



**Achieving Sustainable Construction through
Construction & Demolition Waste
Minimisation in Residential Building Projects**

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Abstract

Human desires and their fulfilment through urbanisation have become a global environmental concern. In addition, the factual claims made on socio-economic and environmental benefits achieved through Construction & Demolition (C&D) waste minimisation, are yet to be fully explored. This research sought to find out the contribution of C&D waste minimisation, to Sustainable Construction.

Worldwide, the Construction Industry (CI) is considered as an instrument for economic growth and employment. As an industry, construction accounted directly for 6% of global GDP. In New Zealand (NZ) the building and construction sector contribute 7% to the nation's GDP. Further, the residential sector in NZ contributed up to half of the total construction value.

The NZ CI is in a period of growth and expected to remain a significant contributor to the national construction value. However, the CI's growth is occurring at the expense of social, environmental and economic impact on the New Zealanders. The impact has urged the need for Sustainable Construction (SC) for the NZ CI. SC is a well-known concept, which is used as a method to optimise resource consumption, minimise waste and maximise investment returns. Three key aspects of SC are social, economic and environmental. All SC aspects are independent yet interlinked. Some of the important environmental elements are resource consumption, land and water pollution, energy consumption and C&D waste.

The literature finding that brought attention was C&D waste labelled as the third largest waste stream in the world, largest waste streams in Auckland and NZ. However, less interest has been shown in minimising C&D waste, especially through life cycle thinking i.e. pre-design, design, construction, refurbishment and demolition. In addition, knowledge gaps exist in the implementation of C&D waste minimisation approaches to advocate SC. The overarching aim to develop a C&D waste minimisation framework considering life cycle thinking is achieved through a mixed-method approach.

This study conducted semi-structured exploratory interviews and on-site observations to achieve the research aim. A pragmatic approach was adopted for the data collection. Further, data analysis was done through multiple techniques, for example. thematic analysis, content analysis and descriptive analysis.

The finding of this study provided factors influencing C&D waste, challenges in C&D waste minimisation and their remedial measures. In the pre-design stage, contractual requirements were identified as the most influencing factors and the top challenge. One of the remedies, is putting a waste minimisation clause (mandatory/voluntary) in the contractor document. Subsequently, in the design stage, the circular economy was identified as the most influencing factor and a leading challenge for CI practitioners, which needs to be addressed through client education and demand. Further, in the construction stage, waste sorting was the most influencing factor and the top challenge. Contractors need to use multiple bins on-site depending on the activities and educate site labourers through tool-box meetings to sort waste efficiently. In the refurbishment stage, environmental impact of refurbishment waste was the most influencing factor and key challenge. The remedy for this challenge was found to be the introduction of compliance for reuse. In the demolition stage 10R thinking (Refuse, Rethink, Reduce, Reuse, Repair, Relocate, Remanufacture, Repurpose, Recycle and Recover) and waste levy, were the most influential factors and top two challenges. Increase in waste levy for landfill and introduction of waste levy for C&D waste fills, was noted as a positive step towards waste minimisation. 10R thinking needs to be stimulated in the Auckland CI through: providing technical and financial guidance to innovative businesses; investing in remanufacturing and recycling infrastructure; and commercialisation of innovative waste minimisation ideas.

This study proposes a waste minimisation framework and required actions from clients, contractors and policymakers and influencers to promote C&D waste minimisation. Some of the most significant actions are:

- Client: Demand for eco-labelled materials and changed attitude towards second life products.
- Contractors: Establish SC group and implement product stewardship scheme
- Policymakers and Influencers: Support innovative businesses

For efficient waste minimisation, actions from one group requires support from other two groups. For instance, if policymakers decide to fund community recycling centres, the client needs to demand sustainable materials, and contractors need to use them. The proposed waste minimisation framework attempts to promote C&D waste minimisation and serves as a guideline for practitioners and researchers to establish a link in current research areas and future trends.

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List of Abbreviations and Acronyms

10R	Refuse, Rethink, Reduce, Reuse, Repair, Relocate, Remanufacture, Repurpose, Recycle and Recover
AMOS	Analysis of Moment Structures
ANOVA	Analysis of Variance
AUT	Auckland University of Technology
AUTEC	Auckland University of Technology Ethics Committee
BIM	Building Information Modelling
BRANZ	Building Research Association New Zealand
BRE	Building Research Establishment
C&D	Construction and Demolition
C&I	Construction and Industrial
CI	Construction Industry
CSR	Corporate Social Responsibility
DEFRA	Department for Environment, Food and Rural Affairs
DoW	Design out Waste
DoWT-B	Designing out waste tool for buildings
DP	Dynamic Programming
ECNZ	Environmental Choice NZ
EECA	Energy Efficiency and Conservation Authority
EPA	Environmental Protection Authority
EPD	Environmental Product Declaration
EU	European Union
GDP	Gross Domestic Product
GHS	Green Home Scheme
GOS	Green Office Scheme
IETC	International Environmental Technology Centre
IgCC	International Green Construction Code
IPENZ	Institution of Professional Engineers NZ

