the cause effect relation of the issues discussed on the overall performance of construction firms currently operating in the industry.

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Performance Differentials in SMEs: The New Zealand Construction Industry

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ABSTRACT

Literature suggests that there are sets of standard variables that are capable of explaining organisational performance differentials. These variables are used to examine performance variance and its contribution to organisation profitability. To date, global studies have identified 18 determinants that govern the performance of small to medium-size enterprises (SMEs). However, no indication of their weight in forming the overall performance has been made so far. Therefore, this paper aims to measure the significance of the identified determinants from the perspective of the industry decision-makers. The New Zealand construction industry was used as the target population for an online questionnaire in the data collection phase. An electronic link to the questionnaire was sent to the decision-makers of the organisations, including CEOs, project managers, and senior engineers. The questionnaire contained five main questions and data was collected from 97 respondents. A Relative Importance Index analysis was carried out to rank the determinants and their importance to the organisational performance. Five main determinants found to have more influence than the others; resources and capabilities (RC), Competitive Strategies (CS), Organisational Characteristics (OCH), environmental Factors (EF) and Effect of Strength of Relationships with Other Parties (ROP). The findings provide a benchmark and guidance for future research on the significance of the main determinants that could affect a construction organisation's performance.

Keywords: Construction organisations, Determinants, New Zealand, Performance differentials, SMEs

1 Introduction

In New Zealand, the construction sector plays a significant role in driving the growth of the economy with a substantial contribution to businesses, employment, and GDP (PwC, 2016). The country considers the construction industry as a national asset that must be developed and turned to meet the challenges posed by the competitive environment locally and globally (Ministry of Business and Future demand for construction workers, 2017). New Zealand's construction and construction-related services have been described as one of the most critical factors in driving the economic growth with 10 percent of national

employment in 2015 (Linlin & Zhao, 2017; PwC, 2016). The construction industry contributed 6.1 percent of the New Zealand's total GDP with even more significant effect with other parts of the economy when integration is considered and after the manufacturing industry was the second-most valuable goods-producing industry in March 2017 (Ministry of Business, Future demand for construction workers, 2017). As a significant contributor of the annual employment growth, the construction industry is engaging with 177,000 employees with 45,400 more employees over the five years period to February 2019 (Statistics New Zealand, 2019).

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Despite all that the increase in the demand from both residential and non-residential building in the New Zealand construction industry, it has been found that construction organisation could not meet the market demand and the industry stuck on the peak point and cannot perform any better (ANZ, 2017). Moreover, Statistics shows that in all construction industry sections, the survival rate for SMEs (businesses with 1-19 employees) that started in 2012 do not exceed 44% after five years. Surprisingly enough, only 80% of the SMEs have survived after the first year (Statistics New Zealand, 2018). Table 1 shows the survival rate for residential and non-residential SMEs that started between 2012 and 2015.

Table 1: Survival rate (%) for SMEs that started in 2012-15 (Statistics New Zealand, 2018)

Residential building construction					
Businesses birth	After 1 Year	After 2 Years	After 3 Years	After 4 Years	After 5 Years
2012	82	67	57	50	44
2013	86	72	60	52	..
2014	85	68	56	..	..
2015	85	68	..	..	..
Non-Residential building construction					
2012	77	62	45	39	32
2013	84	70	60	52	..
2014	83	61	53	..	..
2015	85	69	..	..	..

The construction industry has historically battled with increased competition and unstable operating environments, both in developed and developing countries (Tan et al., 2012). Consequently, "competitive advantage" and its contributing factors continue to receive attention in construction management studies (Tan et al., 2012; Oyewobi et al., 2016). Competitive advantage refers to superior attributes of an organisation

that adds value to its products and services, thus gaining an advantage over its competitors within the same niche (Lynch, 2012). The importance of competitive advantage is not only shown on its ability to enable sustainable growth, but also from its ability to accept globalisation and dynamic competition in today's world (Flanagan et al., 2007). Since the 1960s, several studies have investigated achieving competitive advantage for construction organisations that resulted in forming three leading schools of thoughts (Flanagan et al., 2007): Porter's (1980) competitive advantage and competitive strategy models which postulated that competitive advantage comes from the competitive strategy a firm adopted to neutralize threats or to exploit opportunities presented by an industry (Betts and Ofori, 1992; Langford and Male, 2001). The resource-based view and the core competence approach discuss that firms should develop unique resources and so achieve core competence to sustain growth. (Barney, 1991). Furthermore, the strategic management approach that deals with the turbulence of the business environment and encourage strategic thinking to achieve long-term development (Venegas and Alarcon, 1997).

Recent systematic literature review constructed by Alqudah, Poshdar, Rotimi and Oyewobi (2018) has identified 18 main factors that play the fundamental role as the main determinants of an organization's performance (see Table 2). Despite all the advancements in the organisational performance research, there is a lack of information about the weight each determinant has toward the performance. Therefore this paper identifies the significance of the identified determinants and specifies those with the most significant contributions.

2 Background of Performance Differentials

It is essential that organisations continuously seek to improve their performance to gain a competitive advantage and maintain sustainability in the dynamic and hypercompetitive construction industry (Rudd et al., 2008). One of the cardinal issues in strategic management is to understand the causes of performance differences between organisations. Lenz (1981) identified some factors as the main causes, including competitive strategies, characteristics of the organizations and business environments. While other researchers such as

Bsarney (2011), Teece (2007); and Sun, Ding & Gu (2008) argued disparities in organisations' resources and capabilities and information technologies (IT) as underlying causes of performance differences. Many factors contribute to shaping organisational competitive advantage, which also explains the differences in those performances. Attempting to understand the causes and sources of these differentials, is one of the fundamental motivations in strategic management research (Oyewobi et al., 2016). Construction organisations need this knowledge as a part of their survival strategy.

Table 2: Organisational Performance Determinates (Alqudah et al., 2018)

No.	Determinants	Frequency of reporting
1	Competitive Strategies (CS)	12
2	Organisational Characteristics (OCH)	6
3	Resources and Capabilities (RC)	5
4	Strategic Management (SM)	5
5	Diversification and Internationalisation (DI)	5
6	Total Quality Management (TQM)	4
7	Organisational Learning (OL)	4
8	Environmental Factors (EF)	4
9	Organisational Culture (OCL)	2
10	Knowledge Management (KM)	2
11	Innovation (INN)	2
12	Information Technology (IT)	3
13	Human Resource Management (HRM)	1
14	Procurement Process Coordination (PPC)	1
15	Marketing Resource (MR)	1
16	Factors of Corporate Management (FCM)	1
17	Effect of Strength of Relationships with Other Parties (ROP)	1
18	Construction Equipment Selection Factors (CESF)	1

Alqudah et al. (2018) developed a conceptual framework that presented the interconnection between the performance determinants of a construction organisation (Figure 1). The arrows represent the direct effect of the external and internal determinants on organizational performance.

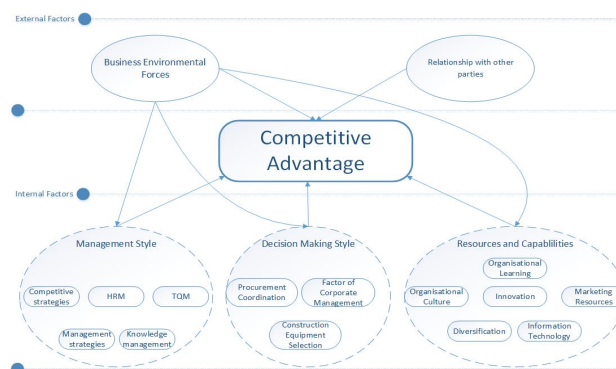


Figure 1: Conceptual Framework of Performance Determinants (Alqudah et al., 2018)

This section presents the developed conceptual framework (Figure 3) of the performance determinates of construction organisations, and the hypothesis are briefly outlined. The arrows represent the direct effect of the external and internal determinants on the organisational performance. All the main determinants and the relationship with the competitive advantage are derived from the review of the literature. The study found that all the determinants could be categorised into external and internal determinants.

As an external determinant, relationships with other parties and business environmental factors are the influencer of the organisational performance. The performance of construction companies is influenced by the strength of their relationships with the parties involved in typical construction projects such as public or private clients, regulatory agencies, subcontractors, labour unions, material dealers, surety companies, and financial institutions. This strength found to have a direct positive relationship with organisational performance (Hausman, 2001; Dainty et al., 2003) while business environmental have a positive effect on organisational performance (Oyewobi et al., 2016) and a moderating effect on organisational characteristics (Oyewobi et al., 2016: 2017).

Internal factors of the organisational characteristics have been categorised into three main themes management style, decision-making style, and resources and capabilities related determinants. Competitive strategies, management strategies, total quality management, knowledge management, and human resources management are min managerial determinants of the organisation performance. Competitive advantage has a positive relationship with competitive strategies (Porter, 1980; Miller and Cardinal, 1994; Tan et al., 2012, Oyewobi

et al., 2016: 2017), strategic management (Dikmen et al., 2005; Isik et al., 2009), total quality management (Lee et al., 2011; Duh et al., 2012; Panuwatwanich & Nguyen, 2017), knowledge management (Yusof and Virgiyanti, 2016; ElFar et al., 2017), and human resource management (Zhai et al., 2013). Business environment influences the competitive strategies positively and moderates its relationship with the competitive advantage (Nandakumar et al., 2010; Oyewobi et al., 2017). While firm size significantly and negatively affects the relation between performance and strategic management (Anikeeff and Sriram, 2008). Regarding management style, performance tends to improve when management appreciates and rewards efficiency, excellence, openness, social skill and contribution to a decision. (Oyewobi et al., 2016: 2017). Competitive strategies suggest a sequence of organised and linked decisions that provide organisations with a competitive advantage over the competitors (Schuler and Jackson, 1987). Moreover, strategic management significantly related to the performance as the way it is used to achieve the present objective (Dikmen et al., 2005).

Decision-making style is a significant area of interest within the field of performance differential, which is acknowledged to have an impact on organisational performance (Amzat and Idris, 2012; Oyewobi et al., 2016). Three determinants have a link to the decision-making style; construction equipment selection, the factor of corporate management, and procurement process coordination. Competitive advantage positively linked with construction equipment selection (Samee and Pongpeng, 2015), the factor of corporate management (Madu et al., 1996; Riantini and Firmansyah, 2008), and procurement process coordination (Lambert et al., 1998; Othman et al., 2015). The better capability of a company's management in planning, instructing, leading, communicating and managing information to determine resources required will improve the company's performance (Madu et al., 1996).

The last theme that deployed in the internal organisational characteristics is the resources and capabilities. Moreover, that categorised into six categories information technology, organisational learning, marketing resources, innovation, diversification, organisational culture. A considerable amount of literature has been published on the relationship between resources and capabilities and organisational performance in the construction industry. These studies

demonstrated that resources and capabilities have a positive relationship with organisational performance and offer competitive advantages (Barney, 2011; Tan et al., 2012; Oyewobi et al., 2016; Tripathi and Jha, 2017).

Competitive advantage is positively and directly associated with information technology (El-Mashaleh et al., 2006; Sun et al., 2008), organisational learning (Wong et al., 2014; Zhai et al., 2013), marketing resources (Zahra et al., 2000), innovation (Crossan and Apaydin, 2010; Martínez-Román et al., 2017), diversification (Oyewobi et al., 2013; Horta et al., 2016), and organisational culture (Li and Jones, 2010). In contrast, some other studies showed that competitive advantage could act negatively with the diversified (Kim and Reinschmidt, 2012; Ofori and Chan, 2000) and innovated companies (Noktehdan et al., 2015) under specific circumstances. Due to the lack of empirical evidence, a vague and neutral situation have been found between competitive advantage and marketing resources (Covin and Slevin, 1991) and diversification (Choi and Russell, 2005; Ibrahim and Kaka, 2007). Resources and capabilities found to have a positive impact on organisational performance in a variety of ways; such as improving internal organisational performance, matching the base of resources with the fluctuating environments, and creating changes in the market.

3 Research Methods

2.1 Sampling and Data collection

A questionnaire was developed for data collection. The questionnaire involved three sections, with the first section covering the demographics (background) of the respondents. The second section included questions on the determinants of the organisational performance as retrieved from literature, while the third section was in the respondents' opinion of any other determinants that they might think it is affecting the organisations' performance in the New Zealand construction industry. The research ensured content validity in the developed questionnaire by adhering to the strategy used by Pertusa-Ortega et al. (2008). Some already validated items of measurement were adapted (as it is adapted from literature) and a preliminary draft was sent to experts who had a strong understanding of the industry. These experts were selected based on their experience working in the industry and their research of interest. The selected respondents possessed adequate knowledge about their organisation strategy and competitive position in the industry. The questionnaire was corrected based on their

input.

The population consisted of the full range of organisations active within the New Zealand construction industry. Out of 13,782 construction organisations, 320 were selected using simple random sampling technique and the calculation of minimum sample size (in line with Ankarah, 2007). Invitations and information were sent through emails to the selected organisations that contained a link to an online questionnaire survey on Qualtrics. Qualtrics is a simple to use a web-based survey tool to conduct survey research, evaluations and other data collection activities. At the end of the survey period, 100 responses were received that equates to a response rate close to 30 per cent. This response rate is considered appropriate in construction management research to generalise the findings (Kale and Arditi, 2003; Tan et al., 2012).

4 Questionnaire survey

4.1 Questionnaire design

The design philosophy of the questionnaire was based on the fact that they had to be simple, clear, and understandable for respondents, and at the same time, they should be able to be interpreted well by the researcher. The questionnaire has a definite advantage of requiring shorter time to be responded and is more accurate in the outcome.

Several meetings with members of the industry were conducted to ensure the correctness of questions and their format.

4.2 Content of the questionnaire

The questionnaire had three sections, with the first section covered general information about the respondents such as their position in the company, duration of working in this position and the number of years of experience in the New Zealand construction industry. The second section contained determinants leading to performance differentials. A list of the 18 main determinants as retrieved from literature was presented to the respondents. They were requested to reflect on their perception about the importance of each determinant towards the overall organisational performance. The perception was indicated on a 5-point scale with the choices of 1 corresponded to “no effect” to 5 corresponded to “very high effect”. The third section enabled the respondents to add any other determinants missing from the initial list.

4.3 Data collection protocol

The questionnaire was formulated based on the determinants identified by Alqudah et al. (2018). The questionnaire was carried out online. The electronic link was sent to the participants following their business function. The result of the questionnaire (statistical analysis) will be available for participants.

4.4 Scoring

Table 3 illustrates the details of the responses in regards to the perceived importance of each determinant. Moreover, the relative importance index (RII) technique (Tam and Le, 2006) was used for analysing data per factor. This index was computed using the following equation:

$$RII = \frac{\sum w}{AN} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5N}$$

Where w is the weighting given to each factor by the respondent, ranging from 1 to 5, for example, n_1 = number of respondents for No effect, n_2 = number of respondents for low effect, n_3 = number of respondents for moderate effect, n_4 = number of respondents for high effect, n_5 = number of respondents for very high effect. A is the highest weight (i.e. 5 in this study), and N is the total number of respondents. The relative importance index ranges from 0 to 1 (Tam and Le, 2006).

Table 3: Total respondent's results of performance determinants.

ID	Determinant description	Number of respondent's scoring				
		(1)	(2)	(3)	(4)	(5)
1	Competitive Strategies (CS)	1	8	17	24	50
2	Organisational Characteristics (OCH)	1	4	17	41	37
3	Resources and Capabilities (RC)	1	2	8	35	54
4	Strategic Management (SM)	12	12	19	38	19
5	Diversification and Internationalisation (DI)	9	37	41	13	0
6	Total Quality Management (TQM)	3	31	37	19	10
7	Organisational Learning (OL)	5	24	35	30	6
8	Environmental Factors (EF)	0	12	22	15	51
9	Organisational Culture (OCL)	6	24	30	26	14
10	Knowledge Management (KM)	4	22	42	29	3
11	Innovation (INN)	3	16	37	36	8
12	Information Technology (IT)	4	18	34	38	6

13	Human Resource Management (HRM)	5	17	30	36	12
14	Procurement Process Coordination (PPC)	3	29	39	23	6
15	Marketing Resource (MR)	8	30	44	18	0
16	Factors of Corporate Management (FCM)	9	32	33	25	1
17	Effect of Strength of Relationships with Other Parties (ROP)	5	5	15	33	42
18	Construction Equipment Selection Factors (CESF)	9	23	36	27	5

5 Research analysis and discussion

The determinants causing performance differentials in the construction industry in New Zealand were ranked based on its relative important index (RII) report. Table 4 presents the results.

Table 4: RII and ranking of performance determinants.

Rank	ID	Determinant description	RII
1	3	Resources and Capabilities (RC)	0.878
2	1	Competitive Strategies (CS)	0.828
3	2	Organisational Characteristics (OCH)	0.818
4	8	Environmental Factors (EF)	0.810
5	17	Effect of Strength of Relationships with Other Parties (ROP)	0.804
6	4	Strategic Management (SM)	0.68
7	13	Human Resource Management (HRM)	0.666
8	11	Innovation (INN)	0.660
9	12	Information Technology (IT)	0.648
10	9	Organisational Culture (OCL)	0.636
11	7	Organisational Learning (OL)	0.616
12	10	Knowledge Management (KM)	0.610
13	6	Total Quality Management (TQM)	0.604
14	14	Procurement Process Coordination (PPC)	0.600
15	18	Construction Equipment Selection Factors (CESF)	0.592
16	16	Factors of Corporate Management (FCM)	0.554
17	15	Marketing Resource (MR)	0.544
18	5	Diversification and Internationalisation (DI)	0.516

As the table shows, the respondents ranked "Resources and capabilities" as the most critical cause of performance differentials in the New Zealand construction industry with the RII index equal to 0.878. "Diversification and Internationalisation" received the lowest RII equal to 0.516.

The overall determinants are classified under two main categories; external and internal determinants (see Figure 1). External determinants included Environmental Factors and Effect of Strength of Relationships with Other Parties. External determinants found to be within the top five determinants receiving 0.810 and 0.804, respectively. Internal determinants, on the other hand, were classified into three main categories; management style, decision-making style and resources and capabilities. Decision-making style was the only category that was not on the top five list. While management style and resources and capabilities were leading and received the highest RII value. Resources and capability as early mentioned ranked as the most influential determinant with RII value of 0.878, which goes along with resource-based view (RBV). Furthermore, that can be logically explained by the RBV propositions, which the organisation's competitive advantage does not depend on the industry structures but stems from the rare, valuable and non-substitutable resources inside the organisation. The organisation must identify and strengthen those specific resources by effective utilization to achieve competitive advantage (Flanagan et al., 2007).

As on the management style category, competitive strategies were ranked the second with 0.828 relative importance index. Porter (1980) argues that for an organisation to have a sustained competitive advantage, some basics of competitive business have to be given adequate attention.

6 Conclusion and recommendations

This research focused on the determinants of performance of construction organisations. Performance can be improved when its determinants are identified. The main aim of this paper was to evaluate the perception of the industry decision-makers about the top determinants of the organisational performance in New Zealand. Further research work could be conducted to ascertain performance differentials within different business hierarchies (small, medium and large-scale construction firms) and to establish performance determinants at the project and stakeholder levels.

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The Predominant Causes of Construction Delays

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ABSTRACT

The inability to complete construction projects timeously remains a major challenge in construction projects all over the world. A greater understanding of the causes that result in late completion will provide project participants with a knowledge base to mitigate the occurrence of delays. A large number of past research studies attempted to pinpoint specific causes of delay. A lack of standardisation in approach and failure to consider key factors that might influence the occurrence of delays impacted on the usefulness of the studies to help mitigate the occurrence of delays. This paper investigates the predominant causes of construction delays globally by analyzing data from sixteen different countries. In general, the results of the study identified change orders, shortage of construction material and poor site management as the predominant causes of delay. The findings demonstrated that there are significant differences between the causes of delay in developed and developing countries. In addition, suggestions are also made on how future studies of this nature can be standardized to provide better results. The identification of common causes will be of assistance to ultimately address the universal problem of the late completion of construction projects.

Keywords: Causes of delay, Construction delays, Delay framework

1 Introduction

One of the critical success factors of a construction project is to complete the project within a restricted time frame. The common manifestation of project overruns further contributes to cost escalations and quality issues (Durdyev and Hosseini, 2018; Lessing, Thurnell & Durdyev, 2017; Shah, 2016). Construction projects are increasing in size and complexity that will further impact negatively on the suggested three project objectives: cost, quality and time (Abdou Saed, Yong & Othman, 2016; San Cristóbal, 2017). Delays are an international spectacle and reducing delays in projects are annually creating problems globally (Venkatesh and Venkatesan, 2017).

This article investigates the predominant causes of construction delays globally by analyzing data from sixteen different countries. The results of the analysis

were utilized to determine whether the causes of delay differ in developed countries compared to developing countries. In addition, suggestions are also made on how future studies of this nature can be standardized to provide better results. The identification of common causes will be of assistance to ultimately address the universal problem of the late completion of construction projects.

1.1 Developing Countries and Developed Countries

O'Sullivan, Sheffrin (2003) defined a developing country as a country with a less developed industrial base and a low Human Development Index (HDI) relative to other countries. A developed country is a sovereign state that has a developed economy and advanced technological infrastructure relative to other less industrialized nations.

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1.2 What is a construction delay?

From previous research, it seems that there is no one general accepted definition for a project delay.

In the study of Sivaprakasam, Shruthi, Sellakutty, Dinesh & Jayakumar, Jayashree (2017) a construction delay is defined as the “time overrun either beyond the date specified in a contract and exceed the initial time and cost estimates.” A construction delay is also defined “any occurrence that affects the contractor’s progress or makes it work less efficiently than would otherwise have been the case” (Ndekugri, Braimah & Gameson, 2008).

1.3 Types of delays

A number of studies focused on the identification of delays and categorised them in terms of the impact, risk and the cause of the delay. Figure 1 suggests a summary of a proposed delayed framework.

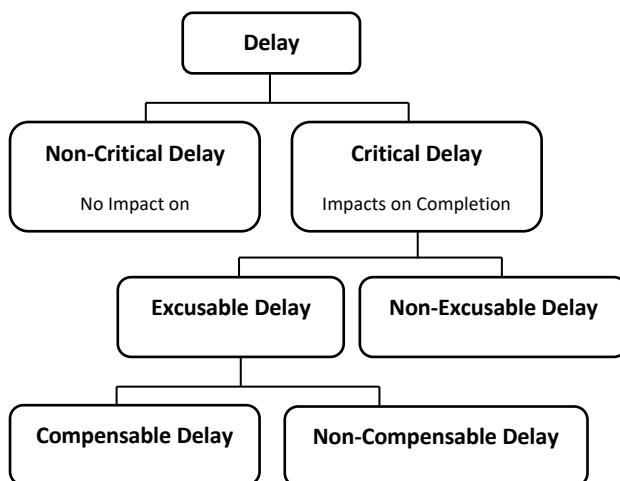


Figure 1: Types of delays (Maritz and Prinsloo, 2016)

A delay to progress is different from a delay to completion. A delay to progress is a significant shift in the planned timing of a specific activity or activities that can occur at any time. Although the start and, or finish of the activity might differ from the original intent it is irrelevant unless it ultimately impacts on the completion date. On the other hand, a delay to the completion date occurs only when the completion date has passed and can only be caused

by a delay to the progress of an activity which is on the critical path to completion.

A delay can be categorized in terms of the ultimate impact on completion:

- 1) Critical delay – a delay on the critical path of the project and as a result the final completion date of the project will be delayed; and
- 2) Non-critical delay – a delay that is not on the critical path and would therefore not impact of the overall completion date. (Ndekugri *et al.*, 2008)

According to Hamzah et al (2011) there are in principal two types of delays; non-excusable and excusable. A non-excusable delay, regardless of its origin, will rest purely on the shoulders of the contractor. In this delay scenario the contractor will not be compensated monetarily or given an extension of time.

An excusable delay, on the other hand, can be described as a delay caused by either of the following two factors:

- Third parties or incidents beyond the control of the client and the contractor; and
- The client or the client’s agents. (Alaghbari, Kadir & Salim, 2007; Hamzah, Khoiry, Arshad, Tawil & Che Ani, 2011; Tumi *et al.*, 2009)

Hamzah et al (2011) further divide excusable delays into two streams: compensable and non-compensable. In the scenario of a compensable delay the client or his/her representatives will be responsible and not the contractor. Whereas if a delay occurred and it was neither the client nor the contractor’s fault, it is referred to as a non-compensable delay. These kinds of delays typically refer to as “acts of God” and is not within the control of any party.

2 Methodology

Keeping in mind that the research is taking place within an applied-science environment, a qualitative approach was deemed the most appropriate for delivering the required results. Qualitative research can be defined as an inquiry process of understanding social or human problems, based on building a complex, holistic picture, formed with words, reporting detailed views of the informants, and conducted in a natural setting. A qualitative study concludes with tentative answers or hypotheses regarding what was observed (Creswell, 2013) and (Glesne & Peshkin, 1992).

The first step in the research process was a comprehensive literature review, followed by the analysis of data obtained from sixteen recent studies conducted internationally on the main causes of construction delays.

The purpose of the analysis was to determine the level of occurrence of each of the different types of delays categorized in contractor delays, owner delays and external factors causing delays. The level of occurrence is expressed as a percentage that was determined by the number of times the delay was sited in relation to the total number of studies conducted.

A separate analysis of the occurrence of delays in developing and developed countries were conducted. The International Monetary Fund's World Economic Outlook Database, October 2018 published a list of countries that are considered as developing countries. This list was utilized to distinguish

This approach made it possible to determine whether occurrence levels differ.

3 Causes of delay

Over the years, a number of studies have been conducted to identify the causes of delays in the construction industry. These studies have been conducted in different countries. This section aims to identify the international causes of delay by reviewing the relevant literature.