JIT	Just In Time
KPIs'	Key Performance Indicators
LC	Lean Construction
LISREL	Liberal Structural Relations
LP	Linear Programming
MDF	Medium Density Fibreboard
MSW	Municipal Solid Waste
NABERSNZ	National Australian Building Environmental Rating System New Zealand
NZ	New Zealand
NZD	NZ Dollar
NZTA	NZ Transportation Agency
OECD	Organisation for Economic Co-operation and Development
PCG	Project control Group
PIS	Project Information Sheet
PwC	PricewaterhouseCoopers
R&D	Research & Development
RBNZ	Reserve Bank of New Zealand
REBRI	Resource Efficiency in the Building-Related Industries
RMA	Resource Management Act
SAS	Statistical Software Analysis
SC	Sustainable Construction
SCM	Supply chain Management
SPSS	Statistical Package for Social Sciences
StatsNZ	Statistics NZ
TUSC	Tools for Urban Sustainability code of practice
UK	United Kingdom
UN	United Nations
UNEP	UN Environment Programme
UNESCAPE	UN Economic and Social Commission for Asia and the Pacific

UNSD	UN Statistical Division
US	United States
USD	US Dollar
USEPA	US Environment Protection Agency
VP Vector	Programming
WasteMINZ	Waste Management Institute New Zealand
WGBC	World Green Building Council
WMA	Waste Minimisation Act
WMIF	Waste Minimisation and Innovation Fund
WMMP	Waste Management and Minimisation Plan
WRAP	Waste & Resources Action Programme

List of Publications

Conference

1. Gade, R., Seadon, J., & Poshdar, M. (2020). The New Zealand construction industry and sustainable construction through C&D waste minimisation: A review of the life cycle approach. 54th International Conference of the Architectural Science Association 2020, Ali Ghaffarianhoseini, et al (eds), pp. 1165–1174. © 2020 and published by the Architectural Science Association (ANZAScA).

Research Report

1. Gade, R., Aladwan, A., Seadon, J. (2020). End-of-life carpets: Achieving a circular economy through circular resources. Jacobsen Creative Surfaces Ltd.

Awards

1. Won AUT X-challenge ‘The Idea’ Award (2019 and 2020) through presenting PhD research as a business model.
2. Semi-finalist of New Zealand Green Building Council ‘Future Thinker of the Year Award’ for 2019 and 2020.
3. Semi-finalists of ‘Niesh: on pitch’ Business model competition 2020
4. Top 8 finalist in Entrepreneurship competition: X Challenge – Accelerator round, Auckland University of Technology, 2020

Presentations

1. Presented a research poster at AUT Post Graduate Symposium 2019.
2. Presented a research poster at Manufacturing, Design and Entrepreneurship (MaDE) 2020 conference

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined the in the acknowledgements), nor material which to a substantial extent has been submitted for the awards of any other degree or diploma at a university or other institution of higher learning.

In accordance with the School of Engineering, Computer and Mathematical Sciences guidelines, this thesis does not exceed 100,000 words (excluding bibliographies and appendices).

Rohit Jindas Gade

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Dedication

This Doctoral thesis is dedicated to:

Almighty GOD;

The Undisputed Champion, Chhatrapati Shivaji Maharaj;

My Father, Dr. B.R. Ambedkar;

My Parents, Ujwala & Jindas Gade;

My Guardian Angels, Rahul, Pallavi, Gayatri and Nikhil;

AND

To all those who we lost to COVID

Chapter 1 Introduction

1.1 Background to the study

The Construction Industry (CI) accounts for 6% of global Gross Domestic Product (GDP). In New Zealand (NZ) the building and construction sector contributed 7% to the nations GDP (MBIE, 2021). In addition, CI was the fifth-largest sector in NZ. The NZ residential construction sector comprises half of the total construction (MBIE, 2021). The CI makes a significant contribution to economic growth and job employment in NZ. By 2024, the CI was predicted to reach NZD 48 billion and remain one of the largest employment sectors (MBIE, 2020b). However, the contribution and growth of the sector impacts the extraction of natural resources and poor control over the consumption of resources and creates need for sustainability in construction (Build Waikato, 2018).