New Zealand

Lessing, Thurnell and Durdyev (2017) investigated the major impacts on cost, duration and quality of projects in the Auckland region. Their research study emphasized that design-related factors contributed significantly to delay occurrences on construction projects. However, their study further highlighted that geological tests lacked comprehensive site conditions, which caused delays during execution of projects. Their questionnaire focused on five areas of delays: project, client, plant/equipment, design team/consultants, external factors, labour, communication and the contractor. Interestingly the project factors that rated highly was the fact that initial contract time frames were not achievable, and, in most cases, the lowest bidder was awarded the contract. Again, project complexity surfaced and proper alignment of construction contracts according to the different selected projects. Changed orders, late revisions and slow decision making were the major culprits that resulted in client delays. Plant rated lower with common aspects such as breakdown, shortages, productivity and effectiveness of equipment. External factors such as ground conditions, weather and sufficient access to the site proved to be possible causes for delays. It was further evident from their study that there is a lack of purpose-fit labour skills and productivity. Aspects that could be detrimental to the latter was lack of coordination and communication between parties. For the contractors, it was mostly a lack of suitable subcontractors and poor site supervision.

Norway

Zidane and Anderson (2018) followed an inductive approach and collected data through a qualitative questionnaire. They used member checking and triangulating to validate their findings. The data they initially collected from project managers working on large construction projects, were clustered into 44 sub-groups, which was filtered eventually into 11 groups. In their findings, poor planning and scheduling proved to be the biggest delay factor on Norwegian construction projects.

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Cambodia

Durdyev, Omarov and Ismail (2017) conducted a survey that was aimed at determining which factors in the residential sector contributed to project delays in Cambodia. They made use of a survey that was e-mailed to 75 contractors that were registered with the Cambodia Constructors Association and received a 64% usable response rate. During their research, they aimed to analyse the different impact levels of project delays through the use of an analytical method, making use of a relative Importance Index (RII). After analysing their results the shortage of materials on-site proved to be the most significant reason for delays, closely followed by unrealistic project scheduling.

United States

Tafazzoli, AP and Shrestha (2017) undertook a study to determine the causes of delays in projects in the United States. The researchers conducted nationwide research to include various regions within the U.S. Their research indicated that owner collaboration with the construction team, quality of design and communication between parties were contributing significantly to construction delays. The researchers identified 27 causes using the relative importance index

Malaysia

Abdullah, Rahman and Azis (2010) conducted a survey to determine the delays experienced by a government agency in Malaysia, known as Majlis Amanah Rakyat (MARA). The results of the analysis revealed that the most significant delay causes were financial difficulties faced by contractors, contractors' poor site management and ineffective planning, and poor scheduling by contractors. Six years later Shah (2016) also investigated the causes of delay in the Malaysian construction industry. Inadequate planning by the contract, poor site management and inadequate contractor experience were identified as the most significant factors causing delays.

Saudi Arabia

Assaf, Al-Khalil and Al-Hazmi (1995) used randomly selected samples in Saudi Arabia to identify the causes of delay in large building projects. Surveys comprising the causes of delays were presented to the respondents requesting a ranking, according to the degree of importance. These surveys provided data that were analysed in terms of frequency, severity and importance of the delays. The study identified 73 causes of delays. The owners who participated in the survey alleged that the delays were as a result of the fault on the part of the contractor and the labourers. However, the final results of the survey contradicted this opinion; as it was found that the majority of the causes of delay resulted from the actions of the employer/owner and his agents/consultants.

Hong Kong

Chan and Kumaraswamy (1997) conducted a survey that was aimed at determining and evaluating the significant factors that cause delays in Hong Kong construction projects. From the survey, it was concluded that poor site management and supervision, unforeseen ground conditions, low speed of decision-making involving all project teams, client-initiated variations and necessary variations of works are the five most significant sources of construction time overrun.

Indonesia

Factors influencing construction time and cost overruns on high-rise projects in Indonesia were discussed by Kaming, Olomolaiye, Holt and Harris (1997). In this study, project managers were surveyed. It seems that cost overruns occur more frequently; and they are more severe than time overruns. The main factors that influence time delays are: design changes, poor labour productivity, inadequate planning and resource shortages.

Turkey

The Turkish construction industry was studied by Kazaz, Ulubeyli and Tuncbilekli (2012) and the causes of time extensions and their level of importance in

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Turkey were identified. According to the results obtained, design and material changes were determined as the most important factors, followed by the delay in payments, cash-flow problems, contractors' financial problems and poor labour productivity.

Thailand

Ogunlana, Promkuntong and Jearkijrm (1996) conducted a survey to investigate the delays experienced in high-rise building projects in Bangkok, Thailand. The findings of this study were then compared with other global studies of construction delays, to determine whether there were special problems resulting in construction delays in developing economies. The findings from the study indicated that the principal problems were mostly related to designers, clients, contractors and finance. However, globally construction projects face a number of factors that cause delays; and these include: Shortage of human resources; machinery and equipment; and construction materials.

India

According to Iyer et al. (2008) the increase in size and complexity of the construction projects in India resulted in a higher number of claims and disputes. The following reasons for delay were identified: late handing over of site, late receipt of drawing, accidents, temporary stoppage, rework and extra work.

Jordan

Al-Momani (2000) undertook a study to determine the causes of delays in 130 public projects in Jordan. Residential, administration buildings, school buildings, medical and commotion facilities were among the projects evaluated. The findings of the study identified the following reasons for delays: user changes, weather, site conditions, late deliveries, economic conditions and increase in quantity.

Nigeria

Emeka, Onozulike, J (2016) investigated the causes of delays in large construction projects. The research

included ninety-three (93) major project stakeholders which consisted of clients, consultants and contractors. Twenty four factors (24) of delays and eight (8) different technologies, addressing the issues of delays, were grouped into the latter three categories. The research results indicated that financial difficulty, lack of working knowledge, lack of consultant site staff, suspension of work by owner, inexperience on the part of the consultant, inexperience on the part of the consultant site staff, poor skills and inexperience of labour, material shortage, poor site management and lack of site contractors staff, as the most important factors causing delays in Nigeria construction industries.

Egypt

A study was conducted by Wahdan, Yousef and Farid (2013) to investigate reasons for delays in Egypt. The ten (10) most significant causes that surfaced were inadequate details & designs, difficulties in obtaining licenses and permits from authorities, lack of planning, activity, material, labour and equipment management, shortage of skilled labour, delays in technical documents during construction phase, disregard of critical activities, change orders during construction, deficient coordination among participants, low productivity and difficulty in submitting requests.

Marzouk and El-Rasas (2014) undertook a study to analyse Egyptian construction delays. The ten (10) most significant delays were determined through the use of a Frequency Index, Severity Index and Importance Index. Causes of delays included ineffective planning and scheduling of projects, difficulties in financing projects by contractors, variation orders, poor site management, type of project bidding and awards, low productivity levels, effects of subsurface conditions.

South Africa

Baloyi and Bekker (2011) investigated the causes of cost overruns and time delays during the construction and upgrading of the ten 2010 world cup stadia in South Africa. Design-related factors were found to

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cause the most delays in the construction of the stadia. When comparing results for global delays and delays implicated by the construction of the stadia, it was found that the increase in material cost was the largest single contributor for both the global and the local stadia-construction delays.

Klopper and Brümmer (2000) conducted a study to determine the impact of delays on building projects in South Africa. In this study, 211 public sector construction projects were reviewed. The identified possible factors were investigated independently, in order to determine the impact on the building projects. Insufficient work-rate was determined to be the main factor that had influenced the late completion of building projects in South Africa (Klopper & Brümmer, 2000).

Botswana

Musuya (2012) undertook a study in Botswana to determine the impact of delays and the inexcusable reasons for delays in construction projects by either citizens or non-citizen construction firms.

Furthermore, the study evaluated the impact of inexcusable delays, in order to outline the reasons for the high occurrence of delays in construction projects undertaken by local firms. The results of the study showed that a large portion of the public sector in Botswana encounter delays. The performance of citizen/local construction firms was inferior to those rendered by non-citizen firms. The results of the analysis/study identified the management style as the main factor of delay in the construction industry in Botswana (Musuya, 2012).

Summary of reasons for delay

In general terms, the reasons for delay can be summarised in three main categories: Contractor delays; client delays; and external factors – where neither the contractor nor the client could be held directly responsible for the delay.

It was evident from the review of local and international studies that delays remain very prevalent in construction projects.

Table 1 – Reason for Delay (Contractor's Risk)

Reasons for delay	Developed Countries						Developing Countries											
	Saudi Arabia	Hong Kong	Norway	USA	New Zealand	Occurrence (%)	Nigeria	Egypt	Indonesia	Turkey	Thailand	South Africa	Botswana	Malaysia	India	Jordan	Cambodia	Occurrence (%)
Contractor:																		
Labour shortage (skilled & unskilled)	✓	x	✓	x	✓	60	✓	✓	x	x	✓	x	x	✓	x	x	✓	45
Site management and supervision	x	✓	✓	✓	✓	80	✓	✓	x	x	x	x	✓	✓	✓	x	✓	55
Accidents	x	x	x	x	x	0	x	x	x	x	x	x	x	x	✓	x	✓	18
Reworks	x	x	x	✓	x	20	✓	x	x	x	x	x	x	x	✓	x	✓	27
Materials management problems	x	x	x	✓	x	20	✓	x	x	x	✓	x	x	x	x	✓	x	27
Planning and scheduling problems	x	x	✓	✓	✓	60	✓	✓	x	x	✓	x	x	✓	x	x	x	36
Equipment allocation problems	x	x	x	x	✓	20	x	✓	x	x	✓	x	x	x	x	x	x	18
Material (low quality and damage)	x	x	✓	x	x	20	✓	x	x	x	✓	x	x	x	x	x	x	18
Equipment (availability/breakdowns)	x	x	✓	x	✓	40	✓	x	✓	x	✓	x	x	✓	x	x	x	36
Contractors' financial difficulties	x	x	x	✓	✓	40	✓	✓	x	✓	x	x	x	✓	x	x	x	36
Contractors' inadequate site inspection	x	x	x	x	x	0	✓	x	x	x	x	x	x	x	x	x	x	9
Slow mobilization	x	x	x	x	x	0	✓	x	x	x	x	x	x	x	x	x	x	9
Productivity / work-rate	x	x	x	x	✓	20	x	✓	✓	✓	x	✓	x	x	x	x	x	36
Interference with other trades	x	x	x	x	x	0	✓	x	x	x	x	x	x	x	x	x	x	9
Delays in subcontractors' work	x	✓	x	x	✓	40	✓	x	x	x	x	x	x	✓	x	x	✓	36
Inadequate contractor experience	x	✓	x	✓	x	40	✓	x	x	x	x	x	x	✓	x	x	x	18

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Figure 2 – Contractor's delay (Developed countries vs Developing Countries)

Table 2 – Reasons for delay (Client's Risks)

Reasons for delay	Developed Countries						Developing Countries											
	Saudi Arabia	Hong Kong	Norway	USA	New Zealand	Occurrence %	Egypt	Nigeria	Indonesia	Turkey	Thailand	South Africa	Botswana	Malaysia	India	Jordan	Cambodia	Occurrence %
Client:																		
Late payment of contractor/ cash flow	x	x	x	x	✓	10	✓	✓	x	✓	x	x	x	✓	✓	x	✓	55
Inaccurate estimates	x	x	x	x	x	0	x	✓	x	x	x	x	x	x	x	x	x	9
Variation orders	x	✓	✓	✓	✓	80	✓	✓	✓	✓	x	x	x	x	✓	✓	x	55
Delays in design information	x	✓	✓	✓	✓	80	✓	✓	x	x	x	x	x	x	x	x	x	18
Long waiting time approval of drawings/samples	x	✓	✓	✓	✓	80	✓	✓	x	x	✓	x	x	x	✓	x	x	36
Inadequate design team	x	✓	x	x	x	10	x	✓	x	x	x	x	x	x	x	x	x	9
Slow information flow between project team members	x	✓	x	x	✓	20	x	✓	x	x	x	x	x	x	x	x	x	9
Delay due to handing over of site	x	x	x	x	x	0	x	x	x	x	x	x	x	x	✓	x	x	9
Design quality/incomplete drawings	x	✓	✓	✓	✓	80	✓	✓	x	x	✓	✓	x	x	x	x	x	36
Deficiencies in coordination	x	x	x	✓	x	10	✓	✓	x	x	✓	x	x	x	x	x	x	27
Design team inadequate supervision	x	x	x	✓	x	10	x	✓	x	x	x	x	x	x	x	x	x	9
Lack of communication between client & consultant	x	✓	x	✓	✓	60	x	x	x	x	x	x	x	✓	x	x	x	9
Slow decision-making	x	✓	x	✓	✓	60	✓	✓	x	x	✓	x	x	x	x	x	x	27
Unrealistic contract durations imposed by client	x	✓	x	✓	✓	60	x	x	x	x	x	x	x	x	x	x	x	0
Inappropriate overall project structure	x	✓	x	✓	x	30	x	x	x	x	✓	x	x	x	x	x	x	9

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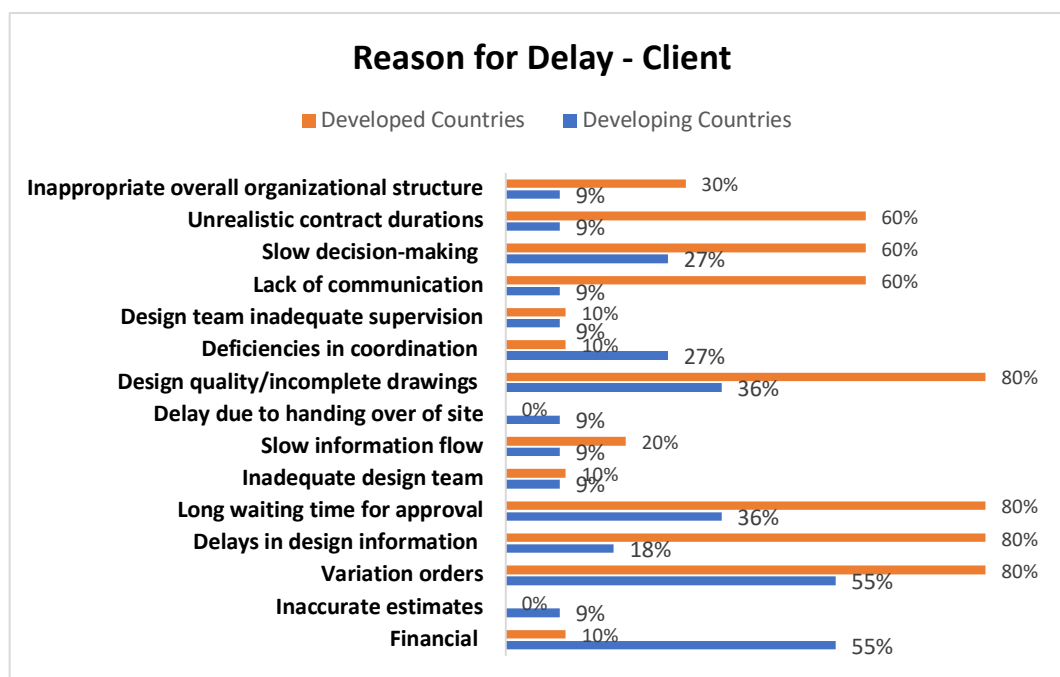


Figure 3 – Client’s delay (Developed vs Developing Countries)

Table 3 – Reasons for delay (External Factors)

Reasons for delay	Developed Countries						Developing Countries											
	Saudi Arabia	Hong Kong	Norway	USA	New Zealand	Occurrence (%)	Nigeria	Egypt	Indonesia	Turkey	Thailand	South Africa	Botswana	Malaysia	India	Jordan	Cambodia	Occurrence (%)
External																		
Shortage of materials	x	✓	✓	x	✓	60	✓	✓	✓	x	✓	x	x	✓	x	x	✓	55
Price fluctuations	x	x	x	x	x	0	✓	✓	x	x	✓	x	x	x	x	x	x	27
Unforeseen site conditions	x	✓	x	x	✓	20	x	x	x	x	x	x	x	x	x	✓	✓	18
Disputes/conflicts	x	✓	x	x	x	10	x	x	x	x	x	x	x	x	x	x	✓	9
Economic conditions	x	x	x	x	x	0	x	x	x	x	x	x	x	x	x	✓	x	9
Confined site	x	x	x	x	x	0	x	x	x	x	✓	x	x	x	x	x	x	9
Problems with neighbours	x	x	x	x	x	0	x	x	x	x	✓	x	x	x	x	x	x	9
Slow permits by govt. Agencies	x	x	x	x	x	0	✓	✓	x	x	✓	x	x	x	x	x	✓	36
Government regulations	x	x	x	x	x	0	✓	x	x	x	x	x	x	x	x	x	x	9
Inclement weather	x	x	x	x	✓	10	✓	x	x	x	x	x	x	x	x	✓	✓	27
Acts of God	x	x	x	x	x	0	✓	x	x	x	x	x	x	x	x	x	x	9
Labour disputes and strikes	x	x	x	x	x	0	✓	x	x	x	x	x	x	x	x	x	x	9
Civil disturbances	x	x	x	x	x	0	✓	x	x	x	x	x	x	x	x	x	x	9
Increase in material cost	x	x	x	x	x	10	x	✓	x	x	x	✓	x	x	x	x	x	27

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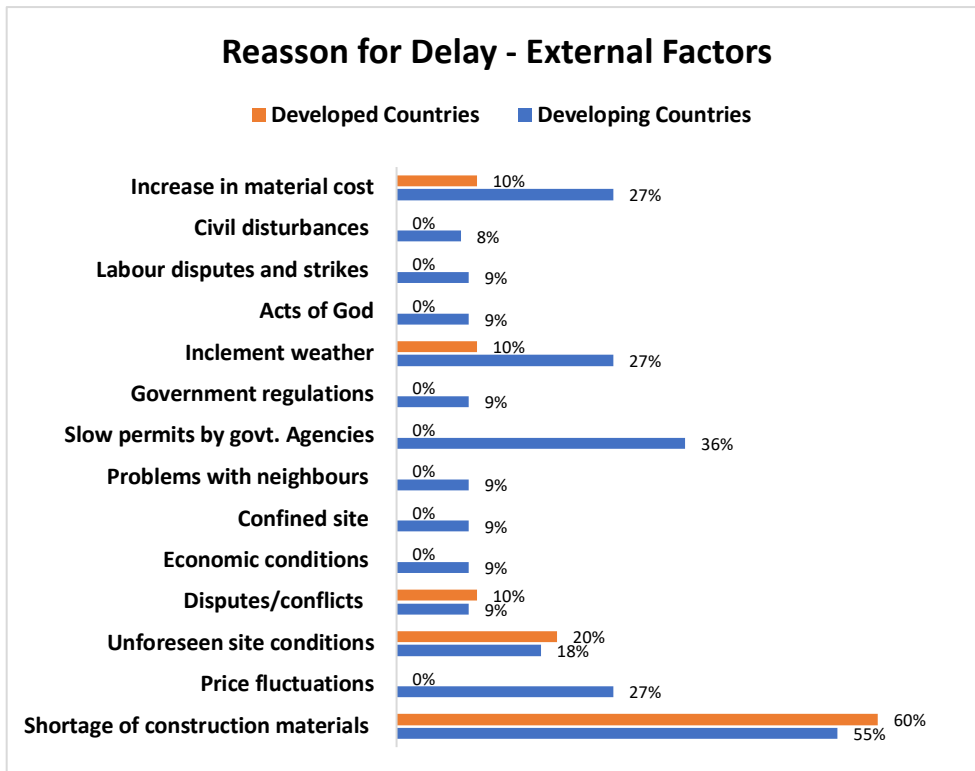


Figure 4 – External Factors (Developed countries vs Developing Countries)

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Findings

The contractors' most prominent delay, both from a developed and developing countries perspective, was site management and supervision. In the latter case labour shortage was also a significant cause. Planning & scheduling difficulties and insufficient contractor's experience demonstrated to be more significant in developed countries while the productivity or work rate delay in developing countries shown to be more significant.

It was evident from Table 3, that external factors influenced developing countries more than in developed countries. The shortage of material indicated to be an obstacle for both types of countries and unforeseen site conditions were very similar in occurrence. Slow permits by government agencies, price fluctuations, inclement weather and an increase in material cost illustrated to be more significant in developing countries than in developed countries.

Figure 3 illustrated that client's delays are playing a much larger role in developed countries than in developing countries. Variation orders showed to be most significant for both developed and developing countries. Although long waiting time for approval of drawings and design quality surfaced in both types of countries, it was much more prominent in the developed countries. In developing countries the late payment of contractors demonstrated to be very significant, whereas delays in design information underlined to be more prevalent in developed countries. The above findings demonstrated that there are significant differences between the causes of delay in developed and developing countries.

It was further evident from the numerous studies reviewed that there were very little standardisation in

approach taken to identify delays. Certain key factors that would likely influence the cause of delay was not taken into account. The model propose in Figure 5 highlights key factors that should be considered in future research to ensure more accurate relection of project delays would be possible. There are different challenges in developing countries than in developed countries Researchers need to distinguish between the two. It is also important to investigate the different sectors within the construction industry (i.e. office/retail, industrial, residential and civil engineering & roadworks) independantly. A bricklayer laying bricks for an affordable house (residential) skills are very different than one that executes work on a 4 storey office building. The monetary value of the project could also influence the type of delays experienced. A \$2 million house is very different from a \$200 000 house. The quality of the finishes and the skill level of participant will be very different. Complexity is another distinguishing factor for different projects. A project can be complex either in structural or uncertainty terms, or in both. Structurally refers to the actual size and independence of elements whereas uncertainty refers to more novel projects i.e. uncertainty in goals or methods

The type of project can also refer to the "conditions of the site" as well as the location of the construction site. A construction site in a secluded area will have very different logistical issues than one situated in the inner city. This approach enable the researcher to be more precise and accurate with which kind of delays will have a higher probability of occurrence than others for every project scenario.

This approach will lead to better initial planning as forecasting of the likelihood of occurance of different delays will be improved.

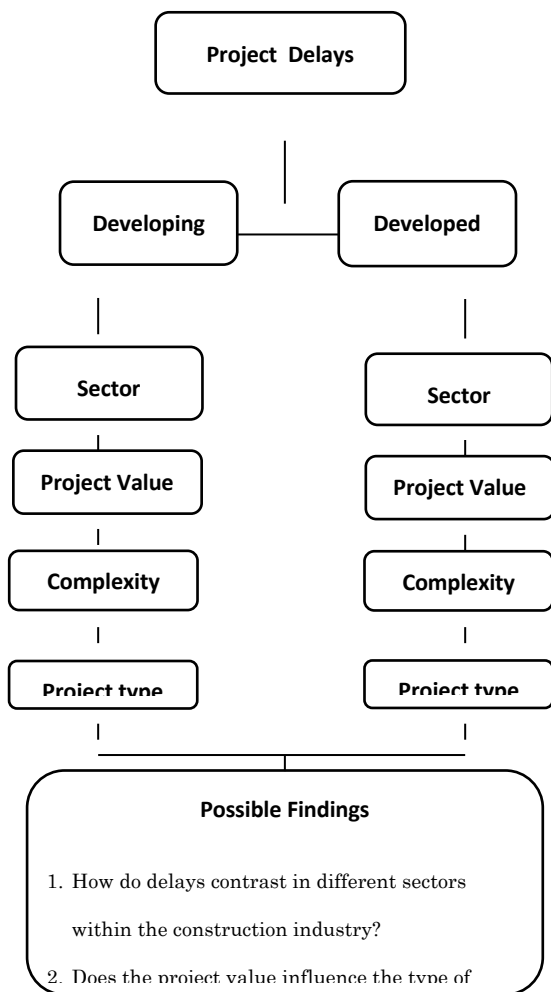


Figure 5: Model for future research

6 Conclusion

This paper explains why it is essential to standardise delays in construction projects. It highlighted the fact from previous local and international studies that delays on projects remain a major concern. The predominant causes varied between the different research studies, although some causes surfaced more regularly than others. It was further concluded that the identification of the causes of delay must be approached as illustrated by Figure 5.

Based on this, the formulation of a standardised delay framework can contribute to more specific identification of common causes within similar projects. The analysis of

the data revealed that developing countries suffer more under external and client delays. Both developing and developed countries indicated variation orders and site management & supervision as being a significant contributor to project delays. A purpose-fit created list of the most critical factors for more similar types of building or construction projects can be used by different stakeholders to minimize the probability of project delays.

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A Comparative Analysis on Housing Policies in Australia and New Zealand: Understanding the KiwiBuild Frustration

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ABSTRACT

Housing affordability is a prominent issue across the world. There is a growing concern that the number of people who are experiencing homelessness is rapidly increasing. As a solution, many countries, including Australia and New Zealand, have introduced affordable housing policies to provide affordable houses to low-medium income families. In New Zealand, the KiwiBuild project was launched in 2018 to increase housing affordability. Unfortunately, in 2019, this project was not able to deliver the targeted primary objective of 1000 affordable KiwiBuild homes set by the government. In this study, a comprehensive document analysis was conducted, primarily focusing on, comparing and contrasting affordable housing policies in Australia and New Zealand. Subsequently, the reasons why the Kiwi Build project failed will be discussed. Recommendations will be made based on policies used in Australia to improve affordable housing policies in New Zealand. This research would contribute to the existing body of knowledge to better understand the affordable housing policies between Australia and New Zealand. The recommendations would be helpful for future researchers to develop workable policies to assist with affordable housing-related issues in New Zealand.

Keywords: Housing affordability, Affordable housing policies, KiwiBuild

1 Introduction

Housing is a prominent issue which many people discuss in this fast-developing era. With the development of economies and the increase in population, securing a house has become extremely challenging for low and medium-income families across the world. However, when the ideal house is unaffordable, affordable housing is considered. "Affordable housing" is defined as the housing, which is deemed as affordable to those with a median household income or below (Bhatta, 2010). Many governments aim at providing effective policies to help their citizens to have affordable houses to live. However, in many cases such as Brazil, China, Ghana, Greece, India, Ireland, Italy, Spain, and the United States, the governments' housing policies have not effectively functioned (Fields & Hodkinson, 2018).