Sustainable Construction (SC) is a well-known concept worldwide. SC covers social, economic and environmental aspects of construction over the life cycle of a project. SC is a creation of a healthy building environment through optimising resource consumption with minimum or no environmental damage and maximum financial benefits (Kibert, 2008). Further, SC optimises resource consumption and improves living standards of communities through economic growth and cost savings (Gan et al., 2015).

Almost 50 % of materials extracted from the earth is converted into building material (World Economic Forum, 2016), but CI suffers from their wasteful consumption. Construction and Demolition (C&D) waste was reported as the third largest waste stream in the world followed by Municipal Solid Waste (MSW) and Commercial & Industrial (C&I) waste (UNEP, 2015b). In contrast, in higher-income Organisation for Economic Co-operation and Development (OECD) countries, C&D waste was the largest waste stream (UNEP, 2015b). In 2018, C&D waste was the largest waste stream in Auckland which lowered the environmental standards of the region , while MSW had a steady growth and C&I waste had rapid growth (Auckland Council, 2018b). C&D waste was forecasted as the most prevalent waste stream in Auckland (Auckland Council, 2017).

The NZ government, research institutes and academic scholars proposed solutions to C&D waste minimisation. However, the knowledge gap in practice still exists in

understanding and implementing the waste minimisation approaches such as governing guidelines, regulations, and tools (Auckland Council, 2019). It has been argued that SC could be promoted through C&D waste minimisation. For instance, C&D waste minimisation reduces the environmental burden as it reduce greenhouse gas emission (Cruz et al., 2019). In addition, C&D waste minimisation provides social benefits such as high standard of living, health and safety and job employment through recycling (Nižetić et al., 2019). Moreover, C&D waste minimisation promotes optimising consumption of resources and reuse of waste, which saves material cost, waste transportation cost and disposal cost (BRANZ, 2014). Thus, C&D waste minimisation provides social, economic and environmental benefits.

Studies on C&D waste minimisation found that C&D waste is generated in different stages over the life cycle of a project. However, there is a lack of empirical research on C&D waste generation and minimisation over the life cycle of building projects (Rosado et al., 2019). In addition, the academic scholars, industry practitioners and Auckland Council have recognised the need for C&D waste minimisation (Auckland Council, 2018b). Thus, this research aims to propose a C&D waste minimisation framework through its objectives and research questions. It also investigates C&D waste minimisation challenges faced by the Auckland CI and provides remedial measures through a waste minimisation framework.

1.2 Rational and Significance of the Study

The primary focus of this research is to learn how SC can be achieved by minimising C&D waste that is generated during pre-design, design, construction, maintenance, refurbishment, and demolition stages of the project. A building construction project that aims to deliver environmental aspects also expects to deliver good standards of living, by encouraging community wellbeing, cost savings, and equal responsibilities; promote overall sustainable construction (Akotia, 2014; Gan et al., 2015). Further, building projects expect to deliver aforesaid factors by understanding the concept of sustainability and by considering the future growth of the CI (Gan et al., 2015).

In 2018, the New Zealand CI was in midst of its growth and for every ten-working people in New Zealand, one was a CI employee with Auckland as the largest labour market (StatsNZ, 2021). The CI became an integral part of New Zealand's overall development, but this development came with concerns of C&D waste. During the same

year, C&D waste contributed to up to 50 % of total landfill waste (Purchas & Ainsworth, 2019).

Though the CI adopted several guidelines and approaches such as the waste management hierarchy, Resource Management Act (1991), Building Act (1991), and Waste Minimisation Act (2008) for achieving SC through C&D waste minimisation in last three decades, the issue still exists and in recent years it became a growing concern in many regions, including Auckland (Auckland Council, 2018b). In 2018, C&D waste in the Auckland region contributed to 40 % of total landfill waste (NZ Transport Agency, 2019). In addition, Auckland CI spent NZD 100 million to dispose of C&D waste during the same year (Thiele, 2019).

Several attempts have been made to find waste minimisation solutions. For instance, involving stakeholders early in the process, promotion of online resource sharing platforms, incentivising recycling infrastructure and creation of secondary and tertiary markets for second and third life products (Gan et al., 2015). The Auckland CI is looking to achieve circular economy through circular resources considering the life cycle of building projects. However, the literature survey concluded that understanding C&D waste, its extent, and the performance of C&D waste minimisation approaches considering the life cycle of project, have not been studied in the Auckland CI (Auckland, Council, 2022). This research aims to analyse C&D waste problem and its extent in Auckland and proposes a waste minimisation framework for minimising environmental burden, uplifting social standards of the community, and provide economic benefits to the project. The social, economic and environmental aspects of SC are interlinked, and this study aims to propose a C&D waste minimisation framework to advocate overall sustainability in construction.