In New Zealand, in 2017, the government published a policy called the "KiwiBuild" project, which was expected to build 100,000 high quality, affordable homes over ten years (Wilkinson, 2019). It was expected to be one of the

effective ways to solve the increasing house price crises and to provide affordable houses for New Zealanders. The New Zealand Herald (2018) reported that over 17,000 people registered their interest in one of the 100,000 KiwiBuild houses with \$2 billion dollars invested over ten years (Gibson, 2017). KiwiBuild was planned to execute in two ways; increasing the supply of affordable houses and transforming the way that houses are built. It was very positive at the beginning. The New Zealand Herald (2018) further reported that there was a massive demand for affordable houses in New Zealand, and many people had high hopes and expectations for the KiwiBuild project. However, unfortunately, the KiwiBuild project was unable to deliver all of its objectives (Wilkinson, 2019).

This study aims to compare and contrast affordable housing policies in Australia and New Zealand. It will then analyse the main aspects of the KiwiBuild project policy. The research study will then attempt to understand the reasons why the KiwiBuild projects have not been successful so far. Subsequently, the reasons why the Kiwi Build project failed will be discussed. Based on the

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affordable housing policies used in Australia, recommendations will be made to improve affordable housing policies for New Zealand.

2 Literature Review

2.1 Understanding affordable housing

Housing affordability is one of the important indexes that measure the social and economic stability of a country. Affordable houses aim to ensure that the housing provided is affordable for low and middle-income groups of a country (Suhaida, Tawil, Hamzah, Che-Ani, 2011). However, the challenge of providing quality affordable housing which is sustainable has resulted in numerous policy interventions by many governments across the world (Fields & Hodkinson, 2018). The term “affordable housing” has recently gained popularity in Australia, which has both general and more specific meanings. The term is used to refer to the rental or purchase of housing that a family with limited means can afford. South Australia provides an example of defining affordable housing, as the regulatory set the price points and specify the types of buyers allowed. For example, affordable housing is provided for low and middle-income families (Milligan, Gurran, Lawson, Phibbs & Phillips, 2009).

2.2 Affordable housing in Australia

Enabling more people to buy houses would allow for a more comfortable life in terms of social, economic, and community aspects. When housing becomes affordable, foreign investment in housing also increases. This increased demand for housing promotes local economic development. In recent years, housing demand in Australia has decreased. The main reason is that spending by households has risen faster than the household income (Lowe, 2019). Therefore, most people can only afford to rent a house instead of buying with a mortgage. In the long term, this may negatively impact local economic development and adversely affects the local housing market at the same time. This emphasizes the need for affordable housing in Australia. In line with affordable housing policy, Australia has introduced affordable apartments that can potentially solve social and economic issues such as an ageing population, unbalanced supply and demand in the housing market, homelessness, low rates of employment and education-related issues (AIHW, 2018).

2.3 The housing market in New Zealand

New Zealand is a geographically isolated small island with a very small population compared with other developed countries. Therefore, New Zealand needs to have strong relationships with other countries in order for its economy to function. Under this global economic condition, New Zealand is easily and heavily influenced by other countries, particularly China, Australia and the USA (Kennedy, 2019). Similar to the Australian housing market, the housing market in New Zealand showed healthy development until 2016 when the average house price in Auckland peaked; after that time, it decreased slightly.

During the past 20 years, the New Zealand housing market has experienced massive overseas demand. One suggested approach was to significantly reduce foreign housing investment in order to reduce housing demand (Kennedy, 2009). As of mid-2019, after the New Zealand government published the overseas property purchase restriction policy (Land Information New Zealand, 2018), the increase in housing prices has started to slow down. It is clear that the New Zealand housing supply at this stage is not sufficient to meet the housing demand. In contrast, the New Zealand construction industry is small and conventional, characterised by a shortage of skilled workers, fragmentation and lack of innovation (NZIER, 2014), leading to inadequate housing supply.

As a demand-side solution, the changes to property investment regulations to reduce the attractiveness of rental investment was proposed by the New Zealand government. From a supply-side perspective, urban intensification was implemented to improve housing affordability in New Zealand (NZIER, 2015). A shift from conventional construction to more innovative practices such as off-site manufacturing, BIM and 3D printing technologies are also widely regarded as the way forward in terms of housing provision (Hargreaves, 2018).

2.4 Housing policy in New Zealand

In the past 30 years, New Zealand housing policies have gone through notable changes to provide better houses. Different areas of New Zealand have different housing strategies for local governments to follow. In 2007, the Christchurch city council published the Christchurch city council social housing strategy. Its primary purpose was to contribute to the community well-being by considering health and safety, accessible and affordable social housing for those in medium to low incomes and facing difficulties towards buying a house (Christchurch City Council, 2007). However, looking at housing policies across New Zealand,

it is evident that there are similar issues to address. The first issue is the undesirable implications of increasing homeownership rates such as increased mobility cost, losing the ability to move to better employment/other opportunities and an inflexible national economy (McCarthy, Rohe & Zandt, 2001). The second issue is the difficulty of controlling the supply of affordable housing to make sure that those in medium and low-income households have the ability to buy houses. The third issue is the challenge of limiting free-up regulatory constraints on new housing developments (Department of Building and Housing, 2010).

2.5 Comparison of affordable housing policies in Australia and New Zealand

The above sections revealed that the housing market in Australia has many similarities to New Zealand. There is a strong need to implement affordable housing policies in both Australia and New Zealand. In 2009, the Australian government implemented a successful non-profit housing development project in New South Wales, Victoria, and Western Australia. The success of this project was based on a secure and ongoing government capital investment program, as well as provision of a mechanism to raise and channel large volumes of private finance and consistent consideration of the building capacity in the delivery system (Milligan et al. 2004). The project also carefully planned and integrated government land to increase the housing supply (Milligan 2005). This policy was targeted to provide advantages for middle-income groups to buy houses. Similarly, Baqutaya, Ariffin and Raji (2016) suggested that the affordable housing policies needed to allow local banks to give advantages for middle-income groups to receive loans in order to buy affordable houses. Consequently, in the long term, the successful implementation of these policies would bring socio-economic stability in New Zealand.

2.6 The KiwiBuild project

In response to the growing concern of increasing housing demand and the number of homeless people, the New Zealand government released the KiwiBuild programme to build affordable quality houses within the next decade. Under the KiwiBuild project, the government planned to build 100,000 affordable houses over ten years with a 2 billion dollar budget, which requires higher levels of innovation and productivity in construction. However, the New Zealand construction industry is still characterised by

low productivity, a lack of innovation, high unemployment, skill shortages and poor quality output even though it is the largest sector of New Zealand's infrastructure and it continues to boom (MBIE, 2019; Mirus, Patel & McPherson, 2018). Due to low productivity, skill shortages and a lack of innovation in the construction processes, New Zealand still utilises traditional methods to build houses. This has significantly contributed to the imbalanced ratio of supply and demand in the housing market. This has brought the attention of implementing prefabrication as a way of increasing the housing supply. In announcing the KiwiBuild project, the housing minister said that half of the affordable houses would be refabricated (Mirus, Patel & McPherson, 2018). In this project, the government works with private developers and manufacturers to build and increase the supply of affordable houses. When the private developers are selected, the housing ministry looks at a number of factors such as financial capacity, price cap and quality standards that would determine the developers' ability to build quality houses within the competitive market (KiwiBuild, 2019). The first home buyers and private developers are connected to ensure that affordable homes are built.

Unfortunately, only a year after the KiwiBuild project was executed, many issues have arisen. Many people have shown a lack of interest in buying KiwiBuild houses due to their location, building facilities and styles that have not complied with public demand. Also, the KiwiBuild house prices are not considered as affordable for first home buyers (Wilkinson, 2019). It is believed that the government has miscalculated the budget of the KiwiBuild project and overestimated the construction efficiency, resulting in unrealistic plans (Edmunds, 2019). The senior fellow of the New Zealand Initiative and director of the Capital Economics, Wilkinson (2019) said the government should be required to release the supply of land for residential projects and reduce the construction costs. He also mentioned that if the KiwiBuild houses are continually built, the number of people renting and owning will increase, rather than increasing numbers of homeownership which is contradictory to the purpose of the affordable house policy (Edmunds, 2019). The National Party's Housing and Urban Development spokesperson Judith Collins has indicated that the average house prices are growing by 1% and three-bedroom KiwiBuild houses in Auckland have increased by up to 8% (The National Party, 2019). This means the purchasing prices have increased faster than the wider market. If the

demand for KiwiBuild houses significantly decreases, this project might be facing failure in the near future. Many experts have provided their views on improving the KiwiBuild programme and dealing with the housing crisis in New Zealand. The Chief Executive Officer of the Property Institute of New Zealand, Church (2019) said the government would need to review the whole KiwiBuild policy and write a conclusion to identify the key problems associated with this programme. A professor from the built environment engineering department at AUT University said the market is trending towards building the wrong type of properties. He suggested that building single-storey buildings over two-storey houses can cut down the additional cost of structural engineering and scaffolding (Tookey, 2019). A lecturer in urban economics at the University of Auckland says that providing more land and houses does not provide affordable houses (Fonseka, 2017). Many experts including the members of the Real Estate Institute, economists, university lecturers and members of the Auckland Council have warned that increasing building fees (building control and resource consent fees) would significantly contribute to increasing housing prices (Bhatia, 2019). Edmunds (2019) reported that according to the solutions provided by experts; the government needs to reduce house manufacturing and construction costs by cutting down the price of land through appropriate regulations, fixing the infrastructure funding model and promoting prefabrication.

3 The research process

This research paper primarily used a qualitative approach. Qualitative information was collected from 30 articles. The 30 research articles included topics such as the importance of affordable housing in general, affordable housing policies in Australia and New Zealand, the current housing market condition in Australia and New Zealand and the KiwiBuild project. Further, the research papers included information about the KiwiBuild project and suggestions by subject matter experts to prevent the collapse of KiwiBuild. The qualitative information collected was analysed based on the research objective established in section 1.

4 Findings and discussion

The study found that the housing policies in Australia have many similarities with the policies in New Zealand. In the past ten years, the housing policies of both countries aim to provide safe and comfortable apartments for low and

medium-income people. Both countries provide a subsidy for local people who wish to purchase their first home. However, in Australia, several local banks support providing a preferential loan policy for first home buyers (Milligan, Gurrán, Lawson, Phibbs & Phillips, 2009). For example, some banks offer preferential loans for low-income first home buyers with low interest. Australia has a stringent housing policy for foreigners. Houses purchased by foreigners only can be used for self-occupation rather than renting out. The Australian government significantly taxes foreigners when they purchase houses. First-time home buyers in Australia are protected with subsidies based on housing policies. The relationship between demand and supply in the Australian and New Zealand housing market is presented in Table 1.

Table 1: A comparison of housing demand and supply:

Australia vs New Zealand

	Demand	Supply
New Zealand	The demand for housing has increased over the past ten years. In 2019, the increasing housing demand in Auckland slowed down. The rest of New Zealand’s housing demand continues to increase at a higher rate than before.	Small private developers play a vital role in housing supply. From 2018, the New Zealand government has increased the government’s contribution to affordable housing through the KiwiBuild project.
Australia	In the last 10 years, foreign buyers have played an essential role in housing demand in Australia. Housing demand for Australians has, however, significantly decreased.	From 2013-2015, the Australian housing market showed a shortage of housing supply. However, from 2016, the housing supply significantly increased, which resulted in a decrease in renting apartments.

Affordable housing is a substantial problem in New Zealand. The construction industry is characterized by low productivity, skill shortages and a lack of innovation, which has led to increasing house prices. The housing crisis in New Zealand has contributed to social issues such as homelessness. Therefore, the housing crisis needs immediate attention and solutions. The Minister of Energy and Resources of New Zealand suggested that affordable house prices should be around NZD 500000. However, average KiwiBuild houses are priced above this figure. Many subject matter experts (SME) say that the New Zealand government has not carefully planned the

KiwiBuild project. The government has primarily focused on increasing the housing supply (Fonseka, 2017), which was unable to result in affordable houses. KiwiBuild house prices are increasing faster than the wider market, which is far removed from the concept of affordable house prices. Therefore, the KiwiBuild project has not delivered the expected project outcomes of its first year. SMEs say that high land and construction costs have led to an increase in house prices.

The SMEs suggests that the government should take consideration of financial assistance, current supply chain and the current state of the construction industry to rectify the major issues with the KiwiBuild project. It is suggested that the New Zealand government needs to look at the successful affordable housing policies implemented in Australia to carefully define the concept of affordable housing. The government needs to work together with the housing supply chain and the industry to reduce construction cost. The construction industry needs to implement lean construction which can increase productivity and construction cost savings. It is important that the government redirects their focus from the number of affordable houses to the affordable housing policy that has a sustainable vision. As successfully implemented in Australia, the Reserve Bank of New Zealand (RBNZ) needs to reduce the Official Cash Rate (OCR) of interest, which leads the banks to charge lower interest rates on borrowers. RBN needs to encourage and give preferential policies for developers to build affordable houses. At the same time, an affordable housing policy needs to continue to make exemptions regarding foreign buyers, enabling affordability for first-home buyers in New Zealand.

5 Conclusion and recommendations

The continuous increase in house prices has dramatically decreased housing affordability in New Zealand. Despite the fact that the construction industry plays a key role in the New Zealand economy (8% contribution to GDP and the 5th largest sector by employment), the industry currently faces issues of low productivity, skill shortages and a lack of innovation. The nature of the construction industry means that it has a very close connection with the housing market. The high cost of construction together with a tight regulatory environment significantly contributes to the housing crisis. In this environment of unaffordable housing, the number of people renting will increase. The New Zealand government initiated the

KiwiBuild project in 2018, which aimed to provide 100,000 houses over 10 years within a \$2 billion budget, for first home buyers. After the government released the Kiwi Build program, many people believed that the policy would provide them with an opportunity to own a house. However, based on the KiwiBuild eligibility criteria (e.g. the couples who earn up to \$180k per year), some people still find that it is difficult for them to buy a KiwiBuild house, which was one of the main reasons why the public was disappointed with the government's affordable housing policy. SMEs believe that the KiwiBuild project is not aimed at low-income families who cannot afford their first home loan due to high KiwiBuild mortgages. Prior literature and SMEs show that the KiwiBuild program is at-risk. The delayed project is characterised by low productivity and over-budgeting. It is recommended that the government reviews the whole project and makes necessary amendments to make sure that the project can progress in the right direction.

It is recommended that the government re-plans urban land to make more land available for residential use. Lower interest rates on loans need to be provided in order to help private developers build affordable houses. Another suggestion is to adopt construction innovation which can help the construction industry develop and progress rapidly. For example, prefabrication could be a solution that would provide high production efficiency with increased construction quality. In addition, lean construction needs to be promoted as an innovative construction process to reduce unnecessary expenditure and reduce construction costs. Small and medium construction companies need to be encouraged to join the design and construction stages of the KiwiBuild project. The New Zealand government's active contribution to resolve this issue is vital as there is a strong need for investing in infrastructure requirements to facilitate building affordable houses. However, the government alone will not be able to provide affordable houses for New Zealanders. The members of the construction industry across the housing supply chain need to collaboratively work with the government. In a broader view, a large-scale development that is driven by simplicity, standardisation, innovative methods in the construction process, regulations, resource management act (RMA) and the consenting process needs to be established. Thereby, through a public and private sector partnership, a wide range of houses can be built to cater to the affordable housing crisis. To sum-up, in order to

resolve the housing affordability issue in New Zealand, it is important to consider the combination of the construction sector, people's incomes and house prices.

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A Review of Innovative Approaches to Rebuilding Following Large-scale Natural Disasters: A Case Study of Post-earthquake Christchurch, New Zealand

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ABSTRACT

Following Canterbury earthquakes 2010-2011 New Zealand government adopted new ways to rebuild the city. Given an opportunity to find solutions to pre-existed issues in the city, the government was keen to rebuild faster and better. The blueprint that was finalized in mid-2012, had 17 anchor projects to lead its rebuilding efforts along with governance and legislative changes to facilitate rebuilding. Drawing on past literature using the case study of Canterbury earthquakes 2010-2011, this paper reviews the rebuilding process in Christchurch. The study suggests there were limitations to the effectiveness of the processes due to the complex post-disaster environment. Literature provides evidence that the innovative rebuilding efforts suffered from time-pressure to rebuild resulting in hasty planning. Legislative and governance changes had limited impact due to incoherence between public agencies and ambiguity of roles and responsibilities. The final plans had limited public input irrespective of lengthy consultation. Evaluation of literature proposes that the changes adopted should have strategic relevance to ensure the final outcomes are accepted by the public. It is recommended that future research focuses on implications of post-disaster rebuilding practices on the wider community, businesses and the government.

Keywords: Anchor projects, Canterbury earthquakes 2010-2011, Christchurch Central Recovery Plan (CCRP)

1 Introduction

New Zealand, given its geographical setting, is especially susceptible to extreme and adverse weather conditions including flooding, landslides, volcanic eruptions and most importantly earthquakes. The country faced one of the worst earthquake sequences of its history from 2010-2011. The first significant earthquake with a magnitude of 7.1 occurred in 2010, 40km west of Christchurch and resulted in water, power and sewerage services being disrupted. With many aftershocks in between, the next and the most severe earthquake followed in 2011, 10km South East of Christchurch recording 6.3 on the Richter

scale, causing extreme damage and destruction to land, building and infrastructure in the central city and the surrounding area (Potter, Becker, Johnston, & Rossiter, 2015).

At the time, reporters and researchers, referred to Christchurch earthquake (2011) as the worst natural disaster for 80 years of the history of New Zealand (British Broadcasting Corporation, 2011; Telegraph, 2011). It took 185 lives and injured several thousands (Davies, 2011; Gillespie, 2019). It is believed many of the deaths were caused by falling structures that were damaged as a result of the previous earthquake in 2010 (Potter, Becker,

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Johnston, & Rossiter, 2015). It is the costliest natural disaster for insurers worldwide since 1950 and it was estimated that the overall cost of the damage caused by the earthquake was equivalent to around 20% of the NZ Gross Domestic Product (GDP) at the time (Potter et al., 2015).

Given the scale of the catastrophe and the devastation caused by it, central government of New Zealand formulated a city-wide rebuilding plan named 'Christchurch Central recovery Plan' (CCRP) that constituted of 17 public projects that were to lead the public rebuilding initiative following disaster. Prior to designing the blueprint, the planners identified that Christchurch had excess supply of bare land in the CBD, incoherence between buildings, a multiplicity of vehicles entering the city center yet with limited available car parks (Canterbury Earthquake Recovery Authority, 2012). Christchurch City Council (CCC), prior to the earthquake, had intentions to revitalize the city to match the likes of Copenhagen, Dublin and Milan (Blundell, 2014). The planners viewed the opportunity to rebuild, as a second chance to remedy the issues within the central city. This called for new rebuilding approach than is the norm in NZ, following large scale disasters.

2 Research Method

Even though innovative practices were incorporated to the rebuilding processes in Christchurch specifically to speed up anchor projects and other rebuilding work, some of the novel practices have failed to deliver the expected outcomes. Therefore, this paper aims at reviewing literature on the innovative approaches to rebuilding in the aftermath of Canterbury Earthquakes 2010-2011. The paper will first introduce literature related to the processes adopted after disaster followed by a review of the process and outcomes of these practices adopted.

Finally, the paper will suggest possible future research directions.

3 Review of literature on innovative rebuilding

EQ Recovery Learning (2019) emphasized that "the disaster destroyed the box so ... have to think outside the box. There is a unique chemistry of circumstance that supports new thinking and ways of doing things". As a result, new tools and approaches to rebuilding were adopted under new legislative and governance frameworks. The most notable ones include:

- Canterbury Earthquake Recovery Act (CER Act) to facilitate rebuilding
- Canterbury Earthquake Recovery Authority (CERA) to lead rebuilding
- Christchurch Central Development Unit (CCDU) to deliver the 17 anchor projects in the CBD
- Christchurch Central recovery Plan (CCRP) constituting of key redevelopment projects
- Anchor Projects as the prime rebuilding artefacts

Literature used for the review, constitutes of government reports, CERA archived documents, independent reports and academic publications.

3.1 Legislative background prior to deciding upon anchor projects

The first major earthquake of the sequence that occurred on 04 September 2010, resulted in the first ever local state of emergency being declared (Canterbury Earthquake Recovery Authority, 2011; Parliamentary Library, 2010). Within two days, the Prime Minister appointed a Member of Parliament solely responsible for the recovery work following the earthquake to send a message of commitment to recovery and rebuilding (Brookie, 2014; Parliamentary Library, 2010). The government had limited authority to influence the decisions of local councils which was perceived to have a crippling effect on rebuilding. Within 2 weeks of the appointment of the minister, new

legislation was passed in the form of Canterbury Earthquake Response and Recovery (CERR). This was justified as needed to avoid bureaucracy and to speed up recovery (Johnson & Mamula-Seadonb, 2014).

Ten days after the earthquake, the Canterbury Earthquake Recovery Commission (CERC) was established under the CERR Act to act as the advisory board to identify and inform of barriers to recovery and priorities of the process, to enable better coordination between local and central governments, that allowed for orders-in-council to the minister (Canterbury Earthquake Recovery Authority, 2011; Greater Christchurch Group, 2017; Johnson & Mamula-Seadonb, 2014).

3.2 New legislation to allow for speed of anchor projects deployment - Canterbury Earthquake Recovery (CER) Act

However, 22.02.2011 earthquake was much worse in scale and damage. With just two months to go before the expiration of existing orders-in-council Canterbury Earthquake Recovery (CER) Act replaced the existing CERR act with greater powers to override several local council plans and resource consents granted under the Resource Management Act (Office of the Auditor-General, 2017). The CER Act gave CERA the power to change or revoke statutory plans, demolish buildings to make space for the blueprint plan and to acquire land to make way for the anchor projects. Minister of Canterbury earthquake recovery was given legislative power to bypass most New Zealand laws to achieve reconstruction objectives (Brownlee, 2012; Canterbury earthquake Recovery Authority, 2016b; Office of the Auditor-General, 2017).

As a result of these powers, a recovery strategy was in place at the end of 2011. The non-influential role of an advisory body without any statutory power such as CERC, was seen to be futile in the aftermath of a disaster of the scale of Christchurch earthquake 2011 (Greater Christchurch Group, 2017). Hence, a new government department with legislative powers overriding any other

legislation in place, was established (Canterbury earthquake Recovery Authority, 2016b; Office of the Auditor-General, 2017).

3.3 A dedicated governmental department for rebuilding - Canterbury Earthquake Recovery Authority (CERA)

According to the United Nations, the main objective of establishing a recovery agent following a disaster should be, to manage the recovery processes through better collaboration between a wider group of stakeholders. It further added that the new arrangement should be rapidly implemented yet be in unison with the existing good governance practices and institutional arrangements. According to Olshansky and Johnson (2014), Thiruppugazh (2014) and Smart (2012) it is common practice to establish an authority after every large-scale natural disaster due to the realization of lack of existing capacity of the authorities and due to the need to return to business as usual for the government agencies. Boin and 't Hart (2010) added that often the government's conduct falls short of expectations especially in managing strategic and operational decisions that are called for during disasters.

On 24 March 2011, just over a month (35 days) after February 22, 2011 earthquake, the government established an innovative organizational framework to lead the rebuilding work, specially the 17 anchor projects that were proposed. Handing over the rebuilding responsibility to an independent authority following a disaster has been practiced elsewhere in the world such as Victoria Bushfire Recovery and Reconstruction Authority following Victoria Black Saturday Bushfires, 2009 and Louisiana Recovery Authority (LRA) following Hurricane Katrina, 2005 and Queensland Recovery Authority (QldRA) following Queensland Floods, 2011. CERA was created as a government department following the example of QldRA but with a different institutional framework. The minister, as a member of the cabinet

indicated more direct control over the rebuild. CERA was a novelty response approach as it was the first time a disaster recovery agent was established closer to the disaster point (Office of the Auditor-General, 2017).

CERA was set up to lead a coordinated response to the earthquakes. Main responsibilities of CERA included;

- To lead and coordinate recovery efforts together with Greater Christchurch, the councils and the communities to ensure timely and effective outcomes
- To handle projects and programmes that are significant to the process (including demolitions and purchase of properties to facilitate the blueprint
- To administer the Act
- To establish and monitor the progress of the recovery process

(Canterbury Earthquake Recovery Authority, 2011)

CERA, given its powers, had the authority to buy land from private landowners and to demolish unfit buildings to allow for anchor projects, formulate a blueprint plan with anchor projects to rebuild the CBD with the ideas from Christchurch City Council's draft recovery plan (Canterbury earthquake Recovery Authority, 2016b; Office of the Auditor-General, 2017; Smart, 2014b).

3.4 A subdivision to prepare a blueprint for the central city – Christchurch Central Development Unit (CCDU)

CERA and the minister of Earthquake Recovery understood that much of the city's rebuilding and recovery was based on the development of anchor projects (Brownlee, 2012). People had lost faith in redevelopment having witnessed demolitions and slow progress for over a year.

CCDU had the main responsibility of formulating a blueprint plan for recovery with the assistance of Christchurch City Council (CCC). CCDU was established as a unit within CERA in April 2012 which was then responsible for the delivery of the blueprint plan

(Brownlee, 2012; Canterbury Earthquake Recovery Authority, 2016a; Office of the Auditor-General, 2017). It was tasked to facilitate the delivery of these projects by streamlining consent processes and coordinating all 17 projects whilst identifying links between them and promoting the city and its developments to attract investors (Canterbury Earthquake Recovery Authority, 2016a). Location identification, concept development and draft design, stakeholder management and promotion of anchor projects were among its main tasks (Brownlee, 2012; Canterbury Earthquake Recovery Authority, 2016a, 2016b).