This research examines the life cycle of a building project to develop a relationship between C&D waste minimisation challenges and their occurrence during different stages of the project. This is to divide all the waste minimisation challenges into stages and provides remedial measures for each challenge from all stages, through a waste minimisation framework. This study aims to promote a healthy building environment by suggesting optimised resource consumption, less waste generation, and effective waste management at the end of the life cycle. In addition to environmental benefits, this research also provides financial benefits such as lower waste disposal cost, cost-saving on use of recycled materials, and employment opportunities in the recycling market.

Moreover, C&D waste minimisation will also help to increase social standards of living by promoting an overall sustainable building environment.

1.3 Research Focus

This research focuses on achieving SC. The significance of the research has already established the need for waste minimisation and its contribution to SC. The following subsections discuss the key elements that would help to construct a clear research focus.

1.3.1 Research Aim

To propose a Construction & Demolition waste minimisation framework for the life cycle of building projects to support Sustainable Construction

1.3.2 Research Objectives

- To investigate C&D waste generation over the life cycle of building projects;
- To analyse factors influencing C&D waste generation to find its causes and the challenges of waste minimisation;
- To examine C&D waste minimisation approaches used in Auckland CI
- To propose a better waste minimisation approach.

1.3.3 Research Questions

1. How is C&D waste generated throughout the lifecycle of building projects?
2. What are the available techniques for C&D waste minimisation?
3. How can a Waste Minimisation Framework aid C&D waste minimisation to improve the sustainability of buildings?

1.4 An overview of Research Methodology

This research was carried out in five steps which are as follows: i) literature Review; ii) Semi-structured interviews; iii) on-site observations; iv) data analysis, and v) development of waste minimisation framework.

Literature Review was conducted to understand the nature of the problem and its extent. The literature examined the CI and its contribution to the economic growth. Further, SC related challenges were discussed focusing on C&D waste. Subsequent sections present state-of the art of C&D waste and its minimisation and develop a

theoretical waste minimisation framework. In addition, the literature identified a knowledge gap and set a foundation to build a research aim, objectives and questions.

Semi-structured interviews were conducted to collect exploratory data from client representatives, contractors and policymakers and influencers. The philosophical stance of this research adopted pragmatism and considered a combination of positivism and interpretivism, to introduce different perceptions on the research; ultimately to increase the reliability of the research (Creswell 2007). The semi-structured interviews were conducted in two parts: pilot interviews and main interviews. In the pilot interviews, six participants (Client representatives, contractors, and policymakers and influencers-2 from each group) were interviewed and subsequently, 31 participants were interviewed for main interviews. The pilot interviews helped the researcher to get insights of Auckland CI.

On-site observations were conducted on nine sites (construction, refurbishment and demolition- 3 from each category). The observations provided a realistic view on the opinions offered by participants during the semi-structured interviews. The observations also validated the findings of interviews.

Data analysis helped to draw results and discussion of the research. The data collected during semi-structured interviews and on-site observation was qualitative and quantitative in nature, respectively. Themes generated qualitative data that was converted into factors that influence C& D waste. In total, 36 factors were identified and labelled from F1- F36. Further, quantitative data analysis confirmed the presence of the factors. Combined, qualitative and quantitative findings guided the researcher to recognised opportunities and challenges in C&D waste minimisation. Further, data analysis also provided remedial measures for the waste minimisation challenges.

Waste minimisation framework was developed to support SC through C&D waste minimisation. The framework included remedial measures for each challenge that occurred during the life cycle of building project. In addition, required actions of clients, representatives, contractors and policymakers and influencers to support SC were discussed.

1.5 Outline structure of the thesis

Chapter 1 (Introduction) presents an overview of thesis starting with the background of the study followed by the rationale and significance for undertaking this study.

Subsequently, the research focus is discussed in the context of research aim, objectives and questions designed for this study. Further, the research methodology that helped to achieve the research aim is explained. The chapter concludes with the structure of the thesis.

Chapter 2 (Literature Review) discusses literature from a historical perspective to state of the art and established a knowledge gap for this research. This chapter studies three key themes: Sustainable Construction; C&D waste; and C&D waste minimisation. Further, the key themes are examined to understand the flow and progress of literature. The chapter then identifies a knowledge gap and establishes a foundation for the research methodology.

Chapter 3 (Research Methodology) presents the methodological approach adopted to fill the knowledge gap and achieve research aim. It starts with the establishment of philosophical stance of this study. Subsequently, different research approaches, techniques and strategies are explored to select a data collection method. Further, data collection and analysis process are discussed. Thereafter, ethical considerations adopted for the research are reported followed by a justification for the credibility of the findings. The chapter concludes with a summary.