3.5 A public-led recovery plan - Christchurch Central Recovery Plan (CCRP)

A report to the cabinet committee by the minister for Earthquake Recovery explained the reasons for new legislative changes, powers of CERA as a result of those changes and the duties resting upon CCDU within the changed rebuilding framework (Office of the Minister for Canterbury Earthquake Recovery, 2012). The minister of Earthquake Recovery allowed CCDU 9 months to prepare a recovery plan for Christchurch CBD. The minister proposed that a recovery plan be formulated prior to a recovery strategy in order to speed up the process by using the draft plan made by CCC using the public input (Office of the Minister for Canterbury Earthquake Recovery, 2012).

The idea generation for CCRP was exceptional with regards to the extent of public input into the process. 10 weeks following disaster, a website –shareanidea.org.nz was developed. The website sought contributions towards

- The use: What activities they would do in the city? How would they want to get from one place to another within the city?
- The composition: What businesses and public places they want to see come back into the city? how they would want to move about the city

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- The means: How can the city attract people back?

Additionally, ideas were sought through twitter, Facebook, drop-off boxes at University of Canterbury, Christchurch Polytechnic and at the community expo where a range of means to express their ideas were made available (post-it notes, Lego, filling in a questionnaire or going online). Schools were encouraged to contribute ideas and there were 10 public workshops educating people about the process to make the public a part of rebuilding the city (Greater Christchurch Group, 2017). Electronic media was also used in the campaign (YouTube, radio and TV advertising, E newsletters) along with traditional print media such as newspapers and tabloids posted to home addresses of 160, 000 residents in the CBD (Greater Christchurch Group, 2017; Johnson & Olshansky, 2016). All of these means generated over 106,000 ideas to rebuild the central city. Furthermore, over 100 stakeholder meetings were held business representatives and individual organizations. With the former, the meetings were regular and more in the form of workshops. An engagement initiative called the 48-hour challenge was open to professional institutes and various interest groups to submit their ideas for central city redevelopment (Greater Christchurch Group, 2017).

These efforts were a result of ministerial briefing papers stressing the significance of incorporating public input into the recovery plan from early stages for a novel and collaborated effort to rebuilding (Office of the Minister for Canterbury Earthquake Recovery, 2012)

A draft plan was released within 100 days by taking the input from the public through the aforementioned idea-generation activities. The exercise was a holistic approach involving urban planners (Boffa Miskell), architects (Warren and Mahoney, Populous, WoodsBagot and Sheppard and Rout) and consultants (RCP), to identify anchor projects based on CCC draft, locate them in the

CBD and establish strategic links between them and to provide guidelines for surrounding areas (Canterbury earthquake Recovery Authority, 2016b; Canterbury Employers' Chamber of Commerce, 2016) The final revised version of the blueprint was publicised in July 2012 with details around the 17 anchor projects. (Brownlee, 2012; Canterbury Earthquake Recovery Authority, 2012, 2016a)

3.6 Anchor Projects as primary rebuilding artefacts

The blueprint constituted of 17 key projects that would lead the rebuilding initiative of the government. These were addressed as 'anchor' projects.

The term 'anchor' projects were commonly used when referring to mega projects that had been planned for Christchurch post-earthquakes. Similar projects are commonly addressed as Priority projects (Novoselov, Potravny, Novoselova, & Gassiy, 2017; Zinovyeva, Pryadilina, Semin, & Skvortsov, 2019) Flagship projects (Loftman & Nevin, 1995; Oyeyoade, Agboola, & Odebode, 2019; Smyth, 2005; Vazquez & Vazquez, 2016) or Catalyst projects (O'Neill, 2015; Roberts Day, 2009; Smart, 2014a) in literature dealing with similar projects to those that are designed for Christchurch.

Otakaro Limited (2019), the company responsible of handling all crown-led regeneration projects in Christchurch after CERA was disbanded, defined anchor projects as those projects which aim to attract people into the city and create opportunities for related establishments to blossom due to their existence in a given location (See Image 1). These projects once completed will be known as places to live, work and visit (Canterbury Earthquake Recovery Authority, 2012). The definition is implying a spill-over effect where the key buildings once established will pave way for other businesses to take root in and around the area.

A similar definition is given by the Victoria Bushfire Reconstruction and Recovery Authority (VBRRRA).

According to the authority, Catalyst projects have an economic significance because they stimulate economic activity that will steer economic recovery by attracting private investment for regeneration of the destroyed cities (Roberts Day, 2009). The location of these projects will determine the extent of return from these projects, be it increased employment opportunities, private

investment land prices or improved inner-city accessibility (Loftman & Nevin, 1996; Smyth, 2005). These projects have underpinning spin-off benefits of creating more employment, bringing in new private investments and also can signal a positive business environment that would stimulate growth (Loftman & Nevin, 1995).

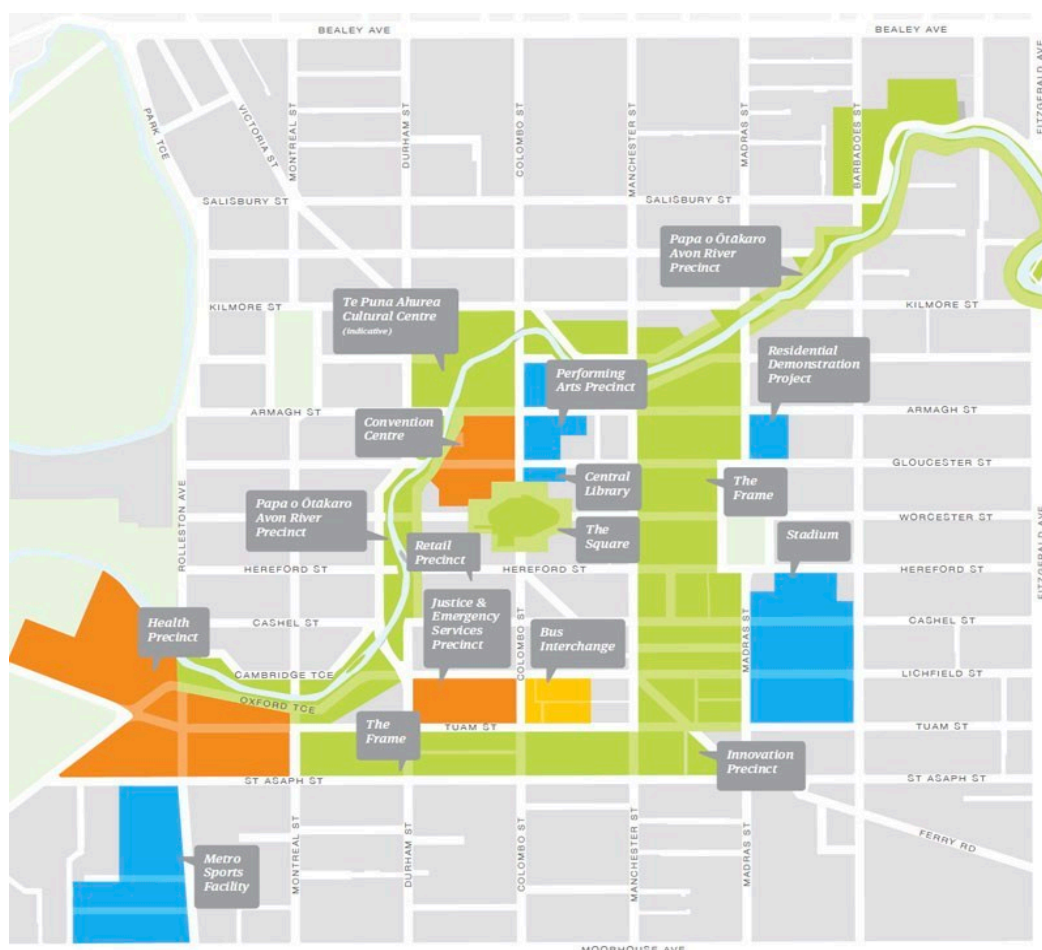


Image 1: Anchor projects in Christchurch CBD

The legislative powers of CERA facilitated the rapid deployment of these buildings allowing the Minister to truncate the process of designating land under the Resource Management Act 1991. The significant effects of the designation were that the landowners had to abide by the wishes of CERA to obtain their lands (either by voluntary agreement or compulsory acquisition) and waive off on the provision of land use consents (Canterbury Earthquake Recovery Authority, 2016a,

Source: Christchurch Central Recovery Plan (CCRP)

2016b). Furthermore, there were restrictions in place, to construction work within the CBD as the first priority was anchor projects (Sheppard, 2014). The government perceived that it was necessary to get the city going again before investors return (Wilkinson, Crampton, & Krup, 2018). These actions were deemed necessary to unveil the plans in place for Christchurch.

Convention Centre, Avon River Precinct, The Frame and the Metro Sports facility were indicated as the first

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projects that would be built to ensure the plan meets its objectives of bringing people back to a more compact CBD that facilitates 'Live, work and Play' concept of CCRP (Canterbury Earthquake Recovery Authority, 2012).

4 Analysis and Discussion

4.1 Changes to government legislative and governance frameworks

According to the views of Thiruppugazh and Olshansky (2014), an authority which takes over the responsibility of recovery work following a disaster, handles challenges better and the rebuilding process is proven to be more efficient and effective. If an existing government body handled the recovery phase following an emergency, it may have conflicting priorities that may divert resources away from recovery. The former also emphasized that the establishment of such an authority sends a public message of dedication and commitment to rebuilding.

Following the 2010 earthquake, CERC was established to allow for better coordination between the central and local governments. However, CERR act faced problems from residents that the recovery was too slow, with rigid processes, unnecessary haste over planning and lacking detail around the establishment of CER Act and the CERC (Brookie, 2014; Greater Christchurch Group, 2017; Johnson & Mamula-Seadonb, 2014). There was much criticism about CERC not having any influence over the recovery process that was mainly led by local authorities. CERC was established as an advisory body or as a representation of the government and a communicator of government decisions (Brookie, 2014).

The governance and legislative changes after the 2010 earthquake were perceived to be flawed. Firstly, the general public was uncertain about the recovery governance process and how the individuals and businesses can contribute positively to the recovery process. This was mainly a result of poor community engagement (Johnson & Mamula-Seadonb, 2014). Secondly, a clear understanding of roles of CCC and CERC

was not achieved. The passive role of CERC was understood to be linked to top level positions remaining undefined and vague in terms of roles and responsibilities (Brookie, 2014; Glavovic, 2014). These issues brought the recovery to a standstill (Greater Christchurch Group, 2017; Johnson & Mamula-Seadonb, 2014).

As a result, when CERA replaced CERC after 2011 earthquake, the emphasis was to facilitate an active lead in the recovery by taking advantage of its statutory power. However, the following are identified as factors limiting the effect of CERA and its rebuilding unit, CCDU.

4.1.1. Absence of a proper legislative framework

Firstly, rigid legislative framework delayed setting up CERA, which in turn slowed down the transition from response to recovery (Simons, 2016).

Secondly, due to the liberty to make decisions CERA had performed well during recovery-initial 6 months. However, in the reconstruction phase, most government departments that work alongside recovery authority go 'business as usual' and CERA suffered from coordinating issues (Controller and Auditor General, 2017, Wilkinson, Crampton, Krupp, 2018). CERA's role and responsibilities became a blur when it had to work with 33 public (national and local government agencies) and private entities (Office of the Auditor General, 2017). Complex and expanding role thus limited CERA's effectiveness as a rebuild agency.

4.1.2. The team and its direction

International best practice suggests having a layer of governance between the recovery agency and the ruling political party but CERA was established as a government department therefore the mechanism was seen as 'untried' and 'untested' recipe that New Zealand was trying (Greater Christchurch Group, 2017).

In terms of composition, the team was made of personnel belonging to different government bodies, who had taken temporarily roles with in CERA. These people most often

were directly affected by or witnessed the disaster and possessed local knowledge (Canterbury earthquake Recovery Authority, 2016b; Office of the Auditor-General, 2017). This strength became irrelevant when the authority failed to clearly communicate the job descriptions to CCDU staff. CCDU staff had previously voiced their concern over the role of CCDU and how it would differ from that of CERA (Office of the Auditor-General, 2017). CCDU is further criticized of lacking commercial know-how that was necessary for anchor project deployment.

In terms of the structure, CERA had a flat organizational structure where teams were reporting to the CEO separately (Office of the Auditor-General, 2017). Absence of an hierarchy allowing people in control to make speedy decisions lead to smoother and effective communication than a tall structure (Smart, 2014b). CCDU being a unit within CERA reported directly to the minister creating complex structural issues. Furthermore, its structure meant that CERA's actions overrode the local planning and created power struggles between the local and national governments delaying the arrangement of funds for the projects (Office of the Auditor-General, 2017). Later in 2012, CERA's lean structure changed to that of a matrix to facilitate the delivery of projects.

The new structure was adopted because it was thought to be more in line with the recovery framework followed by the New Zealand government. It helped enhanced knowledge management by facilitating information sharing. Cross team reporting also paved way to multi-disciplinary ways of working. Key staff was often rotated and therefore became more knowledgeable about the task at hand and were at ease working for a temporary unit due to variation of work. On the negative side, under the new structure the staff had to report to more than 1 manager and received conflicting messages from different managers. There was also uncertainty about decision-

making or ownership of certain decisions that were made (CERA Recovery Learning, 2016).

4.1.3. Absence of longer-term view

CERA's autonomous power with the decisions to demolish and acquire private land to be used for reorganizing of the CBD resulted in backlash from general public whilst creating regime uncertainty. Restricting individuals and businesses to rebuild their homes and business until the city plan was decided meant that people shifted away from the city into outskirts (Williamson, Crampton and Krupp, 2018).

Furthermore, CERA did not have a clear plan or certainty of what it hoped to achieve at the end of its lifetime. However, in 2014, CERA made a transition plan to ensure other agencies pick up from where it left (Controller and Auditor General, 2017). Some researchers therefore appreciate, including a legacy team to the teams that operate within these authorities to ensure smooth transition of remaining workload.

4.2 CCDU as a subdivision of CERA

CCDU was put in place to make sure the 17 projects happen to plan. However, even though the blueprint plan was in place by mid-2012, repetitive aftershocks, delay in developing individual business cases, land acquisition for anchor projects, land remediation work and funding arrangements meant the quick turnaround of projects that was expected took longer (Greater Christchurch Group, 2017; Johnson & Olshansky, 2016; Office of the Auditor-General, 2017).

Office of the Auditor-General (2017) highlighted the importance of Programme Management after a disaster due to resource limitations. The office understood that each of the anchor projects as well as the blueprint as a whole had very vague business cases specially around resource management, governance, Programme responsibilities of CERA and CCDU (Office of the Auditor-General, 2017). Until 2014, there were much uncertainty

surrounding funding of anchor projects and programme management. In 2014, a Programme Management Steering Committee and (PMSC) a Programme Support Office (PSO) were established by CCDU to fill the void (Canterbury Earthquake Recovery Authority, 2016a; Office of the Auditor-General, 2017). Due to the absence of a PSO until 2015, ignoring cost efficiencies across projects with short-sighted scope and benefit changes drew criticism from the general public.

4.3 CCRP as the planning tool for recovery

4.3.1. Hasty planning

The government publicized that public engagement and input were the foundation for CCRP and ran an intensive opinion gathering programme stretching over more than three months (Office of the Minister for Canterbury Earthquake Recovery, 2012). Ironically, a strategic plan for

the urban setting of Christchurch was only allowed 100 days. The plans once confirmed did not offer certainty around ownership of projects (e.g. who is going to own and operate the convention Centre?) or structural relevance (e.g. How the green space (the Frame) will be realized?) (Sheppard, 2014)

4.3.2. Public engagement

It is universally accepted that public involvement and local knowledge are important elements to be fed into the decision-making process for urban development following a disaster (Burby, 2003) which ensure high quality planning (Burke, 1979). However, irrespective of such consultation, it was evident that the government went ahead with its own plan for recovery (See Image 2).

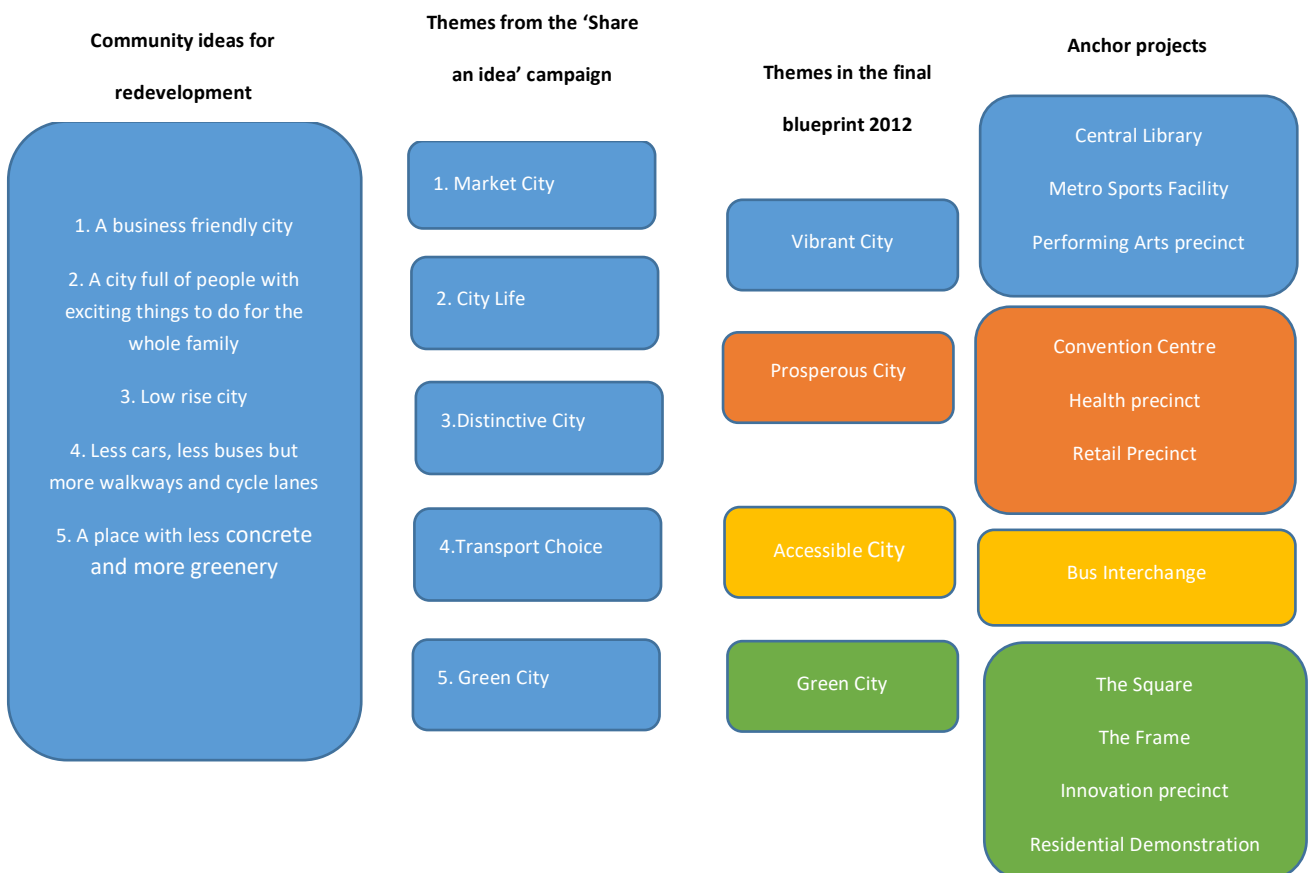


Image 2: Evolution of themes from idea generation to the final version of CCRP

The significance of CERA's opinion gathering exercises for the formation of the recovery plan diminished when the final version of the blueprint was released. Some felt that the final version was a mere selection of projects off the Christchurch City Council draft plan of February 2010 (Menzies, 2015). Transport related rebuilding was put down as secondary. Proposals such as Light Rail network, One-way to two-way street conversions were scrapped. The minister expressed the need to consider implications of some proposals such as

one-way to two-way street conversions and light rail. These were considered time-consuming exercises, given their strategic nature.

Hirschman (1970) emphasized that mere participation without any power to affect decisions may lead the citizens to exit the recovery process, weakening the information base for long-term strategic planning. As a result, some of the projects are considered little relevant to Christchurch but seem to serve national goals of development (Brand & Nicholson, 2016).

4.3.3. Review, monitoring and control of plans

Even though Office of the Minister for Canterbury Earthquake Recovery (2012) recommended keeping the blueprint as the guide to recovery, the plans were never reviewed or revisited.

In terms of Monitoring, the strategic direction was not set until about a year post-disaster (Canterbury earthquake Recovery Authority, 2016b). However, project and programme controls were in place. Blurred strategic direction was mainly due to the staff not having worked in a Project management or government background prior to the earthquakes and as a result the manual was not fully embraced. (Canterbury Earthquake Recovery Authority, 2016a, 2016b). It was amended in 2014 and that improved CERA's overall performance CCDU reported that internal reports, project briefs, weekly status updates to the minister and programme concept reports were on paper as monitoring and control measures but CERA produced its first progress report in 2014 after almost 3 years in operation (Canterbury earthquake Recovery Authority, 2016b). Lack of reporting caused missed milestones, unclear expectations and changes in scope. It was also understood that CERA's ever changing role made it difficult to keep to the promised timelines.

4.4 Anchor Projects

The legislative changes, establishment of CERA and the designing of CCRP all had a significant role in making sure anchor projects are established fast so that the city can recover economically.

However, to date, only 5 projects have been completed in full out of the 17 projects proposed by CERA with the first project being completed in 2013 (See table 1). The sequence of the projects by priority has been missed and all 4 projects that were to be built first are still under construction.

The delay of anchor projects has been associated with CERA giving priority to demolition work, Christchurch Central Development Unit (CCDU) as the responsible entity

for anchor project lacking commercial expertise, delay in purchasing land for anchor projects, delay in arranging funding, overoptimistic budget and timeframes, lack of detailed business cases for individual projects and lack of programme management (Office of the Auditor-General, 2017)

Table 1: Status of anchor projects

Name of Project	Status
The Frame	Mostly complete
The Earthquake Memorial	Completed in February 2017
Cultural Centre	Scrapped
Avon River Precinct	Partially completed with the first phase completed in 2013. Avon Loop repairs are ongoing
The Square	In construction
Retail Precinct	Partially completed and opened to the public
Convention Centre Precinct	Scheduled to open in October 2020
Health Precinct	Partially completed with construction of acute services building underway.
Justice and Emergency Services Precinct	Completed in September 2017
Performing Arts Precinct	Planning with the land to build the theatre secured
Central Library	Completed in 2017
Residential Demonstration Project	20 homes complete, out of the proposed 900 townhouses and apartments
Metro Sports Facility	Construction
Stadium	Planning stage with a business case being commissioned in 2018
Cricket Oval	Completed in September 2014
Bus Interchange	Completed in May 2013
Innovation Precinct	Partially completed with some tech related organizations occupying the space.

5 Conclusion

Literature reveal that, a disaster does not allow for normal project processes. Innovative practices adopted by the government following Christchurch Earthquake 2011 reflect some effective approaches to rebuilding. Facilitating quick turn-around of projects through changes to legislation, having a novel approach to rebuilding with a blueprint of key projects, engaging in public consultation for projects from the outset have worked well for the government initially. However, 8 years post-disaster the end objective of anchor projects leading the rebuilding

has lapsed due to, limitations in terms of timing of projects, prior planning and coherence between each governance and legislative practice, underdefined roles of main recovery agents and stakeholders. Even though legislative frameworks were adopted to facilitate quicker deployment of anchor projects, rigid public sector work patterns delayed quicker decisions in establishing CERA and arranging for prerequisites for building of anchor projects. The public engagement initiatives by CERA are praiseworthy yet these never made a significant contribution to the final version of CCRP leading people to lose faith in government intentions. Prioritizing of anchor projects and having arrangements to incorporate private investment along with these public rebuilding initiatives would have helped the investors gain more confidence in rebuilding. Some coherence between each of the steps of achieving an envisioned urban landscape is recommended. The evaluation reveals the need for further research to understand the implications of these innovative approaches post-disaster, on the community, businesses and the government.

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Urban Resolutions - Auckland and Vancouver comparisons

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ABSTRACT

The topic of Urban Resolutions is a research piece on Auckland's urban plan, with the inclusion of heritage builds for reuse or repurpose. An international comparative analysis with Vancouver's EcoDensity initiative was conducted, to establish whether that model or a similar one, might work for Auckland city; bearing in mind Auckland's unique landscape and culture.

The key Research Question was - 'How does Auckland Supercity intend to integrate a feasible and well-structured urban plan, that includes its heritage buildings?' This question was derived from a sense that there is a general lack of knowledge, regarding the continuous development of Auckland. In addition, there are the complications which occur in communities, when large cities such as Auckland become disconnected. By including the historic buildings in the research, this highlights the opportunities of restoration, to create new uses for heritage to suit today's lifestyles within society.

This research was conducted by undertaking qualitative semi-structured interviews with design and urban planning professionals within the construction industry, that were based in Auckland and Vancouver. This enabled access to experience and knowledge within their individual fields and their unique case studies in which they have been involved.

Auckland is large and growing rapidly, and this research gives an overview into the city's current status and attempts to highlight the obstacles that Auckland faces. Overall, undertaking this research, into 'urban resolutions', has provided an opportunity to open up discussion and review – of what makes a city liveable, and how communities can be created by developing usable integrated spaces, which in turn help form relationships.

Keywords: Global comparisons, Heritage buildings, Integration, Regeneration, Urban planning.

1 Introduction

Auckland's urban plan, with the 1.5 million + residents and continuously undergoing growth, suffers from 'suburban sprawl', a lack of infrastructure to support new developments, and an associated strong sense of disconnection from the city. The following statement from Latham still applies to Auckland today.

'New Zealand's cities are profoundly suburban cities' (Latham, 2000, p. 285)

Heritage buildings are often overlooked for their potential in creating a unique space to provide a residential or commercial space for communities, homeowners or businesses - due to the unforeseen complications which may arise in a repurposed or reused heritage project.

The reliance on cars as the main form of transport around Auckland city, has resulted in congestion and irritability

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amongst commuters, as the lack of public transport around Greater Auckland causes pressure to be put on the motorways and suburban roads.