Chapter 4 (Results) presents the findings of the semi-structured exploratory interviews conducted with clients' representatives, contractors and policymakers and influencers. Subsequently, on-site observations conducted on nine sites were discussed. The chapter then combines the findings of interviews and observations and discusses C&D waste influencing factor over the life cycle of the project. Further, a summary is provided to conclude the findings.

Chapter 5 (Discussion) presents findings of the discussion reported in Chapter 4. The chapter begins with discussion on C&D waste minimisation challenges and presents different perspectives of participants based on their category. Subsequently, remedial measures for the identified challenges are discussed and literature references are made to supports the argument wherever necessary. Thereafter, a waste minimisation framework is proposed to achieve SC through C&D waste minimisation over the life cycle of the building projects. The chapter concludes with a summary.

Chapter 6 (Conclusions and Recommendations) concludes the study by integrating the research findings with research objectives. Further, contribution to knowledge is

discussed followed by recommendations for the industry practitioners, policymakers and future researchers. Subsequently, the chapter describes research limitations and provides concluding remarks on the research.

Chapter 2 Literature Review

2.1 Introduction

This chapter presents literature that compares New Zealand with the world on themes such as the economic contribution of the Construction Industry (CI), the status of Sustainable Construction (SC), Construction & Demolition (C&D) waste and its extent and C&D waste minimisation approaches. The chapter opens with a definition of CI, followed by its history. Further, the chapter discusses the economic impact of construction activities and the future of CI. The chapter then overviews SC and its challenges around the world. Further, one of the most prominent challenges, i.e. C&D waste, is examined to establish a relationship between C&D waste minimisation and SC. Lastly, the chapter assesses state-of-the-art waste minimisation approaches followed by a knowledge gap discussed in the summary section.

2.2 Definition of Construction Industry

There are many definitions for the CI and as the construction sector increasingly diversifies, it looks for a more specific definition (Fernandez-Solis & Arch, 2019). The CI is considered part of the process that creates a sustainable building environment (Manewa et al., 2016). CI involves the construction of residential buildings, commercial buildings, offices, healthcare, educational, religious, public safety, amusement, transportation, sewage, and waste disposal (United States Census Bureau, 2009). CI is seen through different perspectives and has several different definitions. CI is defined as a team of people executing economic building activities, including construction, renovation, and repair (United States Census Bureau, 2009). In addition, CI is also defined as the sector of the national economy engaged in the preparation of land and construction, alteration, and repair of buildings, structures, and other real property (Fernandez-Solis & Arch, 2019). The land preparation represents horizontal construction industry and includes construction, alteration and repair of roads, bridges, pipelines and electric lines, while the vertical construction industry includes but not limited to apartment buildings and skyscrapers (North American Industry Classification System, 2017).

The most commonly known and worldwide adopted definition of CI was established by International Standard Industrial Classification (ISIC). Construction of new work, repair, additions and alterations, the erection of prefabricated members in permanent or

temporary nature is known as the CI (ISIC, 2008). ISIC divided CI into 1) general construction and 2) special construction. Each type of building work is covered in these two categories. Individual countries have adapted these definitions, as shown by the examples in Table 2.1.

Table 2.1: Definitions of Construction Industry

Country	Definition of CI	Reference
Australia and NZ	CI includes the construction of buildings and other structures with their additions, alterations, reconstruction, installation, maintenance, and repairs, while it excludes manufacturing	Australian and New Zealand Standard Industrial Classification, 2006
United States of America	Execution of building works, heavy and civil engineering works, and special works such as site preparation, plumbing, are sectors used to define CI	North American Industry Classification System, 2017
United Kingdom	The construction industry is defined as a branch of manufacturing and trade based on building, maintaining, and repairing structures	UK Standard Industrial Classification, 1996

The definition of CI is similar around the world. The slight changes occur due to the addition or subtraction of the sub-sectors it covers (Australian and New Zealand Standard Industrial Classification, 2006). In Australia and NZ, CI excludes manufacturing, but in the UK CI includes manufacturing as building construction may be termed as mass production of similar items (UK Standard Industrial Classification, 1996). In the USA, the definition is similar to Australia and NZ definition, but it is descriptive about the special works CI includes. Construction of roads, highways, fibre cable, and pipeline is considered under the special site preparation work (North American Industry Classification System, 2017).