With a growing interest in accessibility in the western world, there is a strong demand for amenities to be placed within walking distance to residential developments and incorporation of green spaces – as this provides people with a sense of space and the ability to move outdoors and interact with one another.

To establish how Auckland’s urban plan is functioning, this research looked to the professional experience of people in various job roles, who are working within the construction industry. This was conducted by assessing their main objectives including the constraints and evaluating changes that are occurring within their field, due to the lifestyle of Aucklanders and any influences from offshore.

“Each city has unique local challenges in promoting development, e.g. economic growth, but also needs to find a balance between these targets and demands for sustainable city solutions”. (Jokinen, Leino, Backlund & Laine, 2018, p. 551)

In addition to the main research question - How does Auckland Supercity intend to integrate a feasible and well-structured urban plan, that includes its heritage buildings? The sub-questions included to form the basis of the interviews:

Unitary plan & the Auckland plan (updated in 2018): As have other international cities like Vancouver, how does this compare to their EcoDensity initiative & the Greenest City Action Plan 2020 models?

In terms of heritage buildings, what else is on the agenda to ensure these remain part of New Zealand’s urban communities?

Vancouver based: It has been 11 years since the mayor at the time, Sam Sullivan was successful in proceeding with his concept ‘EcoDensity’ for the city of Vancouver. What

were the findings and general perception of the residents of Vancouver, in terms of what has been most successful, in regard to how the city functions and how people are able to access and move around the city while utilising the amenities provided?

For other countries interested in incorporating the EcoDensity model, in hindsight - what general approach or outcome could have been done differently in Vancouver? Which other international countries could take into consideration when looking at implementing a similar model.

2 Findings

2.1 Individual interviews

The data collection approach used was to conduct one on one semi-structured interviews with 5 participants within the industry, all with relevant and related professional experience, yet employed in very different roles from each other. This enabled an overview across a wide sector of the construction industry to establish contrasting discussions or similar themes between all parties in the topic of urban resolutions.

Five interviewees which participated in the semi-structured interviews, consisted of the following job roles:

- Associate Architect – Heritage Consultant
- Building Surveyor (British Columbia & Auckland based)
- Property Developer
- Rezoning Planer (Vancouver)
- Urban Planner (Auckland)

By choosing a semi-structured method of data collection, it created a more relaxed environment, where the interviewees felt comfortable. As a result, conversation was able to flow more easily and a rapport was built, plus value was established as a result of what each participant shared in conversation.

Naturally, each participant was asked differing questions due to their knowledge, apart from the initial generic queries to establish the length of time in their particular role and any other involvement in unique areas of the industry throughout their career. The next stage of the interview was job-role focussed questions, which were open ended questions. They naturally led to further conversation, branching off of the initial questions, which was a real asset for the data collection process. Interesting findings around people's interactions were realised after the interviews concluded plus when listening to the voice recordings. It was necessary to give feedback and consistent acknowledgement of what was being said by the participants, as this aided conversations to be developed further.

Although the questions were created for their specific job roles, it was interesting to find that there were similar themes running throughout the responses. Which implies that an awareness of the constraints in Auckland has filtered down and across from professional points of view and the international influence on housing and urban planning.

3 Review of literature on innovative rebuilding

EQ Recovery Learning (2019) emphasized that “the disaster destroyed the box so ... have to think outside the box. There is a unique chemistry of circumstance that supports new thinking and ways of doing things”. As a result, new tools and approaches to rebuilding were adopted under new legislative and governance frameworks. The most notable ones include:

- Canterbury Earthquake Recovery Act (CER Act) to facilitate rebuilding
- Canterbury Earthquake Recovery Authority (CERA) to lead rebuilding
- Christchurch Central Development Unit (CCDU) to deliver the 17 anchor projects in the CBD

- Christchurch Central recovery Plan (CCRP) constituting of key redevelopment projects
- Anchor Projects as the prime rebuilding artefacts

Literature used for the review, constitutes of government reports, CERA archived documents, independent reports and academic publications.

3.1.1 *Establishing the themes of: global comparisons, heritage buildings, integration, regeneration, urban planning*

“The idea of cities that are vibrant and successful like Melbourne, Vancouver, Toronto, New York, London and Paris, are cities where people are the most important, where the car is not king, where the pedestrian, rules.” (Campbell-Reid, 2019)

It is notable that it is a common issue for many international cities – to reassess their urban plan, to prioritise the pedestrians and how they are able to move amongst spaces, as opposed to cars dominating the streets, as they have for decades.

A good example of a success story was re-designing streets to create pedestrian only spaces in New York city – designed by Janette Sadik-Khan, (NY city department of transportation and advisor of urban issues). Although the concept was met with resistance, rethinking and redesigning cities resulted in the movement for safer, more liveable streets, pedestrians were then able to utilise and enjoy outdoor zones, which were originally allocated for cars. (Sadik-Khan, Solomonow, 2016)

Likewise, the motion picture, ‘The human scale – bringing cities to life’- featuring Danish Architect & Professor Jan Gehl. Highlights a Melbourne case study, where the inner-city side streets were redesigned to become inviting and usable. As a result, Melbourne is now known as one of the most livable cities in the world, by simply incorporating strategies to compliment the philosophy – the city is made up of people, not cars.

One potential Ponsonby case study which was not favoured by a majority and did not achieve a successful

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vote, was a good comparison of what could have been a reinvention of disused spaces: Running along the back of buildings, a pedestrian street was proposed, connecting the old with the new (cafes, shops, offices), providing developments predicted to be removed actually being removed. (Bower, 2009)

“The street would provide an interesting space as its width and direction would be continually changing and a degree of enclosure would create a more pedestrian-friendly feeling than that of Ponsonby Road. One development alone will not change the area and transform it. For neighbourhoods to work, people need to be able to gather and interact with each other, they need places to meet for recreation”. (Bower, 2009, p. 52)

Ponsonby is known for its heritage buildings and as pointed out by a number of the interviewee’s – you need have a great appreciation for heritage buildings to adopt a heritage project, as they are complex and can easily turn into a financial burden. There needs to be an incentive to encourage potential buyers to carry out a rejuvenation project to bring a new purpose back into historic buildings. As mentioned in the article ‘Architecture as a work-in-progress’.

“How can heritage buildings engage and remain alive and relevant to society if they are frozen in the past”? (Walls, 2013)

The following responses provided by the participants have been formatted to suit their particular occupation. By undertaking the interview methodology and choosing participants from the various fields within the building industry, it allowed for an understanding of how both Auckland and Vancouver are currently functioning in the present, the short term and glimpses into possible future plans.

3.1.2 Associate Architect – Heritage Consultant

Architecture is fundamental to distilling and understanding the essence of a neighbourhood. People’s

lives and how they interact in their community are shaped by the buildings they live and the streetscapes they pay, walk and travel along. (McEvoy, 2015)

How do you incorporate your architectural work into conservation projects?
It would be preferable to see a number of heritage builds be renovated for reuse, which obstacles are the most common for these projects, other than financial issues?
You have carried out your own personal repurpose build, which you then went on to register as a heritage building. What value-adds are apparent to you now since undertaking that project?
What design ideas would you as an Architect like to see, to integrate heritage buildings with their community?
Combating urban sprawl in Auckland - what would your top 3 design ideas be?
As an Architect, what is your biggest challenge when taking on a heritage build project for rejuvenation/repurposing/refurbishment?
Have you noticed an increase of people interested in taking on heritage projects? If so, what are your views on the relatively new concept of partial funding for foundation strengthening in historic builds?

3.1.2.1 Summary of interview

The Architect interviewee acknowledged that Auckland is crying out because our infrastructure is not coping, the city is intensifying without building the other parts of it. With urban design placing people in close quarters, there is the need for incorporating spaces for them to expand into. A local park for example, needs to be within walking distance for it to be properly utilised – in combination with shops which would essentially cover the range of resources in which people need, to ensure neighbourhoods become easily accessible.

“People will live in a 30m² house if they have too, or by choice, if they have plenty around them to satisfy the need to socialise”. “Design should have a more holistic approach, as it is common practice to design within a site, how about a within a street or design within a neighbourhood”.

Not everywhere in Auckland is able to be like Hobsonville Point, where everything was built from scratch as it was bare land.

Top design ideas to combat these obstacles include: “Intensification – it is happening, but it needs to happen better, which leads on to the remaining 2 ideas - we are doing the buildings, but we are not supporting them and that would come in urban planning and infrastructure”. “Auckland has been good at getting the rail system up and running and that is a good start but that is not the only thing that people need”.

The Architect also expressed the importance for heritage buildings to be included in Auckland’s urban plan, for reuse or repurpose for future use – the builds need to be occupied, to ensure they are not left neglected as commonly seen throughout the city. As acknowledged, it is further explained that although there needs to be the will to take on a historic project, the issue with adopting heritage comes back to money every time; whether it be strengthening requirements, which needs to take place or the initial heritage features report. However, by establishing the purpose of appropriate use is essential although challenging, there needs to be the questions of what is actually needed by the occupant(s).

A good example also discussed was of a successful heritage build project within a community, is the Swanson road train station in West Auckland. Originally the old Avondale station relocated in 1995, then repurposed and functioning with the building split into two – 2/3 running as a café and a 1/3 is a room dedicated to the community. The community room can be used for free, with the costs of running and maintenance for the build is sponsored by the rental of the café. With profit in the bank, this has allowed funding of facilities within the community, such as the local Kindergarten playground and heat pumps for the Church. This highlights how communities could be planned to function, with a business serving its local

residents by donating a usable, interchangeable space to utilise.

“As a city evolves and functional requirements change, it is not uncommon for once important and notable buildings to become disused and derelict. At the same time new opportunities for the building’s future can arise. How architectural design which encourages and contributes to the functioning fabric of an urban centre while preserving its historic heritage can be applied to such buildings and surroundings”. (Collins, 2012, p. 100)

On a personal note, it has been almost 20 years since the Architect transformed a former old school house from Mangere into the character filled home it is today. From its relocation, it required 2 years of full-time work of fixing the outside - the value-add over the long term, established it a financially viable project to under-take. By retaining many original aspects and sourcing many materials such as old kauri floorboards it ensures that the home remains in the era of its previous life. While now listed as a heritage build, the adapted-to-suit dwelling acts as a comfortable home with central heating and period features, giving a sense of purpose and a strong sense of home.

3.1.3 Building Surveyor

Canada’s and New Zealand’s building codes are known for being quite similar. Apart from central heating, what differences do the builds have from each other in your experience?
Rejuvenating heritage builds for repurpose, what would be the ratio of the occurring in NZ, in contrast to the development of new builds in Vancouver?
What ideas could you see Auckland adopting from Vancouver’s strategic and implemented urban plan, which could be considered for improving the usability of a build?
What patterns from the same industry in Vancouver, have you seen occurring in Auckland to date, when it comes to building projects?
Auckland is quite disconnected, I am assuming due to the EcoDensity Initiative, that Vancouver is the opposite, is that true? If so, can you elaborate on this from a resident’s point of view?

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What assets do you think your working background from Vancouver gives the Auckland industry, given our location is quite remote?

3.1.3.1 Summary of interview

With the background experience as a Building Surveyor in both British Columbia and now Auckland, this enabled insight into how each city (Vancouver and Auckland) either differ or contain similarities with each other for their housing, heritage builds and their current urban plan. An additional advantage conversing with building professionals from Canada, is the ability to draw from the country's previous experience with leaky buildings in the mid 1990's.

It was noted from the interview that the impression New Zealand gives within the industry, is that it is very much has a reactive approach to housing and urban planning as opposed to a proactive approach. Implying that NZ is not proactive in carrying out risk evaluations to the full extent as other countries and as a result either cause an immediate obstacle to a project, impacting on cost and time. Likewise, if an unforeseen issue is discovered much later eg; leaky buildings, these carry the same implications but on a greater scale.

To evaluate how this traditional reactive approach of NZ could be changed, one suggestion could be to adopt an equal standard of the Canadian building code, as according to the Building Surveyor, it is much stricter than NZ's building code.

"NZ's approach to the building code is also focused on keeping the outside elements out rather than what is happening within the home". "If denser living is a preferable option for housing and development in Auckland, then this focus needs to increase to air changes within a building".

As pointed out by the Building Surveyor, it is important to consider people's health within the building of med – high density living, as air changes are vital to ensuring that the

building elements are not sitting and rotting, especially considering many apartments are quite small and only contain limited access to fresh air.

Auckland and Vancouver are both expensive cities to live in, however Vancouver has established 'Micro-suites' (Micro apartments) to assist in easing the pressure for the cost of living in an expensive city. Micro-suites range from 150 sq feet (14 m²) to 350 sq feet (32.5m²) and offer relatively low-priced accommodation. Canada's building code addresses secondary suites more so than is seen in Auckland.

"They have a specific set of standards for it, where-as Auckland it is made to be more of a daunting task than it needs to be – it is therefore a lot of money invested for very little return".

A further explanation was given, emphasising - due to Vancouver's limitations on space and a number of restrictive jurisdictions, the city has nowhere else to go – except by intensification. Vancouver, however, has put pressure on Property Developers to provide green spaces, to ensure that residents have access to a comfortable outdoor environment that is inviting and creates interaction. Rooftops are an example of this being a popular option, especially in high density apartments, where the proximity to such locations are more difficult. Planners are now involved with densifying, including incorporating strategies to reduce cars on the road. Bearing in mind, Vancouver city has implemented pedestrian only zones for the city centre and is facilitated by the Sky Train for accessibility.

As acknowledged from a visitor's point of view of Auckland, that the culture is focused on car ownership. People do not take advantage of the public transport system as much as overseas – although the infrastructure is currently and predominantly designed for cars and until the focus changes into making Auckland more accessible throughout, this is unlikely to appeal for people to change.

Heritage

New Zealand is on a par with British Columbia in terms of retaining heritage buildings, although it is noted that they are of a Victorian style heritage. This stems from being an older country than NZ. It would be valuable to undertake an assessment of the reuse or repurpose projects to assist in forming additional ideas for Auckland’s heritage buildings.

3.1.4 Property Developer

Popularity of apartment living is continually growing. What lifestyle changes have you noticed taking place, that attracts buyers to apartment living?
How does the Unitary plan affect your specific development proposals, in your experience?
Within the last 10 years, which changes in Auckland’s lay out have impacted property development the most, in your experience?
You apparently favour inner city suburb location the most, for your projects based in Auckland. Apart from city accessibility, what are some of the other reasons?
For the overall design of your apartments, do you look internationally for ideas? If so, where were they and why?
You also have had experience with heritage builds for commercial businesses. How was this experience in contrast to planning a project for the construction of new buildings?
Is this a type of project you would be interest in doing again in the future? If so, why would that be?
Adopting a large heritage build to transform in to apartments – from a property developer point of view, on top of financial reasons or building availability, why do you think that is this not a popular option?

Summary of the interview

It seems that people from the age bracket of late 20’s – early 50’s are predominately residents of apartments for this particular Property Developer, who specialises in medium density housing. There is an indication that apartment living has increased over the last 10 years and is no longer occupied by a majority of students. Influencer’s have come in from overseas, where this style of living can be an enjoyable experience. “Expats in particular come back to Auckland, demanding this

approach, and at the time there was a gap in the market for apartments built with design in mind”.

An example of projects is a current property that is 2200m² with 105 apartments. In the suburbs this would be commonly subdivided into 4 houses.

What prompts a person/couple or young family to apartment living, is usually driven by the time saved by not needing to commute back and forth to work; often being at a cost of 2 hours per day out of their schedule.

“Apartment living in the city fringe allows convenience to amenities and like all apartments it is a low maintenance option, allowing the ability to lock up and leave, in comparison to a stand-alone home”.

Further elaborated, were the developments in suburbs such as New Lynn in West Auckland have had an improvement in land values, up to triple due to the Unitary Plan with the development of an updated transport system.

“It is this sort of development occurring in Auckland which enables families to ditch the 2nd car for city accessibility”.

“A step in the right direction if we think about the future of Auckland, consider Sydney which is about 10-15 years ahead and New York 10-15 years ahead of them”.

“Looking at those 2 cities, you can see what Auckland will eventually be like”.

With international influence for a new build or the incorporation of including the building’s previous life into a regeneration project, some Property Developers have provided Auckland with well-designed and aesthetically pleasing apartments as an option for residential housing. This is an essential ingredient, for opening up the option to buyers as a way of living, as opposed to further adding to urban sprawl – where the continual spread puts the focus back on infrastructure, water supply and transportation to get the facilities out to these new developments.

Heritage

Heritage is in actual fact quite challenging to undertake, whether residential or commercial projects the constraints are similar. Uncertainty around what needs repairing or replacing until the building element has been exposed. Often easier to demolish and start from scratch if the building is not protected by a heritage status. One particular dilemma of project managing a heritage build comes from the other professionals within the industry. “An example of this would be where a Structural Engineer would demand that an old sash windows be boarded up for earthquake proofing requirements. Whereas a Heritage consultant might say you must keep the original kauri double sash windows”. “Solutions must be reached, to balance both viewpoints.”

Therefore, the project becomes quite complex and less appealing for the majority of people to consider taking on.

3.1.5 Rezoning Planner - Vancouver

The EcoDensity initiative, in what ways has it assisted or been damaging in working towards the Greenest City Action plan 2020?

It has been 11 years since the mayor at the time, Sam Sullivan had been successful in proceeding with his concept ‘Eco-Density’ for the city of Vancouver. What has been the most successful aspects in terms of how the city functions, and how the residents are able to access and move around the city while utilising the amenities provided?

For other countries interested in incorporating a similar model, what could have been done differently in Vancouver, which other international countries could bear in mind whilst also identifying constraints in adopting such a concept?

What other international models are out there that are/were referred to in Vancouver’s plan as a worthy example of a good urban plan?

Having a pedestrian only zone in the central city, how has or hasn’t this benefitted the city?

What is the new focus for urban planning in Vancouver now in 2019?

3.1.5.1 Summary of the interview

As a Rezoning Planner facilitating the rezoning process and negotiating with developers on a variety of policies including heritage, housing, form of development, sustainability and engineering – not a subject matter expert on sustainability and eco-policies but has a general sense of the City’s approach.

“There is the perspective that by putting pedestrians first as opposed to cars has been a focus ever since the EcoDensity initiative”. “Although the EcoDensity initiative allowed people to live, shop and work, within close proximity to their residence, there is still a large section of Vancouver that are single family neighbourhoods but there is a current push to change that; to create a more sustainable form of development. The city is currently doing a city-wide plan, so will probably see some changes in those single family neighbourhoods to increase the density, which includes widening sidewalks and adding cycle-paths, which both contribute towards accessibility”. The Planner addressed how Vancouver has a policy of creating job space outside of the central business district (CBD), resulting in certain areas of the city designated to have job space and office space along transit lines. The idea is to funnel people seamlessly onto transit.

Included in the conversation was how the Greenest City Action Plan 2020 initiative, seems to have morphed quite a bit into different policies, as the year 2020 rapidly approaches, and perhaps it is the ongoing pace of development in Vancouver, with a lot of pressure, as a result the affordability of the city is high with a lot of people struggling to afford living there. This is similar to Auckland in that sense. So, whilst Vancouver has made a

lot of strides with creating better spaces and density in Vancouver due to the EcoDensity plan, housing affordability is still a major issue in the city. A common complaint from residents that the Policies are not clear and open to different interpretations.

When asked about future projects in Vancouver, it was highlighted that a current proposal aligned with the Greenest City Action plan in the city, is a 60-storey residential tower built to passive house standards, which would be the largest passive house building in the world. This is the direction for construction standard the City is trying to incent and push, although it doesn't come without its impacts on other things, for example: shadowing on neighbouring buildings. There are a number of policies in place, that Vancouver City holds developers to certain sustainability standards.

3.1.6 Urban Planner - Auckland

Looking at the objectives in the Auckland 2050 plan, how does this impact your role here in 2019, in terms of urban planning?

The new development of Hobsonville Point seems to be a model of what future living in Auckland will be like. What is a common point of view, on the subject of density living as a Planner?

What are some of the strategies in place, for ensuring that heritage builds are part of Auckland's future?

Dealing with many project proposals in Auckland and seeing that there is a current trend for medium density housing, how popular are heritage renewal projects?

What do you think are the main factors preventing someone from taking on a heritage build project?

With the Government now providing financial assistance for foundation strengthening for eligible heritage buildings. What impact has this had on the number of applications for renovating a historic build?

What successful practices for the life cycle of a build could be implemented for heritage builds; when they are undergoing renovations?

There are pockets of growth and new developments around Auckland, which further result in urban sprawl. A better connection throughout the city if preferable, how is this planned for if we think of the unitary plan?

National Geographic printed an article in regard to London. "Planners fashion new neighbourhoods from defunct industrial sites, they balance the city's historic character with its future needs". Is this something Auckland could also facilitate, do you think? (Parker, 2019, p. 130)

Observing Auckland's current buildings and infrastructure, there are lots of international cities to model from. However, when I looked through the Auckland Plan, I only saw overseas cities mentioned once under the topic of cycling in and around the city. How do Planners assess what would make a city useable?

3.1.6.1 Summary of the interview

Higher density living is necessary from a Planning perspective as it can be cheaper land where amenities are all close by eg; schools, supermarkets. A prime example of this is Hobsonville Point. However, many of the residents there will still need to commute to work as there is the need for denser living of this standard to be located closer to the city. The obvious implication there though is the lack of available land.

"The Resource Management Act (RMA) needs to be more responsive in getting density into city fringe suburbs, where the cost of land and the cost of building is prohibitive".

The Urban Planner interviewed, considers it shocking that people are still building stand-alone homes in Auckland.

"There are no incentives in terms of having an original home and then allowing more homes on the same piece

of land". "With the current subdivided properties, there is often a lack of thinking at the concept stage, resulting in terrible parking layouts, enforced infringements, height to boundaries, building coverage". "The difficulty with resource consents, the regulatory division cannot make people do anything". "A simple solution with the subdivision issue could be that the existing dwelling get moved to the front, to create more space and visually you would see the original dwelling plus 2 more".

Auckland does not seem to be a planned city in terms of connection, developments, urban sprawl, stated the Urban Planner. Currently future urban means that it is not serviced at all, no stormwater or wastewater, which becomes a reaction to get the services out to the new developments, as previously mentioned, a proactive approach would be more desirable. By following with a reactive approach, this takes resources away from other areas that had been previously planned for - but there is the need to prioritise resources. The Urban Planner acknowledged the Government has given the indication that there is money there to be given for infrastructure, but the Property Developers have to come onboard as well. Otherwise, it was concluded that the outcome will be big developments relying on cars, which is not ideal.

"It is a difficult scenario, the plan did not facilitate development, as it didn't necessarily provide the transport links and hubs". "An example of this for a car owner – if an apartment is built, the developer does not need to provide a car park".

The conversation digressed to Hobsonville Point as it is an interesting case study to discover it was the first subdivision in West Auckland, where you weren't just allowed to have as many car parking spaces on your site as you wanted. Even under the Waitakere plan it limited you to one car parking garage and one car park space out front. The verdict is any additional cars will need to be parked on the street, but the street itself only contains

limited car parking. People are quite reluctant as Aucklanders and have a certain mindset on vehicle ownership. There is the need to change this mindset for things to improve. When thinking of the future, where not everybody will own a car, there is the unfortunate gap in between the present and the future, where public transport needs to catch up.

While cities such as London are looking to their industrial sites to create new neighbourhoods, for example the Battersea Power Station project has just gone through a regeneration project process to make it a residential precinct.

"Auckland is not there yet, as it still relies on the industrial land, where perhaps London pushes their industrial industry out of the city". "Auckland fights to protect the industrial land for industry, not residential use". "There are some industrial areas though, that are close to the inner-city suburbs that will possibly get rezoned".

One of the main objectives explained, is a Planner's job is about creating neighbourhoods, where it becomes walkable and consists of public transport and hubs. However, being a regulatory department, they are constrained by the rules, which they do not make. The rules are created by policy counterparts. International influence, but primarily Urban Planners would look to other countries, but it is necessary to bring back relevant considerations to Auckland's own landscape which includes water and volcanoes and Maori culture.

3.1.6.2 Heritage

The Urban Planner reflected that historic builds are often seen as too expensive to get the project off the ground, there are success stories in regard to their heritage protection, as long as the building is scheduled.

As explained, the unitary plan contains a schedule of all the heritage builds, listing 1,2,3 depending on their grade. One being the highest and three being the lowest. Without a schedule, it is harder to protect and some just

have a façade protection with the ability to incorporate any design behind the façade.

As also mentioned by the Property Developer in another interview, the Government funding for strengthening of heritage builds, is microscopic in comparison to the overall cost, so in the urban planning sector there is little interest due to the scheme. However, this could relate to the location of Auckland involved. Central suburbs may have a different story.

Established in the interview, there are additional challenges when it comes to a heritage project, the requirement to apply to council approval for resource consent, undertake their own heritage report and a specialist peer review is undertaken from the department, so the Planners cannot give advice unless there is the supporting documents. Resulting in a lot of work that in fact might not get the owner of a heritage build anything to allow commencing the works. Therefore, a lot of people rightly feel that a heritage project is too uncertain.

4 Discussion and Analysis

As this research piece on urban resolutions was conducted, it was necessary to assess the current urban plan in Auckland while also addressing the need to preserve the city's historical culture. With a focus on the dis-use of heritage builds, resulting in buildings becoming neglected and a forgotten piece of NZ history; it was therefore acknowledged the importance of an assessment of how heritage builds could be re-integrated back into the communities that serve Auckland.

As a result, the research was divided up into the following themes: Auckland's urban plan, building and planning issues, heritage builds and Vancouver's EcoDensity initiative. With the five interviewees from the various areas of the construction industry, this allowed for a comparison to evaluate any similarities or contrasting findings from the interviews.

The participants' responses highlighted challenges in regard to Auckland's urban plan and housing issues, from their perspective. Due to the experience and background in the industry of each participant,

dissimilarities of feedback reflected their job roles - with discussions primarily about design issues of Auckland's or Vancouver's urban plan or the design of buildings. In contrast, building technology issues were addressed for both heritage or new builds from the technical occupation of the Building Surveyor. While interestingly, the Architect was able to elaborate on a broad scale for the design of buildings, Auckland's urban plan and the technical aspects of a building. This seemed to be a reflection of Architectural studies consisting of a more holistic approach, by incorporating a link between the design of a proposed building to integration within its surroundings.

As noted from a NZSEE (New Zealand Society for earthquake engineering) conference paper titled 'The relationship between seismic retrofitting & architectural qualities':

"Preserving and enhancing existing buildings for both architecture and seismic engineering aspects is critical. As they contribute to the economical cultural and visual identities of their communities" (Allaf & Charleson, 2014, p. 8).

Likewise, with feedback from the Architect during the interview, who expressed the importance of the urban plan supporting the buildings. A comprehensive approach is preferable, as opposed to design purely within a site. Kathryn Collin's article 'Provocative Preservation' had a similar echo. "The underlying theme throughout the project is the necessity to tie the building functionally back into the city" (Collins, 2012, p. 89).

Although the context of discussion with the participants were more aligned with similarities to each other, with the shared viewpoint of Auckland's necessity to move towards denser living and provide outdoor spaces within a close proximity for recreational use. It was likewise for Vancouver, where this remains a focus for the ongoing process of accommodating a large population, in a condensed environment. Reflecting back to the EcoDensity initiative for Vancouver's urban development, it was proven fundamental to ensure a connection between how people live and work by providing zones where communities could come together through their activities. The process of bringing residents onboard with the initiative proceeded to take time and compromise to finally being accepted by the majority

of the public - shows that from the implementation of EcoDensity in 2008 through to the published book 'Planning practice in New Zealand', a demand from the public to be included in the concept stage, has been heard when implementing new strategies for urban planning.

"There is a move towards placing the emphasis on public participation at the plan-making, rather than plan administration, stage". (Miller & Bettie, 2017)

It should be pointed out that even with the best of practises, it is not possible to have everybody onboard with leadership strategies. Marit Rosol's article 'Vancouver's "EcoDensity" Planning Initiative: A struggle over Hegemony?' is an example of opposing views on how successful the EcoDensity initiative was presented to the public.

The selection of Vancouver as a comparison to Auckland, is justified by the following:

Both Vancouver and Auckland are expensive cities with a shortage of housing (Rezoning planner and Building surveyor). Similar building codes (Auckland Council). Vancouver is listed as one of the world's most livable cities - an advertised Auckland city goal promoted by Auckland Council. New Zealand being a small country and with limited resources in comparison to Vancouver, could benefit from reviewing the long term outcomes as a result of implementing the EcoDensity initiative.

5 Conclusion

Auckland has a lot of potential to accommodate denser living, within a community that supports the residents by offering them the ability to be more self-reliant with close-by resources of parks, schools, shops and public transport systems. It is not feasible or possible to start a complete urban plan from scratch in Auckland, but with design in mind, new developments, refurbishments or repurpose projects, could take place with a holistic approach by creating builds which intentionally connect back into the community. This integrated approach of urban density and liveability, would offer economic, social and environmental benefits to the residents.

The following quote highlights the importance of good designs and is crucial when planning for deintensification.

"While a high degree of compactness is desirable, too much density can be detrimental to liveability, health and urban well-being". (Lehmann, 2016)

Lehmann went on to interview former city planner of Vancouver Brent Toderian about the urban overhaul. .

"For the last decades the environmental movement rejected cities and focused on pastoral areas. The truth is there is nothing greener than density if you do it well, because it diminishes the pressure on agricultural land, it significantly reduces the cost of growth in a sprawl pattern, and it improves everything from our climate footprint to our health, which has huge economic implications. Doing density well is as much about providing privacy as it is about civic life. Density brings people together". (Lehmann, 2016, p.

By looking to international cities, this has given insight to how Auckland could incorporate or adapt a model that suits the city's landscape and the unique culture. Auckland is obviously moving in the direction of denser living with many developments being constructed throughout the suburbs, allowing the residential market to accommodate a lot of people within a smaller space. With careful design and planning, a smaller square metre dwelling has the ability to be an enjoyable space to live. Together with repurposing heritage buildings, initiating infrastructure prior to developments taking place and listening to what communities want in their existing or new neighbourhoods – Auckland city has the ability to be an attractive, well-functioning and liveable city.

Urban resolutions research topic was not set out to provide solutions for Auckland's urban and heritage build predicaments. The aim was to provide a topic that initiated conversations, subjective in nature, to question what makes a city usable. A conversation also gives way to the reader being creative in forming ideas and further discussion to the topic.

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6 RECOMMENDATIONS

With reference to the conclusion in this report, it is recommended that any change of urban planning or housing developments are far more accepted and therefore more likely to achieve successful results, when change is broken down into smaller projects to achieve the overall new concept. People can find change difficult or overwhelming and are prone to resisting all ideas which relate to an overall proposed project.

i.e. creating pedestrian only zones within the city and re-establishing traffic routes to accommodate this. By working on smaller areas initially, this would be a feasible approach to both test out an idea and gain interest and acceptance of the change from the general public.

Assessing the urban plan to include historic buildings - repurposing or renovating heritage buildings needn't be so daunting if an integrated approach is adopted, between the professional parties involved in the early initiation stages of the project. By establishing the requirements as a team approach; this will avoid the conflicting advice which Stakeholders of a heritage project often receive and establish problem solving as a collaborative unit. As a result, Auckland would likely see an increase of heritage projects being adopted for rejuvenation, which would benefit the communities as a whole.

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A Literature Analysis: Creating Happy People in Cities

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ABSTRACT

Purpose: The purpose of this paper is to identify and discuss those elements that create happiness in cities. After identification, it can be implemented in cities. These elements affect the happiness, health and wellbeing of city residents. A comprehensive study of the literature was utilized in this article. A synthesis of existing literature from a range of various authors revealed several elements that influence happiness in cities. These elements were analysed; and those correlating elements that overlapped, were combined. This resulted in a final list of essential happy-city factors. A city needs to have pathways, landmarks, districts, effective land use, as well as a geographical ensemble, public-asset enhancement, housing characteristics and housing stock. There needs to be a focus on combating crime. Job development and education need to take place in a city. The residents' comfort and their needs must be considered and access to exercise, sensory stimulation, and access to open green spaces should be available. Forms of transportation need improvement – with shared parking available and a decreased need for automobiles. Effective food systems with healthy options and retail attraction are required. These elements all contribute to happiness in cities. The study contributes to the knowledge base regarding happy cities in general. City planners and architects incorporating the final happy-city elements combined in this study would possibly create happiness for residents; providing opportunities for residents to secure meaningful and long-standing happiness as they thrive in their daily endeavours.

Keywords: Happiness, Happy city elements, Residents, Cities, Wellbeing

1. Introduction

Urbanisation and population increase are causing the development of existing cities and the creation of new cities. Globally, attention is being paid to smart city developments, thereby looking at both the technical aspects and also the elements of psychological wellbeing. People living in these city spaces are positively or negatively affected by their surroundings (Montgomery, 2013). The built environment needs to be created or transformed in a manner that contributes to the wellbeing and nourishment of its cities, thereby influencing the happiness of the residents (Du Plessis & Hes, 2014).

It is essential to note that determining the happiness of individuals in cities should not be based on income levels

alone. Although wealth is a powerful tool, this acquisition is not a sure determinant of ones' personal happiness (Montgomery, 2013).

2. The Literature overview

In the literature overview insight is offered on the background of happy cities and also on certain elements that contribute to happiness in cities. The background offers an explanation of happy cities, by explaining the term and the role players involved. The elements that contribute to happiness are discussed. Insight is offered on aspects that may be integrated in cities and city design in order to improve resident satisfaction and happiness.

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2.1 The Background of Happy Cities

In order to create happy cities, attention to the cities' architecture and sustainability is essential. The physical form has an impact on the city's outlook (Lynch, 1960). Cities need to aim for happiness and not only for wealth. In order to attain this, the role players need to collaborate and to become involved (Montgomery, 2013).

All cities, including smart cities, will benefit by integrating happy city elements in their spaces. Often the focus of smart cities is on systems and technology. However, cities need to ensure that various happy elements, that extent further than systems and technology, are implemented (Wharton, 2017 & Urenio, 2019). All cities will benefit by incorporating happy city elements.

The Architecture of Happiness

The establishment of sustainable building types can contribute to city formation and the impact this has on individuals' wellbeing (Du Plessis, 2013). For instance, establishing shopping centres in cities is fundamental to city vibrancy, as shoppers are drawn for reasons beyond merely shopping, such as socialising and for leisure activities (Burger, 2014). The social and physical environment both have a strong impact on the happiness of those that are in contact with the spaces (Brereton, Clinch, & Ferreira, 2008).

Incorporating Sustainability into Happy Cities

Achieving sustainability in cities and establishing green buildings would impact on the residents' happiness; as this is cost-effective for the residents, due to the efficient utilization of natural resources in the natural environment (Du Plessis & Hes, 2014). In ensuring that sustainability achieves its purpose in cities, objectives should be met such as social progress that addresses the needs of everyone, protecting the environment, together with the effective usage of natural resources (DETR, 2000). With these objectives met, it is probable that the long-term happiness of the residents in these areas would be impacted.

Wealthy Cities vs Happy Cities

Quality-of-life and the wellbeing of the individuals are often measured through factors, such as income levels, consumption, wages and rentals, in addition to local

amenities (Ballas, 2013).

The World Values Survey data (Deaton, 2008) reflected that high-income countries are happier than low-income countries; however, regarding these high-income countries, there is no relationship between national income and the national happiness (Layard, 2005). The combination of the two (wealthy cities considered as happy cities) should be the goal, in order to promote both happiness and economic growth (Montgomery, 2013).

Role Players of Happy Cities

Formed partnerships and role players, such as architects, neighbourhood activists, public health experts, network theorists and politicians can tribute in forming and developing cities into more livable, happy spaces (Montgomery, 2013 & Hall, 1988). It is essential in this section that the background of happy cities is discussed, thereby providing clarity on the understanding of happy cities and helping to determine the various elements that create happiness in cities.

2.2 Elements of Happy Cities

An in-depth literature review revealed the various elements that assist in creating happiness in cities. These elements are:

Paths

These consist of road networks in cities, thereby enabling easy movement for the residents. Paths may contain street names, thereby making it easy for individuals to find specific locations within a city (Lynch, 1960). Seidel, Kim & Tanaka (2012) also explained how the establishment of pathways in neighbourhoods promotes easy movement for residents within these areas, enabling residents to stroll around without difficulties (Quercia, Schifarella & Aiello, 2014).

Districts

These are sections of a city, recognized by the activities that take place. Based on the identity given to the areas, these assist individuals in navigating through cities easily; thereby influencing their wellbeing (Lynch, 1960). This element is similarly discussed by Anderson, MacDonald, Blumenthal & Ashwood (2013), revealing that obscure areas should be given some clearer identity, in order to reduce criminal activities.

Design features promoting social engagement and personal security

This deals with incorporating designs, such as creating public spaces in cities that would encourage social interactions amongst the residents; also establishing buildings with designs that make dwellers vigilant of activities going on in the area, thus providing security aimed at residents living comfortably (Pfeiffer & Cloutier, 2016). Planners may establish design features that complement the desires of the residents, also providing security for residents to thrive (Seidel *et al.*, 2012).

People-in-place

This deals with the human dwellings in areas. Ascertaining residents' routines, attitudes, ways of reasoning; the demographics and living standards measure (LSMs) of households in areas. These are all fundamental in improving socio-economic developments in cities (Seamon, 2012). Similarly, Anderson *et al.* (2013) revealed that the density of areas is associated with the level of crime present; with high-density areas connected more with increased crime. High-density areas may therefore be remedied through strict security measures, in order to make the residents feel less threatened.

Access to open, natural and green spaces

Having access to open, natural, green spaces has been observed to be a way that individuals can alleviate stress, thereby making them feel happier (Pfeiffer & Cloutier, 2016). Wells, Evans & Yang (2010) added that, as land may be allocated for city building and other developments, natural and open spaces should equally be considered in planning decisions; since the natural environment may have positive impacts on people.

Transportation improvement

Establishing well laid-out transportation infrastructure in cities helps to improve the living conditions of residents; as they proceed to their desired locations, thus influencing their wellbeing (Pendall *et al.*, 2013 & Fan, 2017: video). The strategic points in cities are characterized by activities that the individuals access, such as major railway stations or bridges. These help residents to reach their destinations; and they enable convenient commuting (Lynch, 1960).

Geographical ensemble

This deals with the material and environmental qualities

of places, such as topography, weather, natural landscape, buildings, road networks; and the impact on residents' happiness (Seamon, 2012). Elements, such as land use zoning, connecting roads and building designs are likely to give neighborhoods a more ordered layout in which the residents can thrive (Ben-Joseph & Szold, 2005).

The geographic ensemble may also constitute the boundaries of cities in the form of water bodies or the establishment of walls (Lynch, 1960).

Land use

Proper land use and zoning-regulation considerations are indispensable (Anderson *et al.*, 2013). The apportionment of land into various uses, including commercial, residential, agriculture and industrial may also help to establish a better city lay-out for residents to function happily (Ben-Joseph & Szold, 2005).

Public asset enhancement

In keeping buildings in the cities from getting to the stage of dilapidation, refurbishing existing building structures, to enhance their appearance, would help in impacting the happiness of the city dwellers (Pendall *et al.*, 2013). Also, architects focusing on fusing refurbished buildings into a collection of existing buildings, thus producing the right blend and increasing the neighborhood aesthetic, may be essential in impacting the residents' happiness (Seidel *et al.*, 2012).

Housing characteristics and quality

Improving the quality of building structures involves paying attention to factors, such as sanitary practices, building heights and interior designs; thereby enabling building occupants to live pleasantly (Wells *et al.*, 2010). The conditions of houses is important in influencing the residents, as houses in poor conditions may lead to health problems, thereby impacting residents negatively (Pfeiffer & Cloutier, 2016).

Job development and educational opportunities

Establishing educational institutions, and creating employment opportunities in cities would improve the living conditions of those residents, who secure these job positions and enroll in the educational institutions (Pendall *et al.*, 2013). The composition of educational systems and other institutions would create employment opportunities to better living conditions; and it should enable residents to live harmoniously, hence positively

impacting their wellbeing (Ben-Joseph & Szold, 2005).

Edges

Edges are observed to be either boundaries between two kinds of areas; or they possess the role of holding together widespread areas in the form of water bodies or established walls (Lynch, 1960). Edges contribute to the formation of cities, together with other features, such as the topography, natural landscape and street networks. These may be considered by city planners to help create suitable environments for the residents (Seamon, 2012).

Nodes

These are junctions, places of a break in transportation and general strategic points located in cities, where transportation activities transpire, such as railway stations and taxi ranks (Lynch, 1960). Pendall *et al.* (2013) explain that having effective transportation systems in cities may contribute to the wellbeing of the residents; as they facilitate mobility and commuting.

Housing diversity and conditions, transportation infrastructure, and polluting land uses

This element constitutes housing conditions directly affecting happiness; for instance, residents that have poor housing conditions are likely to be unhappy (Wells *et al.*, 2010). Also how transportation operations enable easy movement of the residents, thus impacting the happiness of the residents (Pendall *et al.*, 2013). Finally, polluted environments, such as air and noise pollution can influence the wellbeing of the residents (Pfeiffer & Cloutier, 2016).

Designs for easy movement in the neighbourhood

This element deals with the designs implemented by planners that are aimed at ensuring safety and improving the ease-of-movement for the residents; hence, generally improving neighborhoods (Seidel *et al.*, 2012). Paths planned and constructed effectively give significance to any city; as they make movement and commuting easier (Lynch, 1960).

Improving aesthetics by merging new buildings with existing buildings

This element aims at improving the attractiveness of buildings, thus impacting the moods of the residents

positively (Seidel *et al.*, 2012). Refurbishing the existing buildings to improve their appearance, hence adding to the beauty of the neighborhoods; making them attractive areas to dwell in may impact the wellbeing of residents (Pendall *et al.*, 2013).

Areas designed for social interaction

This deals with the designs and the environments created that promote social interaction. (Seidel *et al.*, 2012). Pfeiffer & Cloutier (2016) added that a more compact neighborhood setting may increase the interaction between the residents, thereby possibly improving their quality of life.

Considering general living and social conditions in the neighbourhood

This element deals with planners considering the comfort and welfare of the residents, their needs, and how easily accessible these needs are, be they physical or social needs (Seidel *et al.*, 2012). Social needs may include the need for social engagement among the neighbours by creating public spaces, such as parks (Montgomery, 2013).

Nature and open space

Wells *et al.* (2010) opined that city planners may designate land significantly to open spaces, in order to impact the physical environment, and in turn the wellbeing of the residents in these neighborhoods. Access to the natural environment, such as botanical gardens and parks may provide residents with the opportunity to heal their emotional wounds (Day, 2002).

Elements of urban form

This constitutes many components, such as land-use mix, road geometry, transportation infrastructure, sewage and drainage management; when combined to form city environments that are suitable for residents to thrive (Wells *et al.*, 2010). Seamon (2012) supports the view that the environmental qualities of a place, which include topography, building types, natural landscape and weather can all contribute to the wellbeing of the residents.

Spirit of place/genius loci

This deals with the ambience that sparks the emotions of residents in a physical environment (Seamon, 2012). The

ways by which people may benefit from having access to the natural environment should be considered by city planners; since the atmospheres of spaces impact the emotions of the inhabitants (Pfeiffer & Cloutier, 2016).

Territoriality and permeability

This element aims at differentiating between spaces in cities; including safe areas and dangerous areas, in order to mitigate dysfunctional areas, thereby impacting the wellbeing of the residents (Anderson *et al.*, 2013). Identifiable areas in cities characterized by activities may be essential; as they enable individuals to navigate by knowing their locations (Lynch, 1960).

Density

This deals with the population of areas playing a role in impacting residents' happiness; as low-density areas may be linked with safer environments; and high-density areas may be linked with criminal activities (Anderson *et al.*, 2013). Demographics are important elements to consider in city formation; as individuals contribute to the vitality of the areas (Seamon, 2012).

Physical urban infrastructure

This element includes buildings established to aesthetically attract attention, embarking on functional zoning and developing effective, connecting roads within the neighborhood (Ben-Joseph & Szold, 2005). These factors help to configure the lay-out of cities, thereby improving the quality of the lives of the residents (Jain, 2019 & Seamon, 2012).

Social infrastructure

This entails the composition of institutions in cities, such as educational systems, hospitals and community housing; aimed at enabling residents to live harmoniously (Ben-Joseph & Szold, 2005). This process may lead to the creation of job opportunities, thus improving the living standards of the people (Pendall *et al.*, 2013).

Landmarks

This deals with the unique physical features in cities, such as water bodies, buildings, trees, signs or stores used as reference points for the purpose of individuals confirming their location (Azeri, Bagheri, Pourhasan, 2015 & Lynch, 1960). Using reference points in cities for the communication of routes enables residents to navigate around areas (Raubal & Winter, 2002).

Crime attractors/ reducers

The use to which land is used may be associated with the level of crime present in those areas; for instance, alcohol outlets and bars, restaurants and gas stations are spaces that may be linked with robberies (Anderson *et al.*, 2013). Areas in cities associated with high level of criminal activities should be identified, in order to implement mitigation measures more easily (Kinney, 2008).

Access to comfort, welfare and daily needs for residents

City planners should obtain information on the activities in which the residents have interests, as attention is drawn on the convenience and welfare of the residents (Seidel *et al.*, 2012). Similarly, the designs of buildings in neighborhoods may be aimed at promoting harmonious living between neighbours (Pfeiffer & Cloutier, 2016).

Encouraging regular exercise in pleasing places

Open spaces that promote exercise may be relevant; as city dwellers may meet up in these fields to either exercise, stretch, play soccer, or perform other sporting activities; encouraging healthy living (Seidel *et al.*, 2012). Wells *et al.* (2010) similarly opined that public areas in cities may be spaces used by residents for activities, such as exercising.

Designs to activate the sensory stimuli of the residents

Building structures and designs in cities play a fundamental role in impacting the emotions of the residents (Kraftl & Adey, 2008). This element focuses on design factors in cities with the activities that transpire influencing sense of hearing, smell, touch, and the visual stimuli of the residents; hence improving the quality of life (Seidel *et al.*, 2012).

Reduction in the use of automobiles

The reduction in the use of vehicles in cities, in turn promoting public transportations, would aid in easy movement around cities by the residents, thus improving their wellbeing (Montgomery, 2013). Countries, such as Germany, Spain, France and Denmark have started planning the implementation of reducing the use of automobiles on the streets, in order to improve mobility (Garfield, 2017).

Established shared parking spaces

Households prefer living in walking distance to amenities,

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thus driving less in neighbourhoods (Koschinsky & Talen, 2015). The creation of ample spaces by city planners, specifically for car parking, discouraging on-street parking, and enabling space for a walkable city environment, would further create happiness for residents (Speck, 2013).

Retail retention and attraction

Retail centres play a huge role in city lives and individual lives; as they offer a sense of structure and control to the lives of the shoppers (Burger, 2014). It is important to establish retail facilities in cities; as these seem to contribute to improving economic activities and the wellbeing of the residents (Pendall *et al.*, 2013).

Healthier food options

The presence of healthy food options in stores enables residents to eat healthily, thus living healthy happy lives in cities (Pendall *et al.*, 2013). Affordable healthy food stocks would be convenient for customers; as they gain access to them, thus drawing more customers and increasing footfall (Wells *et al.*, 2010).

Food systems, availability and affordability

Ball, Timperio & Crawford (2009) opine that individuals of low economic status are more at risk of consuming unhealthy food diets than individuals in high economic positions – due to factors, such as ignorance and the affordability of healthy food options. There should, however, be food options that cater to the needs of residents at affordable prices (Wells *et al.*, 2010 & Florida & Mellander, 2013).

Neighbourhood and housing stock reinvestment

Planners may improve neighbourhood happiness by implementing construction plans and policies concerning these neighbourhoods, as they engage with the residents in the process (Pfeiffer & Cloutier, 2016). Developing mixed-income housing units in cities (that is, houses that cater for a mix of all income groups) may impact residents' wellbeing (Pendall *et al.*, 2013).

Natural surveillance

Residents may be their own 'eye on the streets', being proactive in contacting the police when incidents occur, thus preventing unlawful activities and discouraging crime (Anderson *et al.*, 2013). Neighborhood planners may also consider designs that promote security, such as houses

that possess anterior garages and front porches; so that neighbours are mindful of activities on the street (Pfeiffer & Cloutier, 2016).

Target hardening

This deals with the installing of building codes, such as quality door locks and door frames, laminated glass and motion-activated lights; ensuring safety to residents (Anderson *et al.*, 2013). As the number of places prone to attacks increase, the less desirable target hardening becomes due to the increased expense involved; thus resources should be allocated optimally to target hardening, in order to ensure the safety and the security of the residents (Haphuriwat & Bier, 2011).

Physical disorder

Wei, Hipwell, Pardini, Beyers & Loeber (2005) reveal that higher levels of physical disorder in neighborhoods are linked to factors, such as increased crime rates, homicides, teen births and poverty. Physical disorder in cities may be reduced by implementing strategies, such as regular building maintenance, anti-littering campaigns and police patrols, to ensure residents' wellbeing (Anderson *et al.*, 2013).

In summary, the literature analysis indicates 39 elements that create happiness in cities.

3. The Research Methodology

Literature-based methodology is research studies that examine the literature, in order to produce findings (Comerasamy, 2012). A comprehensive literature analysis was conducted in this study. The research process started with discussions with researches in the field. This led to the identification of possible keywords. Keywords were used in further literature searches that were conducted. The keywords and keyword combination were used in literature searches. A wealth of information was retrieved from various authors in the literature section. . From each article studied, happy city elements were indicated. Thirty-nine elements were listed. Similar elements were grouped together that resulted in a final list of 25 elements. This enabled an understanding of the research study and provided possible solutions to the problem statement namely identifying happy city elements that were most important in creating happy cities.

4. Results

4.1 Selected happy city elements

This section indicated 39 elements that affect the happiness of individuals in cities, based on the opinions of these authors in the field. After a thorough research analysis, it was concluded that some of the 39 elements could be grouped together. The research has a list of 25 final elements; since 14 elements strongly correlated to some of the 39 elements.

In Table 4.1 the first column indicates the elements that were dropped; whereas column two represents the related elements with which the dropped elements correlated and with which they integrated:

Table 4.1: Elements integrated into correlating elements

Dropped elements	Final elements
1. Areas designed for social interaction 2. Considering general living and social conditions in neighbourhood 3. Social infrastructure	- Design features promoting social engagement and personal security
4. Edges 5. Elements of urban form 6. Physical urban infrastructure	- Geographical ensemble
7. Nature and open space 8. Spirit of place/ genius loci	- Access to open, natural and green space
9. Nodes	- Transportation improvement
10. Housing diversity and condition, transportation infrastructure, and polluting land uses	- Housing characteristics and quality - Transportation improvement - Land use
11. Design for easy movement in the neighbourhood	- Paths
12. Improving aesthetics by merging new buildings with existing buildings	- Public asset enhancement
13. Territoriality and permeability	- Districts
14. Density	- People-in-place

4.2 Final combined happy city elements

The combined final elements form part of the final 25 final elements. Table 4.2 lists the 25 happy city elements:

Table 4.2: 25 Happy city elements

Elements
1. Paths
2. Landmarks
3. Districts
4. Design features promoting social engagement and personal security
5. Natural surveillance
6. Target hardening
7. Crime attractors/ reducers
8. People-in-place
9. Considering access to comfort, welfare and needs for residents
10. Encouraging regular exercise in pleasing spaces
11. Designs to activate sensory stimuli of residents
12. Access to open, natural, and green space
13. Physical disorder
14. Reduction in the use of automobiles in cities
15. Establishing shared parking spaces in cities
16. Transportation improvement
17. Retail retention and attraction
18. Healthier food options
19. Food systems, availability and affordability
20. Geographical ensemble
21. Land use
22. Public asset enhancement
23. Housing characteristics and quality
24. Neighbourhood and housing stock reinvestment
25. Job development and educational opportunities

Table 4.2 lists elements that all cities need to consider. Smart cities, should focus not only on smart system and technology solutions, but also ensure all 25 happy elements are present.