The CI definition is given by Australian and New Zealand Standard Industrial Classification and was further trifurcated by the Building Research Association of New Zealand (BRANZ) by dividing all building structures into three different types: Residential; Non-residential; and Infrastructure (Page et al. 2014). This research aims to achieve sustainable construction through C&D waste minimisation in residential buildings and hence the focus is on residential construction literature throughout the thesis. In addition, interviews and on-site observations were also conducted in the context of residential buildings.

2.2.1 Definition of Construction Industry in New Zealand

The word construction was derived from the Latin word ‘construere’, meaning ‘putting together’ or ‘building together’ (Oxford, 2020). The word has various definitions depending on its interpretation. In NZ, the meaning of the word ‘construction’ is described as build, erect, prefabricate, and relocate (Building Act, 2004). Construction is a work applied to construction, erection, renewal, alteration or building improvement for which a building consent is required under the Building Act 2004 (Building Research Levy Act, 1969). Moreover, construction includes construction and conversion, and additions and alterations to an existing building (RMA, 1991). This research attempts to study life cycle of building projects (pre-design, design, construction, refurbishment and demolition) and hence uses the ‘construction’ definition given by Building Act 2004.

Construction is also defined as the execution of building works and management of construction activities (Bagnasco et al., 2015). Further, construction is a process of constructing buildings and other structures and their additions, alternation, reconstruction and repairs (Australian and New Zealand Standard Industrial Classification, 2006). According to the Construction Contract Act 2002 Section 6, building construction refers to the execution of new construction, erection, installation, alternation, repair, maintenance, extension, and demolition of building work (CCA, 2002).

In addition, building construction is an execution of activities such as construction, alteration, demolition or removal of a building and includes sitework (MBIE, 2014). When these activities are performed together, they form the base of the construction industry (CI). The definition given in the Construction Contracts Act has been widely adopted in the NZ, and hence similar definition was adopted for this research.

2.3 Construction Industry: An historical perspective

The existence of building construction is known to be as old as the existence of humans, and the construction of human shelters was the first form of building construction (Constructible, 2019). The history of construction and CI have long roots. The agricultural revolution around 12,000 BC triggered early human settlement (Tattersall, 2013), and humans started to build earth homes instead of hut shelters. Full-scale farming in 10,000 BC promoted human settlement in large amount (Kern, 2018). The

first sun-dried bricks and mortar made homes were built at the construction site of Jericho just after the beginning of full-scale farming. Mud brick houses were first present in human history, and today, Jericho is regarded as the oldest city in the world (Taha, 2010).

Different parts of the world experienced different sites of human settlement in later centuries (Hodder, 2012). The construction site at Catal Huyuk around 7000 BC was best known for the invention of ceiling holes for ventilation, lime-rich clay plaster to walls and floors and an oven for cooking in each house (UNESCO, 2012). Further advancement in building construction was observed at the construction site in Mohanjo Daro, present-day Pakistan, around 3250 BC. In addition to brick homes, the colony was well planned for wastewater management. Each house had a dedicated washing platform and toilet hole to dispose of the waste. In addition, the colony had a sanitation system to channel waste water (Ratnagar, 2014).

Over the years, humans started working as a team and improved their construction skills. The construction of the Great Pyramids of Giza around 2500 BC can be said to be the first notable construction performed by the CI (Teclé and Mahelet, 2012). The Babylonian king Hammurabi (18th century B.C.) established the first platform of the CI. He made 282 different edicts, including family laws, administrative laws, and professional contracts. For example, code 233 from ‘Hammurabi laws for construction’ says that if a builder builds a house and it falls, the builder is responsible for its reconstruction at his own expense. Moreover, if the house falls in and kills the owner, the builder shall be put to death (Code 229). The laws laid the foundation for the establishment of the modern-day CI (Harper, 1904; Nagarajan, 2011).

The earliest studies on modern CI and the use of building materials are dated back in the late 17th century (Lauriks et al., 2016). At that time, wood, stone, and brick were the common building materials used, which are still in practice, with steel and concrete added in the 18th century. In the mid-19th century, the development of CI showed technological advancement in construction, which introduced man-machinery combinations and started the new era of construction (International Bank for Reconstruction and Development, 1973). Later, the 1970s Middle Eastern boom increased building construction worldwide by a factor of five (Strassman, 1988). Further, the use of advanced machinery saved time and improved productivity. As construction demand increased, employment opportunities in the region increased. As a

result, the Middle Eastern region witnessed massive construction labour migration from Asian countries by the mid-80s (Strassman, 1988).