City planners need to consider combining the 25 happy city elements, in order to create better living conditions;

since the presence or absence of these elements influences the happiness of the city's residents.

5. Conclusion

The literature analysis produced 39 happy city elements. Of these, 14 strongly correlated with certain of the other elements. Consequently, the integration of certain elements took place, thereby producing 25 final happy-city elements.

These elements include pathways, landmarks, districts, effective land use, geographical ensemble, public asset enhancement, housing characteristics and housing stock. Job development and education need to take place and the combating of crime is essential. The residents' comfort has to be considered with available open green spaces and access to exercise and sensory stimulation. Forms of transportation need improvement, with available shared parking and a decreased need for automobiles. Effective food systems with healthy options and retail attraction are required.

During the development of smart cities, happy city elements should be considered by role players, such as planners and architects. Creating happy smart cities, thereby improving the overall wellbeing of its residents, needs to be the aim.

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SECTION III

Extended Abstracts of Research Works-in-progress

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Has NZ's Construction Industry's Productivity Related GDP Contribution Increased by the Productivity Commission's Target of 20% by 2020

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SYNOPSIS

The construction sector in New Zealand is considered to have a continuing low level of productivity. The industry has been contributing less to the National GDP than construction industries in America, Australia and the United Kingdom. This research aimed to determine via document analysis and survey questionnaires, whether New Zealand's construction industry might accomplish a 20% increase in GDP contribution (ie 5.4% to 6.48% by 2020) as set by the Productivity Partnership in 2012. Publications suggested the construction industry's contribution to the National GDP follows the average profit-based productivity trend of four large NZX listed construction or construction related companies. If true, it is forecasted that the target of a 20% increase will not be reached. Since 2017, the four selected NZX listed companies' productivity has plateaued, or decreased. A survey questionnaire undertaken, with selected Auckland based commercial construction related employees focussed on gauging whether the respondents' companies placed an emphasis on productivity measures and reporting. The productivity results from the survey questionnaires, evidenced that managerial and human resources are plaguing the construction industry. Conversely, the results showed that management and systems enhancers are the likely factors needed to improve productivity in the construction industry.

Keywords: Construction sector, GDP, NZX, Productivity

INTRODUCTION

The Productivity Partnership formed in 2010 by the New Zealand government and industry, agreed to a common goal to improving construction productivity by 20%, by the year 2020, (Productivity Partnership 2012). The suggested areas for improvement were: Skills, Evidence, Procurement, and Construction Systems (Productivity Partnership 2012). In addition, 'The Research Strategy for the Building and Construction Industry', (BRANZ, 2013), compiled a list of research areas to be investigated being Industry structure, Productivity measures, Industry processes, Skills, Technology, Client value, Operating environment, Canterbury rebuild and Auckland's growth. In terms of industries and contributions to the economy (and Gross Domestic Product - GDP), construction's contribution has been lacking during the past three to four decades in New Zealand. When comparing New Zealand's construction GDP contribution of 5.4%, with the United Kingdom's 8%, America's 9% and Australia's 7%, it was evident there is significant potential for improvement, (BRANZ 2013). This research was undertaken to gauge how the initiative has been tracking if NZ is to reach the goal of a 20% productivity increase, and how that has been and will be evidenced and measured. The results relate to national, construction, and industry specific GDP contributions over the past 10 years, and summarise the publicly available published financial statements of four NZX (New Zealand Exchange) publicly listed construction, or construction related companies. The financial statements were compared in terms of Revenue, Profit and the Assumed Staff Hours of Work during the past 5 years. In addition, an analytical survey focussed on potential productivity

inhibitors and enhancers, was completed by respondents working in mid to large scale commercial sector construction companies in Auckland.

Defining Productivity – There are several published literature definitions-for example, The Oxford dictionary (2018) states - “*The effectiveness of productive effort, especially in industry, as measured in terms of the rate of output per unit of input*”, which aligns closely with the Productivity Commission’s view. A common line of thought was to measure productivity by dividing output by input, whilst a definition by Teicholz (2013, p.1), focussed on the greater construction industry - “*when measuring the output of the entire industry rather than a task, output (productivity) is defined in dollars of revenue (for a given base year) per work hour*”.

Fuemana *et al.* (2013), listed a lack of communication, strategic planning, management training, reviews of past projects building regulations as negative productivity drivers in New Zealand. This was confirmed by Chancellor *et al.* (2015, p.64), who stated that “*regulatory impediments hinder productivity growth*”. Lean construction principles and tools, specifically the Last Planner System (LPS), have also been suggested to improve construction productivity at a project level, (Bosnich & Kestle 2015).

RESEARCH AIM AND OBJECTIVES

The Research Question attempted to establish what local commercial construction companies know about their own productivity and whether managers are monitoring productivity levels. An additional aim was to establish what the companies knew about New Zealand’s construction sector productivity nationally. There were two sub-questions underpinning the main question - “which productivity inhibitors, accelerators, and productivity measurement methodologies are being used by commercial construction related companies in Auckland?”

RESEARCH METHODS

A mixed method research approach was undertaken involving qualitative survey questionnaires with directors, project managers, design managers, commercial managers, digital engineers and quantity surveyors, and a document analysis. Data collection focussed on current construction practice and experiences of the stakeholders. Fellows and Liu (2009) argued that survey research, has the ability to yield effective data, and Denscombe (2010) stated that “official documents present authoritative data in a short timeframe”, therefore underpinning the methods adopted for this research. The document analysis was undertaken using published statistics involving 4 large NZX construction or construction related companies’ (including the financial statements). How the construction industry is tracking since the Productivity Commission’s report in 2013 was explored using freely available online NZ Statistics databases.

SUMMARY FINDINGS

Document analysis - NZ Statistics - The NZ construction industry contributes a small percentage of the overall contribution to the National GDP. Of note is that the National GDP has increased every year, and the year-on-year the net effect has been positive for most of the past 9 years. Construction showed a decrease (negative growth) at 2011, however it has shown positive growth since.

Document analysis - NZX Companies - Productivity, when calculated using company revenue, showed slowing or negative growth. The average trend of the selected 4NZX

companies was negative from 2017 (3 of the 4 companies), and the associated productivity calculated using company profit was more pronounced compared to the revenue for the period.

Survey Questionnaire -. Productivity-reporting results - 11 of the respondents reported that their companies do measure and report on productivity, where it was being recorded, and to whom it was being reported.

RESEARCH SIGNIFICANCE

The NZ GDP has increased during the past 5-10 years, as has the construction average contribution to the GDP (44% over the past 9 years). However, the slowing /negative productivity trend from 2016, means productivity is on a trajectory to miss the 20% improvement by 2020 - (needs to be 6.48% of NZ GDP). This is due in part to Christchurch's reparatory/rebuild slowdown. The productivity inhibitor results from the survey questionnaires, showed that managerial and human resources were plaguing the construction industry, whilst management and systems enhancers were the key factors to improve productivity in the construction industry. The productivity of sub-contractors was not the primary focus of this research, but would be a relevant and related future research project as would exploring any ITA (Industry Transformation Agenda) links. Another recommendation is for government to initiate the annual preparation of a national productivity report, comprising all NZX listed companies.

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Reliable Assessment of Drawings on Architectural Technology Courses.

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SYNOPSIS

The purpose of this project is to refine and rationalise the process where different tutors assess architectural drawings in order to mitigate personal subjectivity thereby generating more reliable assessment decisions. The study seeks to provide a structured approach to drawing assessment across teaching teams to reduce possible complaints regarding apparently inconsistent results between different classes. Objectives include promoting consistent drawing assessment between tutors on level 5 drawing papers within the Unitec Diploma in Architectural Technology. A clear structured method is envisaged whereby tutors evaluate content and draughtsmanship across individual drawings to produce more consistent assessment decisions across different cohorts on papers. Methodology in this project includes document analysis of early assessment material on the relevant papers. Reflection on the value of this material towards reaching consistent assessment decisions led to the development of more detailed marking rubrics for use across numerous drawing papers. After each course iteration reflection discussions and feedback were noted regarding the utility of the resource, drawing assessment criteria and specific criteria weightings. Recent feedback indicates that the latest rubrics are effective and close to final forms. Many tutors have indicated their satisfaction with rubric design, format and ease of use. Project findings will benefit tutors across construction drawing papers, helping them generate clear, reliable and consistent assessment decisions both individually and collectively. The approach can be utilised to assess drawings at various project stages and demonstrates clearly to tutors and students what is being assessed and also importantly, how it is being assessed.

Keywords: Architectural, Drawings, Assessment, Feedback

INTRODUCTION

This study has its origins in observations of numerous approaches to assessing different architectural drawing types across 27 years of teaching including presentation drawings shown to clients and construction drawings used to build projects. With large teaching teams, a potential risk of marking diversity and surfeit of personal opinion was noted. This project investigates marking rubric development for drawings seeking to generate reliable results whilst mitigating subjective tutor opinion.

RESEARCH AIM AND OBJECTIVES

This study's objective is to generate marking rubrics enabling reliable assessment of architectural drawings within teaching teams through a clear process broken down into two main criteria, content and draughtsmanship. Aims include consistent assessment decisions based on a structured approach helping reduce potential student complaints.

RESEARCH METHODS

Methodology included literature review, reflective analysis and action research. Reflective analysis utilised the author's extensive experience of teaching drawing papers. Action research

includes discussions with Unitec colleagues in course meetings and discourse at Architectural Technology National Moderation events over the last 4 years. Literature review is mainly from books due to the lack of papers found relating to the specific research topic.

PRELIMINARY FINDINGS

Literature yielded a number of important points regarding specific architectural drawing explanations to students and for justifying assessment approaches to tutors. Drawings have an intended purpose and draughtsmen should be aware of who will view them. What are the drawings supposed to do? Why do they even exist?(Leibing, 2009). Builders are not concerned with drawing preparation methods as long as information is accurately presented and correct (Osamu A Wakita, 1999). Drawings should be comprehensible and easily understood with no unintended distractions (Ching, 2015). Literature unanimously agreed that drawings need to be clear with one stating the concept of the 4 cs. Clear, Concise, Complete and Care (Leibing, 2009). Other drawing qualities deemed essential were neatness, legibility, unambiguity and logically arranged (BRANZ, 2018). Drawing organisation was highlighted including the LACS system used in early level 4 and 5 drawing studio papers on Unitec's Diploma in Architectural Technology. LACS categorises drawings as Location, Assembly, Components and Schedules and drawing interrelationship was also emphasized (Clarke, 2016; Osamu A Wakita, 1999). Uniformity in organisation was stressed as was referencing and version control where revisions made (Ching, 2015; Clarke, 2016; Leibing, 2009). Architectural and engineering drawings need to be comprehensive, correct, accurate and informative but architects tend more to use line weight variation to communicate information and clarify exact requirements (Leibing, 2009). Clashes, where lines or symbols appear on top of others are to be avoided as these can obscure vital information. Avoiding misinterpretation is equally important with builders having apparently built unintended things such as revision clouds (Shaan Hurley, 2007). Errors can be mitigated by basic good practice such as not interrupting or crossing dimension lines nor running leader lines across details (Osamu A Wakita, 1999). Drawing content involves providing comprehensive, correct information with layout control whilst retaining intent and purpose. Checklists were seen as an effective way to confirm suitable drawing content especially where addressing regional needs and considerations necessary (Leibing, 2009). Content discussions within literature did not explicitly address drawing assessment, a prime aim of this report which focuses on construction drawings assessment but can relate also to presentation drawings intended to persuade a client of a design proposal's value (Ching, 2015). This report proposes breaking assessment of drawings down into two parts, drawing content and draughtsmanship, factors typically relevant to the vast majority of drawings whether presentation or construction. Students typically want to know What is being assessed and How is it being assessed. Literature, key words emerging such as knowledge, checklists, accurate etc equate to the What element and map easily onto the Drawing Content we will assess. Others such as graphical depiction, legible, logical sequence, neat, comprehensible etc. relate to the How aspect which again maps neatly onto the Draughtsmanship element of our assessment approach.

Drawings have relevant and complete content such as structure, construction systems and main checklist items.	0	1	2	3	4	83			
• Cover page - 2	0	1	2			2			
• Ground Floor plan - 8	0	1	3	4	5	6	7	8	8
• 4 elevations 4	0	1	2	3	4	4			
• Component drawing and Schedules. 4	0	1	2	3	4	4			
• Site Town planning 4	0	1	2	3	4	4			
• Timber Sub Floor 8	0	1	3	4	5	6	7	8	8
• Concrete Slab 8	0	1	3	4	5	6	7	8	8
• Roof framing plan 8	0	1	3	4	5	6	7	8	8
• Roof Cladding plan 4	0	1	2	3		3			
• Construction section 8	0	1	3	4	5	6	7	8	8
• Assembly details 18	0	3	6	9	12	15	18	18	
• Ext finishes schedule 4	0	1	2	3	4	4			
• Internal finishes schedule 4	0	1	2	3	4	4			
Good Draughtmanship eg:-	Fail	Ok	Excellent	Possible 30					
	0	1	2	3	30				
• Lineweights and Styles	0	1	2	3	3				
• Sheet Layouts	0	1	2	3	3				
• Set out of Notes and Legends,	0	1	2	3	3				

Figure 1: Extract of previous rubric showing assessment approach (MMG. Unitec 2017)

Figures 1 and 2 show how assessment approaches at Unitec have evolved over recent years. The 2017 rubric breaks down marking into content and drafting with guidance regarding drafting criteria. In practice it was unwieldy and cumbersome involving assessing each drawing twice, first for content then revisiting for drafting. Results were reliable but process impractical and time consuming. Reflection led to development of the 2019 rubric where content and drafting are marked simultaneously without revisiting drawings, a more efficient timely method which still maintains a rigorous and comprehensive assessment process.

		Max mark	Awarded	TOTAL
1	COVER SHEET			0
	Content	2		
	Layout Design	3		
2	SITE AND TOWN PLANNING			0
	Content	5		
	Draftsmanship	5		
3	CONCRETE SLAB PLAN			0
	Content	5		
	Draftsmanship	5		

Figure 2: Extract of current rubric showing allocations for each drawing (MMG. Unitec 2019)

RESEARCH SIGNIFICANCE

This study is important as utilising consistent approaches to assessing architectural drawings will help avoid perceptions of tutor inconsistency in marking of student work across different cohorts. The dearth of literature on architectural drawing assessment also justifies this study and its ability to progress the discussion and analysis of the main factors for consideration. This approach is a work in progress but various tutors in Unitec have used it to date and found it works well. Drawing weightings and marks allocation opinions may differ but can be discussed and adjusted. This method also recommends a professional judgement mark of significant weighting in any final rubric to moderate the overall final outcome. Unitec tutors agree that numbers alone do not tell the whole story and this professional judgement component is felt to be an important arbiter of the final grade for drawing sets submitted for assessment.

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Augmenting Industry Collaboration with Architectural Practices through Development of Productive and Fair Work Placement Schemes

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SYNOPSIS

This project investigates how industrial engagements between Unitec and local architectural practices can be reinforced through work placement schemes providing Architectural Technology students with diverse learning opportunities in real world scenarios under professional supervision.

Arrangements are discussed around scheme structures highlighting factors for consideration seeking to provide clarity and confidence for participants in their overall understanding of the scheme, its intentions and participant obligations.

The aim is to establish guidelines regarding suitable arrangements for industry, Unitec and the students setting out clear organised structures whereby local practices feel more confident in their roles thus generating positive outcomes for all. This project promotes engaging local practices more within the learning experience of placement students whilst enhancing collaboration with college tutors. Methodology involves action research, literature review and reflective analysis discussions with teaching colleagues and scheme participants.

The first placement scheme was completed with a local architectural firm in July 2019. Ideas formulated in discussions with the practice have been a success based on feedback from participants. However, reflection has identified where lessons can be learnt in aspects such as marketing of scheme to students and amendments to this and other areas will be looked at in future schemes.

The enhanced collaboration opportunities provided by the internship schemes will effectively inform teaching within the Construction school and help tutors demonstrate current practice in their delivery. A successful scheme can also provide benefits to students, the company and the college in areas such as reputation as well as strengthening industrial links overall.

Keywords: Architectural, Internship, Learning, Work placement.

INTRODUCTION

This project resulted from initial discussions with a local architectural practice around sponsorship of awards for students on Unitec's Architectural Technology Diploma programme. Rather than just presenting a certificate, plaque or cheque, it was proposed that a period of work placement within a practice would be of more tangible benefit to student's future careers. Benefits to Unitec, the students and the company were identified and backed up by literature which also highlighted a major problem with internship schemes being paid or not (Curiale, 2010).

RESEARCH AIM AND OBJECTIVES

A key motivation for the project was the opportunity to place students in real workplace scenarios which benefitted their academic studies and the educational aspects of internship type schemes led to the exploration of various work placement options. Another aim was to reinforce industrial links between Unitec and local architectural firms thereby helping Unitec ensure its Architectural Technology programmes are current, relevant and fit for purpose.

RESEARCH METHODS

The research methods for this study included action research, empirical research, literature review and reflective analysis. The study focuses on a scheme carried out in 2019 which was developed early in that year and completed in July. Information was garnered through informal interviews and discussion with participating practice staff from project conception through to completion. This process also collated scheme feedback from their side and opinions were also obtained from the two participating students.

PRELIMINARY FINDINGS

Various issues in developing placement schemes came to light with major problems including timeline, practice commitment, whether payment is appropriate and the actual design of any suitable compensation model. The form and structure of any proposed scheme was also a challenge in terms of finding a format acceptable to all stakeholders although not every participating practice may necessarily employ the same scheme arrangements, e.g. timeline or agreed means of payment. Employment education schemes can take many forms and names including internships, externships, field attachments and work placement but typically involve working in a temporary position where the focus is on education rather than employment output by the student (Weible, 2009). Durations vary from perhaps a few days or weeks to much longer periods but our programme envisaged a duration of 2-3 weeks at most. Most schemes involve partnerships between the educational institution and the business company involved and provide full or part time experience based education (Bukaliya, 2012). An additional aim of this scheme was to reinforce industrial links with local architects as a way of improving Unitec's academic standing and reputation whilst also seeking to engage students in schemes primarily providing enhanced student learning through hands on experience (Furco, 1996). Potential industry participants will have to make large commitments in terms of time for mentoring and supervision and in certain schemes, payment to the student. Some countries specify this has to be minimum wage which for a two-week scheme of 37.5 hours per week in New Zealand adds up to a substantial sum of NZD1327.50. The whole issue of unpaid internships has been a hotly debated topic in various architectural press recently and some offices are reluctant to engage in schemes which could lead to possible adverse publicity. A practice in Chile, Elemental Architects actually ended unpaid internships for this reason having being drawn into a debate highlighted by the discovery that unpaid interns in Japan may have worked on a competition winning project for the Serpentine pavilion in London (Block, 2019). Suitably detailed discussions should be held with potential practices to allay any fears they may have of reputational damage whilst also avoiding any students placed in work being exploited. The issue is a sensitive one with unpaid internships being traditional in countries like Japan and in others the laws can be complex if they exist at all (Curiale, 2010). Forms of payment whether wages, college credits or scholarships can and have been part of discussions (Callanan & Benzing, 2004).

Other factors include how much remuneration, payment form whether wages or stipends and laws which could apply (Kovacic, Vasilescu, Filzmoser, Suppin, & Oberwinter, 2015). Literature does present many fiscal aspects for consideration but the situation with regards to architectural practices has not been adequately resolved. Some architects anonymously claim unpaid internships are traditional and therefore fine whereas in the UK where unpaid internships are illegal this attitude has sparked outrage. How to develop a scheme which sits well with relevant stakeholders and ensures no workers are exploited is a significant challenge whose solution could vary depending on geographical context. This report will focus on efforts to find consensus on these matters in New Zealand. The benefits to placement scheme stakeholders are well covered in literature covering students, educational institutions and participating companies and therefore seeking to develop a scheme which will work in the local New Zealand context seems worthwhile. Advantages for students include higher starting salaries, better career preparation whilst for employers they can potentially get first choice of the best students, a consideration which local companies have already identified during informal discussions. Colleges meanwhile can benefit from improved reputation, better student recruiting, professional discipline practitioner input, and the catalyst for this study, access to forms of funding such as scholarships.

This report describes efforts made to develop a work placement scheme pertaining to local educational institutes and architectural practices. A scheme which was completed across two weeks in July 2019 resulted from meetings and discussions with representatives from Jasmex and the scheme format was tailored to their specific needs and timeline. Variations on this format could be easily made to suit other interested practices. The scheme was introduced to Unitec students in May 2019 and applications from interested students sought by May 31st. Two interns were selected in mid-June and took up their 2 week placements on 1st July. Feedback on this initial iteration of the placement has been very positive on both sides and Jasmex want to repeat the scheme in 2020. Neither of the student participants felt exploited in any way regarding lack of wages and both felt that the experience of working in such a prestigious practice was payment enough whilst also augmenting their CVs. One student stated that they would recommend the experience despite the lack of payment as they felt benefits such as company connections, networking and career motivation outweighed the lack of salary.

RESEARCH SIGNIFICANCE

The findings from this research will help inform the design of work placement schemes attractive to all stakeholders including payment issues and compensation models which sit comfortably with the practice and students involved. Open discussion on this issue will help allay fears by practices of student exploitation and highlight to students the many other tangible benefits of work placement. Factors for discussion with potential practices in addition to the above should include; scheme duration and timeline related to college academic calendar, marketing of scheme to the students in terms of format, commitment, timeline and possible duties during office placement, clarify application material required for scheme whether drawings or other media and allow sufficient time for students to collate. Ensure process is clear to students around application and submission of material for assessment. Clarify lines of communication between all parties including how students will be notified of success or otherwise. Consider the material students will submit for assessment, especially by company and workload for them involved. Establish good feedback processes involving all parties to improve future schemes and celebrate successful schemes making sure they are well publicised.

Resolution of the above will help produce a scheme acceptable to all and with good prospects of producing the benefits highlighted in literature.

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Individual Competence Requirements for Digital Technologies in Construction Management

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SYNOPSIS

Digitalisation is an important change driver in the construction industry. However, most of its potential can be lost as the industry professionals lack the required competences. This paper presents part of a larger research in progress, where the aim is to facilitate construction management professionals' development regarding the use of digital technologies to respond to the changing competence requirements in construction management created by digitalisation. In the part presented in this paper the research objectives have been to define the core terminology, to define what digital technology means in construction management context, and to identify the current demand for digital technology competences within the construction management discipline. The research as a whole is a multi-method qualitative research relying on the constructivist paradigm. The research design has some exploratory features, but is mostly descriptive. Research methods are a combination of literature reviews, document analyses, interviews and focus groups to inform the different stages of the framework development. In this part of the research state-of-the-art and systematic literature reviews, and document analysis have been used. Concepts of digital technology, construction management and competence have been defined. The nature and type of digital technologies in construction management has been discussed and digital technology related competences have been explored.

Keywords: Digital Technologies (DT), Construction Management (CM), Competences, Continuous Professional Learning (CPL)

INTRODUCTION

Digitalisation is changing both our personal and our professional lives. This change is continuous and fast paced, and it has many names: 4th industrial revolution, Industry 4.0 or Digital revolution ((Roblek, Meško, & Krapež, 2016; Schwab, 2016; Vogel-Heuser & Hess, 2016, Zezulka et al., 2016). Oesterreich and Teuteberg's (2016) systematic literature review and a case study showed that Industry 4.0 has not gained much attention yet in the construction industry compared to other industries. Friedrich et al. (2011) and Leviäkangas et al. (2017) argue that construction industry is the least digitalised industry sector. This is supported by a range of research, which shows the limited amount of investment in research and development in the sector (Barlow, 2012; Hernández et al, 2014; Morrison, 2001; Winch, 2003).

Even though lagging behind other sectors, digitalisation is emerging also in the construction industry, Building Information Modelling (BIM), cloud computing and mobile computing being the most mature technologies (Azhar et al., 2012, Oesterreich & Teuteberg, 2016). Due to digitalisation, jobs are changing and disappearing ((Degryse, 2016; Ford, 2015; Frey & Osborne, 2013; Roubini, 2015). New competences are required not only to use digital technology (DT), but also to cope with the change itself. For a construction management (CM) professional, the change involves construction technology, manufacturing technology, technology on site and the technology for the project management and communication itself.

Digitalisation has the potential to revolutionise the construction industry. However, most of its potential can be lost if the industry professionals lack the required competences. Changes are

needed both in formal education, but also when thinking what continuous professional learning (CPL) would look like.

RESEARCH AIM AND OBJECTIVES

The aim of the larger research in progress is facilitation of CM professionals' development regarding the use of DT to respond to the changing competence requirements in CM created by digitalisation. To create the framework, CM tasks will be connected with enabling and supporting DTs, the competence requirements for these DTs will be mapped and at the end these competence requirements will be addressed with appropriate CPL methods.

The objectives for the part presented in this paper have been to define the core terminology, to define what DT means in CM context, and to identify the current demand for DT competences within the CM discipline.

RESEARCH METHODS

The larger study in progress is a multi-method qualitative research relying on constructivist paradigm. The research design has some exploratory features, but is mostly descriptive, describing the identified problem more in detail, to answer the 'what' and 'how'. Research methods are a combination of literature reviews, document analyses, interviews and focus groups to inform the different stages of the framework development. For the part presented in this paper, traditional state-of-the-art literature review, systematic literature review and document analysis have been used.

Traditional state-of-the-art literature review was used to define the terms 'digital technology', 'construction management' and 'competences'.

Systematic literature review can be described as explicit and reproducible, quantitative, comprehensive and a structured process (Pickering and Byrn, 2014). During this process a selection of relevant (CM) quality assured publications with high international status were looked at to investigate

- longitudinally how often DT was discussed in the selected publications from 1985 to 2018 and through that defining the pace of change, and
- what DT were mentioned in the selected publications and how often each was mentioned, to define what DT means in the context of CM.