2.4 The Economic Contribution of the Construction Industry

The CI has always been a topic of interest for business people and different institutions due to its notable economic contribution to GDP (Oleg, 2018). CI is considered one of the largest industries in most countries and considered a highly volatile industry to the economy (Timofeeva, 2017). Though CI in many countries is characterised by extreme competitiveness, high risk, and usually low-profit margins in comparison with many other industries (Mokhtaiani, 2017), the contribution of CI to economic growth and long-term national development is widely acknowledged (Dakhil, 2013; Ofori, 2015); it forms a significant part of many country's GDP contribution, employment growth, and sustainable development.

The CI is expected to grow rapidly across developing and developed countries, with forecasted growth particularly concentrated in India, China, and the USA (International Labor Office, 2018). In recent decades, increase construction investment, employment opportunities and direct competition resulted in the real globalisation of the CI.

The construction sector was at the core of the global economy. As an industry, construction accounted directly for 6% of global GDP (World Economic Forum, 2017). The global construction output was expected to rise to the USD 12.7 trillion in 2022 up from the USD 10.6 trillion in 2017 (Market Insider, 2018). China, the USA, and India were predicted to account for 57% of all global growth in the CI by 2030 (Global Construction Perspectives & Oxford Economics, 2015). Table 2.2 shows the contribution of CI to GDP and Employment in different regions.

Table 2.2: Examples of the contribution of the Construction Industry to the economy

Region	Countries/Part	Value of CI (in billions of USD)	GDP contribution (percent)	Employment contribution (percent)	References
Asia	China	3110	9.2	7.7	National Bureau of Statistics China, 2018
	Japan	470	10	10	Statistics Bureau Japan, 2018
	India	140	9	14	Make In India, 2018
North America	USA	1300	4.3	6.1	United States Department of Labor, 2018
	Canada	170	7	12	National Statistical office, 2018; Build Force Canada, 2018
South America	Brazil	68	4.7	9	Barbosa & Vilnītis, 2017 ; Trading Economics, 2019
	Chile	28	3.4	8.4	Turner & Townsend, 2018
Africa	West Africa	98	7	8	Deloitte, 2018
Europe	United Kingdom	145	7	7	Office for National Statistics, 2018
	Germany	144	5.3	8.1	UN Economic Commission for Europe, 2018
	France	101	5.5	6.4	Business Wire 2018; OECD, 2018
Australasia	Australia	112	8.1	9	Department of Jobs and Small Business, 2018
	New Zealand	25	7	10	MBIE, 2019

As shown in Table 2.2, China, Japan and India had a construction value of USD 3.7 trillion, the highest by any region in the world. China consider CI as an economy builder to provide economic development in times of financial crisis (National Bureau of Statistics China, 2018). During the Asian crisis (1998) and Global Financial Crisis (GFC) (2008), investment in construction saved Chinese and other countries' economies including NZ from falling (Liew, 1999). The GFC was much worse than the Asian crisis, and it created similar circumstances to the 1930 global depression in the Chinese economy (Chow, 2010). The Chinese government invested USD 586 billion (NZD 894 billion) in housing and infrastructure, public health, education, and technical renovation as an immediate response to GFC. The Chinese CI received 80% of the total investment (Chow, 2010, pp.72). The CI helped to fill the void created by the export industry during the global recession (World Bank Group 2010). Subsequently, China's construction market was the largest in the world, having surpassed the US in 2010 (Bagnasco et al., 2015).

Table 2.2 shows that Japan led the Chinese CI in contribution to the GDP and employment. The contribution of Japanese CI to overall Japan's GDP was the highest by any construction industry of any country in the world (Statistics Bureau Japan, 2018). Further, India exceeded Japan in the context of employment contribution and employed the highest percentage of people from the examples shown in Table 2. During the Asian crisis, India invested USD 50 billion (NZD 76 billion) in the CI, which became a safe strategy and saved the economy from collapsing (Laskar & Murthy, 2004). India increased its construction investment over the years and in 2015 the Indian CI became the fastest growing CI in Asia (Make In India, 2018).

It can be seen from Table 2.2 that in North America, the United States Department of Labour (2018) reported that CI's value was second highest in the world. The CI also made a significant contribution to employment. During the GFC, the investment and spending became more cautious (United States Department of Labour, 2018). Like China, USA initiated the stimulus programme of USD 168 billion (NZD 256 billion) and invested a large amount of funds in construction activities to save their economies from collapsing (American Recovery and Reinvestment Act, 2009). In Canada, the construction activities are considered vital for economic growth (Build Force Canada, 2018). In 2018, the Canadian CI provided massive employment and emerged as the second-highest contributor to employment in the world (National Statistical office, 2018).