Document analysis using job advertisements was used to identify the current demand for DT competences within the CM discipline. This method has been used for example by Succar et al. (2013) and Barison and Santos (2011) to investigate BIM roles and required competences. The analysis was qualitative focusing on explicitly expressed DT related competences in 295 job advertisements from Finland, Singapore, UK and US. These job advertisements will also be used to define and understand the CM tasks in-depth.

At a later stage of the research document analysis with state-of-the-art literature review will be used to investigate the current CPL methods. Interviews will be used to inform and confirm the framework development and focus group to further develop and finalise the framework.

PRELIMINARY FINDINGS

For the purposes of this research, the key concepts of the research, ‘construction management’, ‘digital technologies’, and ‘competences’ have been defined through state-of-the-art literature review in Puolitaival, Davies and Kähkönen (2019):

- “Construction management addresses the forecasting and planning, organising, communicating, coordinating, monitoring, and controlling functions required to manage time, cost, quality, health, safety, security and environmental aspects of a construction project”
- “Digital technologies include all types of electronic equipment and applications that produce, store or use information in the form of numeric code”
- Work of McConnell (2001) and Winterton, Delamare-Le Deist & Stringfellow (2006) have been used to define ‘competence’. “Competence refers to an individual’s capacity to perform job responsibilities. ‘Competence’ is used as a summary term to include cognitive competence (knowledge and understanding), functional competence (skills), social competence (behaviours and attitudes) and meta-competence (facilitating learning)” (p. 4)

Through the systematic literature review approximately 100 different examples of DT in CM context were identified. The most discussed examples were BIM, digital imaging and extended reality (Puolitaival, Kestle & Kähkönen, 2018). When the DTs were investigated further, it was noticed that their nature is relatively complex including hardware and software, most often in various combinations; DTs sit at different levels, some are enabling and generic, where others are specific or applied; DTs can also mean different things to different people; and they are in constant change (Puolitaival et al., 2019).

The findings from the job advertisement analysis show that for most roles the companies “do not identify any CM specific or advanced DT competences; rather, the expectation is that employees will be proficient in general computer and office software use” (Puolitaival et al., 2019, p. 7). Digital hardware related competences were even more rarely seen. More work will be needed to understand the competence requirements fully.

The diversity of the CM tasks needs to be understood to address them appropriately in the framework. This is currently in progress and the findings will be submitted to a journal in early 2020.

The research will continue with an in-depth look into CPL methods through document analysis and literature review. The first draft of the framework will be developed after that. It will be further informed and confirmed by interviews and focus groups.

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Integrating Acoustic Scene Classification with Variable Acoustics, to Intelligently Improve Acoustic Comfort in NZ Classrooms

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SYNOPSIS

Artificial Intelligence (AI) is at the heart of our emerging built environment, as it provides increased efficiency, automation and optimization of smart building services and systems. Additionally, AI technology used in smart buildings has the potential to significantly improve occupant comfort within all main areas of Indoor Environmental Quality (IEQ); thermal, light, acoustics and air quality. Despite previous neglect, acoustics share similar importance to other IEQ's. Intelligent Acoustics (IA), an emerging concept, is achieved through the integration of Acoustic Scene Classification (ASC) a Machine Learning (ML) method, and Variable Acoustic Technology (VAT). The aim of this study is to integrate ASC with VAT toward developing IA, to improve acoustic comfort in New Zealand (NZ) classrooms. Objectively, the study will evaluate the current state of NZ classroom acoustics, and then will work to optimise the desired acoustic parameter values. An optimised IA prototype will be developed, which will use real-time sensor inputs into an ASC ML model, to mechanically adjust VAT. The effect the prototype has on acoustic comfort in NZ classrooms will be analysed, for which, a mixed field experiment of 'true experiment' and 'one group pre-test post-test' will be used to prove and demonstrate the causal relationship between IA and optimised acoustic comfort. Statistical analysis will thus reveal the impact of the developed prototype in NZ classrooms on Reverberation Time (RT) and Speech Transmission Index (STI). IA would achieve acoustic comfort by constantly maintaining an acceptable RT for any given situation or activity in any given space, seeing significant improvements in STI. If deployed, the technology would reduce distractions and disruptive noise, subsequently increasing concentration, productivity, mental wellbeing and communicative clarity within classrooms.

Keywords: Acoustic Comfort, Artificial Intelligence, Classroom Acoustics, Intelligent Acoustics, Variable Acoustics.

INTRODUCTION

Acoustic comfort can be expressed as how humans feel and perceive pleasantries within their aural environment, or the absence of unwanted sound (Vardaxis, Bard, & Persson Waye, 2018). Many spaces measure the apparent 'acoustic comfort' by how appropriate the Reverberation Time (RT) is and thus, speech intelligibility is for the unique building use (Visentin, Prodi, Cappelletti, Torresin, & Gasparella, 2018). It is not appropriate to apply one single RT to a dynamic space such as a classroom, as teaching approaches performed in typical NZ learning environments are varied in nature. When using classrooms for different purposes, inappropriate RT's arise, and reverberation effects prove problematic for acoustic comfort (Scannell, Hodgson, García Moreno Villarreal, & Gifford, 2016). Classroom activity, based on how many people in the room are speaking and at what sound level, should determine which RT is required for a space (Cummer, Christensen, and Alù (2016, p. 6). Unfortunately, the extent of present solutions which specifically address RT discomforts are inadequate, specifically in classrooms where discomforts are numerous and detrimental to the successful growth and knowledge development of children. The nature of discomforts for classrooms are all associated with an acoustic environment causing distress for speech or related cognitive tasks. Students spend a significant portion of their time at school (Ministry of Education, 2019) and since these environments are critical to the development, growth and progression of nearly the entire

population at some time in their life, it is the most critical space where appropriate RT should be addressed with VAT. Variable Acoustic Technology (VAT) solutions primarily achieve acoustic comfort by varying Reverberation Time (RT) to create consistency between room acoustics and a spaces' intended use. Advancements have been made from manual to automated VAT, with programmable automated systems achieving the highest level of intelligence for this technology. The Machine Learning (ML) method Acoustic Scene Classification (ACS) presents an attractive option to be integrated with VAT, along with sensors, actuators and wireless functionality, to see this technology develop further. ACS has been trialled in classrooms however not integrated with VAT to optimize and manipulate RT. If the acoustic comfort can be determined by how close the RT is with what is desired, ASC can be implemented by embedding pre-determined values into a mechanical VAT system, to match acoustic classifications with desired RT's.

No current systems utilize measuring instruments to detect sound and acoustic classification of building use, and adjust the RT accordingly to suit that event. Other building services have systems which can interpret data and adjust settings and variables to optimise the thermal and illumination comfort in a space. Room acoustics are yet to see these systems in place, and since there have been no papers addressing the topic area of Intelligent Acoustics (IA), no studies have suggested feasibility status of the idea. A diverse range of RT discomforts exist in our built environment, negatively impacting acoustic comfort. Through understanding these discomforts, it is possible to formulate that IA could improve health and safety, communication clarity and occupant wellbeing. IA would achieve acoustic comfort by constantly maintaining an acceptable RT for any given situation or activity in any given space. Therefore, if deployed, the technology will reduce distractions and disruptive noise, subsequently increasing concentration, productivity, mental wellbeing and communitive clarity in classrooms.

RESEARCH AIM AND OBJECTIVES

The aim of this study is to integrate ML capabilities with VAT toward developing IA to improve acoustic comfort in NZ classrooms. A research question understanding what the effect of IA in NZ classrooms has on acoustic comfort will be answered, by achieving 4 main objectives; evaluate the current state of NZ classroom acoustics, optimise the desired RT values for NZ classrooms, develop an optimised IA prototype and analyse the effect IA has on acoustic comfort in NZ classrooms.

RESEARCH METHODS

The initial research process will follow a quantitative experimental method, for structured and ridged validity (Cypress, 2017), as the nature of the research is based upon testing a device to measure quantitative improvements of appropriate RT's. Various Auckland University of Technology classrooms that resemble the population of all classrooms will be categorized. The classroom categories will include; prefabricated classrooms, small classrooms older than 10 years, medium classrooms older than 10 years, open plan / larger space, and small lecture halls. One classroom per category will then be randomly selected for initial data collection. A VAT system will be designed, constructed and set up in the spaces. The setup will be used in a normal occupied setting to develop datasets of RT's which maximise Speech Transmission Index (STI) for various aural situations and classrooms. The datasets will then be used to design an algorithm which calculates these RT values. Measured values of RT and STI will be statistically compared with desired RT and maximised STI.

This will demonstrate the error that currently exists in classroom spaces between measured and desired RT and STI. Next, audio recordings of each aural situation in various classroom spaces will be collected, to train a ML model. An IA prototype will then be built by integrating the VAT with this trained ML model, as well as other hardware and embedded software. The prototype will then be validated by comparing its function in a small test space with simulation results. Finally, the prototype will be deployed in the 5 selected spaces. New RT and STI values will be found for each aural situation whilst using the prototype in a normal occupied setting. The values of RT and STI without the prototype will be compared with the values whilst using the prototype, to determine the effect of IA on acoustic comfort. Data analysis will be conducted, comparing RT pre and post condition of using the system prototype. The mean can be used to segregate the sorted samples into statistically significant and statistically insignificant (if any) groups (Mbachu, Egbelakin, Rasheed, & Shahzad, 2017). Range, variance and standard deviation values will also be determined to summarize the outcomes of the descriptive statistics. Simultaneously, inferential statistics will be analysed using the Shapiro-Wilk method to test for normal distribution. If normally distributed, a Pairs Sample T Test will be conducted, or else a Wilcoxon Signed Rank Test, proving or disproving the null hypothesis that there are no improvements in RT or STI whilst using the prototype. Multivariate regression analysis will be conducted to determine the affective variables in the experiment.

ANTICIPATED (OR PRELIMINARY) FINDINGS

As hypothesize from literature, the expected findings of this study are to confirm the need for IA, and to reveal positive IA capabilities, demonstrating the significance this technology could have in NZ classrooms. Acoustic comfort should be achieved in accordance with AS/NZ2107:200 and optimized in the final stage on the research methodology. Technologies utilizing functional automation are shown to exhibit positive effects on enhancement and quality of life (GhaffarianHoseini, Dahlan, Berardi, GhaffarianHoseini, & Makaremi, 2013). IA is expected to achieve acoustic comfort by constantly maintaining an acceptable RT for any given situation or activity in any given space, achieving numerous extended benefits as well.

RESEARCH SIGNIFICANCE

Recently, strong links have been discovered by Reinten, Braat-Eggen, Hornikx, Kort, and Kohlrausch (2017) between room acoustics, the sound environment, and its impacts on human performance. However, their study confirmed the existence of ill effects due to an unfavourable sound environment and affirmed that the link between room acoustics and human performance was lacking in research. As part of the IEQ of a building, acoustic comfort considerations have been largely neglected in academia and industry (Al horr et al., 2016). In any instance, approximately 17% of the NZ population is attending school full time (The Ministry of Education, 2019b); (Worldometers, 2019), which is considered as 30 hours per schooling week (The Ministry of Education, 2019a), excluding higher education institutions. The criticality of these spaces, as well as the apparent lack of attention for both acoustic comfort and IA, highlights an opportunity to add significant value to academia and industry in this research area.

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Effective Deployment of Passive House in Cooling Dominated Climate

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SYNOPSIS

Currently, about 40% of energy generated globally is used within buildings, mainly for heating and cooling purposes in order to achieve a comfortable indoor thermal environment. Now due to the global warming challenge caused by the main source of energy generation (fossil fuel). It has become imperative to deploy energy efficient buildings. Also, buildings which offer conducive indoor thermal environment in order to promote healthy living. This is why the Passivhaus concept is growing rapidly. 'Passivhaus' (Passive House) is known to reduce energy use in building by about 70% and achieve indoor thermal comfort. This concept which was standardized in Germany, has seen its growth and success in other heating dominated regions such as the other parts of Europe, United States of America and Canada. But increasing energy usage and indoor thermal conditioning is a global problem.

Thus, this research aims to investigate how this concept can be effectively deployed in a cooling dominated climate. The passive house standard uses five main techniques; super insulation, air tightness, advanced window technology, heat recovery ventilation system, thermal bridge free construction. The sole aim of these techniques is to trap or retain heat in the building. However, in cooling dominated climates this is undesirable, hence passive house requires an improved understanding. This work will use building energy simulation models to explore how the Passivhaus framework responds to implementation in a cooling dominated climate.

Keywords: Cooling Dominated Climate, Passive House (Passivhaus).

INTRODUCTION

On average, people spend around 80-90% of their lives inside buildings (Al horr et al, 2016), whether at home, in offices, museum, school, health centre, shopping malls etc; hence, it is vital to achieve a comfortable indoor thermal environment within buildings. About 40% of energy consumed in a building is used for heating and cooling purposes (katili et al, 2015). The high rate and continual need for heating and cooling could suggest that currently, the indoor thermal environment is not conducive unless they are supported with mechanical systems such as heat pumps, radiators and fans which consume lots of energy. Buildings such as Passivhaus, which maximises the use of 'natural' sources of heating, cooling and ventilation to maintain a comfortable temperature range in the home can reduce the amount of energy consumed within buildings leading to an energy efficient house (Passihavs Institut, 2019).

Passivhaus uses the least amount of energy to tackle the age long problem of comfort within buildings especially in heating dominated climate. It achieves this using five basic techniques such as super-insulation, airtightness, thermal bridge free construction, advanced window technology and heat recovery ventilator (Passivhaus Institut, 2018). The concept has seen its growth in countries around the world especially heating dominated climate like parts of the United Kingdom, United States of America, Australia and Canada but not so much in cooling dominated climate most of which lie in the tropics ((Passihavs Institut, 2019). Cooling dominated climate is the term used in this paper to define regions where cooling is

predominated required more than heating and/or where heating is negligible such as most countries in the tropics. Currently, around 40% of the world's population live in the tropics. The United Nations in recent report (UN, 2017) stated that at current rates of population growth, by 2050, more than half of the world's people will live in the tropics. Therefore, deploying this concept also in the cooling dominated climate will play a significant role towards achieving global sustainability.

RESEARCH AIM AND OBJECTIVES

The aim of this work is to develop a standardized technique which can be used to achieve Passivhaus in cooling dominated climate as the five basic technique currently used, were developed with the heating dominated climate as the focus. Hence, the research question;

How can the passive house standard be achieved in cooling dominated climates?

RESEARCH METHODS

This research will be carried out using computer simulation. A reference building (Tseri Passive House) was chosen to form the basis for the research work. The building is a Passivhaus certified building in a sub-tropical region (Cyprus). The sub-tropical region which could sometime have very hot weather similar to those experienced in the tropics could give us some insight on how to achieve a passive house in the tropics. Also, the “Tseri Passive House” has been tested for its post occupancy performance. This post-occupancy data can be used to validate results from the computer simulation carried out and in addition could inform the direction of this work. The study will be carried out in three research phases (RP).

RP 1: Simulation of the reference building using computer modelling package (Integrated Environmental Solutions-Virtual Environment). Research phase 1 will investigate how a certified Passive House in a heating dominated climate functions in a cooling dominated climate. Does the building achieve thermal comfort and meet the requirement under the passivhaus framework?

RP 2: Result Analysis

According to (Schnieders et al, 2015), the basic principle of the Passive House is to minimize all heat flows at and within the building envelope. Therefore, Phase 2 will investigate how the building envelope (Table 1) affects the thermal performance of the building. Using computer simulation to examine the effect of each factor (such as orientation of windows, glazing, thickness of insulation, and natural ventilation) on the indoor temperature and energy demand for the building.

Table 1: Reference building (Tseri Passive House), Building Elements Thermal Transmittance ($\text{W}/\text{m}^2\text{ }^\circ\text{C}$) according to (Fokaides et al, 2016).

Building Element	Thermal Transmittance ($\text{W}/\text{m}^2\text{ }^\circ\text{C}$)	Minimum NZEB Requirements ($\text{W}/\text{m}^2\text{ }^\circ\text{C}$)
External walls	0.18	0.4
Roof	0.15	0.4
Ground floor slab	0.48	N/A
Window frame	1.3	
Glazing	0.8	2.25

RP 3: Application of findings from RP2

In the final research phase, following the outcome of RP 2, a Passive House suitable for a cooling dominated climate is designed. The design is based on the architectural model of the reference building, using same building geometry. However, the envelope of the building (thermal transmittance) and other factors are modelled on the inferred outcome from RP 2 in order to adapt to the cooling dominated climate. Indoor temperature and humidity can be a challenge in the cooling dominated (Schnieders et al, 2015) and (Fokaides et al, 2016). Hence, these factors will also be observed.

PRELIMINARY FINDINGS

Reviewing diverse research on Passive House, it is clear that there is huge interest and prospect for Passivhaus. As summarized in (Fokaides et al, 2016), the performance of Passive House in various climate research shows that under extreme climatic conditions Passive Houses fail to meet the design limits (Kylili, et al, 2017).

As seen in the Camden Passive House which is the first new London dwelling certified to the Passive House Standard. Ridley et al, (2013) reported that although airtightness standard, measured specific fan power, efficiency of the Mechanical Ventilation with Heat Recovery (MVHR) met passive house standards, and the indoor air quality good; the annual primary energy demand was $125\text{kWh}/\text{m}^2$, marginally above the $120\text{kWh}/\text{m}^2$ target. The measured internal heat gains of $3.65\text{W}/\text{m}^2$, 43% more than the standard value $2.1\text{W}/\text{m}^2$ suggested as standard for dwellings. Overheating during the summer was also observed.

In another study carried out by (Rhodin et al, 2014), reporting on the experience of the occupants from nine passive houses built in Linköping (Sweden). Comparing with conventional buildings, as regards the indoor thermal comfort and the use of energy. It was discovered that the indoor thermal environment is generally found to be good; however, the post-occupancy evaluation revealed complaints of discomfort by occupants including cold floors in winter and larger air temperature variations and higher summer air temperature (Rhodin et al, 2014). Reporting that there are higher number of complaints related to high temperatures during summer in the Passive Houses. And the effect of varying temperatures was also observed in the Passive Houses to a higher degree than in the more conventional buildings (Rhodin et al, 2014).

Schnieders et al. (2015), presented a detailed study about Passive Houses in different climate zones represented by Yekaterinburg, Tokyo, Shanghai, Las Vegas, Abu Dhabi and Singapore.

This work employed hygrothermal dynamic building simulation to prove that the realization of Passive House in climates that differ fundamentally from central Europe is achievable. It also revealed that although annual energy demand for space conditioning of the Passive Houses is 75 to 95% lower than that of a traditionally insulated building of the same geometry (Schnieders et al., 2015). In hot and humid climate, the total useful energy demand for sensible and latent cooling may exceed 70kWh/(m²a) even in a Passive House (Schnieders et al, 2015). It showed that in hot and humid climate the cooling load exceeded the standard requirement of 15kWh/(m²a) by about 300%. Also, that in humid climates like Shanghai or Singapore, a special attention must be paid to humidity.

RESEARCH SIGNIFICANCE

So far, various work done on Passive House especially in relation to post-occupancy, shows there is a reoccurring issue of overheating during summer periods even though the passive house standard is met.

This further reinforces the need for improved understanding of this concept, specifically in the cooling dominated climate. Therefore, developing a standardized technique applicable in the cooling dominated climate to achieve both an ‘acceptable’ indoor thermal environment and passive house framework will further inform the improvement of the Passivhaus framework.

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Climate Change Adaption Legislation and the Construction Sector

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SYNOPSIS

Climate change will inevitably, drastically impact the coastal nation of New Zealand. Through literature review, it was identified that much of the existing work in relation to climate change literature, legislation and policy had been focused on mitigation, or carbon emission reduction, and very little had looked toward future-proofing and adaptation processes.

This research paper aimed to answer the research question below:

“Which countries have climates similar to that of New Zealand, what are their climate change and adaptation legislative approaches, and which of these approaches could potentially be adopted in New Zealand in relation to the NZ Construction industry?”

The aim of this research was to purposefully establish understanding of relevant international adaptation approaches, identify which, if any, could be relevant to the New Zealand context and/or inform potential process change in relation to the construction industry.

This research focused on climate change adaptation;

- 1) Identification of countries with a similar climate to New Zealand;*
- 2) Document Analysis to identify and analyse international climate change, adaptation, and construction sector legislation processes;*
- 3) Interviews to reflect on, discuss and identify potential approaches to apply to the New Zealand context.*

Preliminary findings showed that very few countries have looking toward future adaptation, and even less connect adaptation to the construction industry. Norway’s approach looks to be the most relevant to New Zealand, in relation to technical requirements, moisture management, zoning and flood risks. Interviewees unanimously agreed that our government makeup, culture and current processes may in fact require a mixture of adaptation and mitigation strategies.

Keywords: Adaptation, carbon emissions, climate change, frameworks, legislation.

INTRODUCTION

A Literature Review undertaken focused on the topic of climate change and its impact on the construction industry both internationally and in New Zealand. Through exploration of the this topic through themes such as project management (delays, material availability, etc.) productivity/performance/H+S (temperature thresholds), and legislation and policy change (including to contracts, building codes, HSWA, etc.), it became clearer how vitally important it

is becoming to understand and adapt to the inevitable impact of climate change on New Zealand and the New Zealand Construction Industry.

Literature explored in IP1 looked to a small number of countries (UK, Germany, USA, Australia) being identified as having current climate change and adaptation legislation processes underway that were of interest to the NZ scenario. Other than the one Ministry for the Environment document referenced, there was little literature found that specifically identified other current international processes. This research paper looked to do a more thorough exploration of relevant international documents, analysing and comparing them in order to inform which approaches (linking down and incorporating to industry and construction) could be potentially adopted in New Zealand.

RESEARCH AIM AND OBJECTIVES

The aim of this research was to purposefully establish understanding of relevant international adaptation approaches in order to identify which, if any, could potentially be relevant to the New Zealand context and used to inform potential future processes within New Zealand. The research focused, as closely as possible, on legislation that linked back to the construction industry.

RESEARCH METHODS

This research focused on climate change adaptation, first identifying countries with a similar climate to New Zealand, and then undertaking Document Analysis to identify and analyse each country's climate change, adaptation, and construction sector legislation. Finally, interviews were coordinated with leaders in the climate change realm in New Zealand, all with different experience and perspectives (climate strategist, MfE, List-MP, Senior Research Fellow (VUW), in order to reflect on these documents and discuss different perspectives on each identified approach and potential application within the New Zealand context.

ANTICIPATED (OR PRELIMINARY) FINDINGS

Preliminary findings were different to that anticipated, with far fewer countries having implemented adaptation legislation honing down into enough detail to consider the construction industry than expected (only Netherlands, Denmark, Germany, Norway and Australia). Norway's approach was identified as being most relevant to New Zealand, focusing on legislation amendment in relation to technical requirements, moisture management, zoning and flood risks (Regjeringen, 2019).

COUNTRY	APPROACH
Netherlands	Built environment specifically addressed in relation to future spatial adaptation to ensure climate proof and resilient future urban design (Delta Plan on Spatial Adaptation, 2018) (Ruimtelijkeadaptatie, 2018).
Denmark	Regional plans such as the (Copenhagen Climate Adaptation Plan 2011) delves into specific impacts in relation to the Copenhagen context, identifying legislation requiring amendment, as well as adaptation in relation

	to the building context via design approaches ensuring a resilient housing stock. The (Copenhagen Building Act 2010) is an example of a piece of legislation that has been constantly reviewed to keep up with climate change impact expectations. (Klimatilpasning, 2011; IEA, 2010).
Germany	(The German Government's Climate Action Programme 2020) mentions housing, but mostly in relation to mitigation (climate neutral building stock). The (Climate Action Plan 2050) mostly explores a mitigation focus, however, touches on reviewing design standard legislation towards a climate neutral building stock. The (German Strategy for Adaptation to Climate Change 2008 (amended 2011)) discusses amending legislation in relation to zoning and flood risk in relation to climate change predictions. (BME, 2014; LSE, 2016; Prevention Web, 2011).
Norway	(Meld. St. 33 2012–2013 Report to the Storting white paper - Climate change adaptation in Norway) mentions amendments to legislation such as the Planning and Building Act (via technical requirements, moisture management, land-use planning/zoning) discussed, but nothing yet amended. (Regjeringen, 2019).
Australia	(National Climate Resilience and Adaptation Strategy 2015) Framework establishing priorities for action, while also enabling informed engagement of people/institutions/sectors. Each state works to determine their own specific approaches. (Pathways to a climate resilient Queensland - Queensland Climate Adaptation Strategy 2017–2030) enables sectoral adaptation approaches such as the (Built Environment and Infrastructure Sector Adaptation Plan 2017) formalising work done between specific sector parties and govt in relation to climate change adaptation in line with the Q-CAS. (Australian Government, 2015; Queensland Government, 2017; Queensland Government, 2017).

Table 1: Adaptation approach findings broken down by country.

On reflection over their own experience, and the documents analysed, interviewees agreed that due to our government makeup, culture, industry strength and relationships, and current processes in line with legislation, a mixture of adaptation and mitigation strategies may in fact be a better way forward than solely focusing on one or the other. Participant A identified there are non-legislative approaches that combine mitigation and adaptation currently occurring in places such as Germany that may be an alternate solution for New Zealand. Participant B identified new processes occurring within government in line with the Zero Carbon Bill, including establishment of an independent Climate Change Commission, will ensure climate change is an active consideration across all legislation. Participant C also identified that new world-leading research in process in relation to decision-making under uncertainty would unlock the potential to apply flexible thinking to all future decision-making.

RESEARCH SIGNIFICANCE

As the impacts of climate change are now considered to be inevitable, considerations of the impacts of climate change and close communication with those implementing legislation reviews that will affect the future of the construction industry is vital. Discussion and debate within the construction industry must begin occurring now for us to adapt in time for anticipated impacts, which are already being felt across the globe. The sooner we establish how best to make this happen, the better for the industry.

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