In South America, the GDP contribution of CI in all countries was not available (Barbosa & Vilnītis, 2017; Trading Economics, 2019). However, the overall construction GDP of South America was 13.1% (OECD, 2018). CI is considered to be one of the promising industries of the region, with Brazil and Chile as top contributors due to the acceleration in their residential and commercial construction (Turner & Townsend, 2018). However, the OECD report mentioned that the construction activities in other South American countries were much less than in Brazil and Chile.

In Africa, construction activities and infrastructure development were very limited. Despite being the second largest continent by landmass, the construction growth in many parts was slow, except the western region of Africa (PwC, 2016a). The lack of investment in the construction sector was one of the reasons for the region's slow growth. Western countries, especially Nigeria, Senegal, and Sierra Leone, emerged as construction hubs in the region (Deloitte, 2018).

The CI employed 18 million people and contributed to 9% of the European Union's GDP (EC, 2018; UN Economic Commission for Europe, 2018). The CI was considered as a key source of economic development and job creation. As a result, the UK, Germany and France invested large funding in construction (Office for National Statistics, 2018). The UK construction sector was the sixth largest in the world (UK Government, 2017). Further, German CI employed the highest percentage of people in Europe (Health and Safety Executive, 2018). Like German CI, the French CI also contributed significantly to employment (Business Wire, 2018; German Construction Confederation, 2018).

In the Australasian region, CI was the fifth largest industry in Australia and New Zealand. In Australia, investment in CI increased in the last few decades (Department of Jobs and Small Business, 2018). In particular, through a stimulus programme followed by GFC, the Australian government invested a large amount of funds in construction activities (Infrastructure Competition and Consumer Division of Australia, 2009). When the GFC affected NZ, the NZ economy was small, and it was closely linked to the international financial system. This resulted in a reduction of credit and finally slowed down the economy (RBNZ, 2012). The NZ government adopted an entirely different approach to tackling this issue. Unlike many countries, the government did not announce any investment or stimulus package. Instead, they introduced policy reforms and balanced the budget by focusing on tax cuts. In addition, the government increased

infrastructure spending by NZD 500 million for three years (Giesecke & Schilling, 2010).

It can be seen from Table 2.2 that, by providing a noteworthy contribution to GDP and employing a large number of people, the CI has become an integral part of any country's infrastructure and industrial development.

2.5 Construction Industry in New Zealand: An historical perspective

New Zealand was the last landmass in the world to be occupied by humans. The history of the first human settlement in NZ was still a topic of debate, but most believed it was around the 13th century (Irwin & Walrond, 2016). The early homes in NZ were constructed with wooden frames covered in leaves with mats on earth floors (Brown, 2014).

Around the 15th century, the Polynesian (Māori) population increased, which introduced concepts of sleeping houses with several rooms, which also added pataka (storehouse), and kauta (cooking house) to existing houses (Schrader, 2013). However, the construction of houses remained similar to 15th century houses for the next three centuries until the mass European migration happened in the mid 18 Century (Watters, 2018).

Though European settlers arrived in NZ on several occasions between the 17th and 18th centuries, it was the Treaty of Waitangi that made NZ a colony in its own right (Watters, 2018). Many of the natives adopted European-styled houses after this period with the introduction of high roofs and glass windows as an addition to timber homes. In the late 18th century, building materials such as nails, sawn timber, and metal sheets were first used in NZ for construction work (Brown, 2014).

The beginning of the 19th century saw growth of construction activities in NZ. With NZ being an earthquake-prone zone, people started constructing timber houses with brick as a veneer after the Hawkes Bay earthquake in 1931 (Salmond, 2010). It was 1930 when the '10-year global depression' struck NZ and created a scarcity of houses (RBNZ, 2012). The NZ government launched the state housing programme and invested in commercial construction activities to achieve stable economic conditions (RBNZ, 2012). During the mid 20th Century, many construction firms were established, and the foundation of the CI was laid. During the 1960s, the total amount of building work had increased with increased demand for factories, schools, hospitals, and offices (Walrond,

2010), but in the early and mid-70s, NZ's economy took a downturn (Stats NZ, 1980). It was one of the worst periods for the NZ building and construction industry.

The major impact happened to residential construction with only 14,300 new homes were completed, the lowest in almost thirty years compared to 15,800 in 1950 (Stats NZ, 1980). Further, infrastructure investment by the early 90s by private enterprises and government strengthened the overall value of CI. (StatsNZ, 2009). The construction of Bowen House in Wellington during the same year became the foundation stone towards CI growth. (NZ Parliament, n.d.). In addition, the construction of Sky Tower in Auckland and other skyscrapers in the early 90s increased construction investment, and by the late 90s, CI became the sixth largest employer in NZ (StatsNZ, 2009). Figure 2.1 shows the contribution of the New Zealand CI to total GDP and Employment.

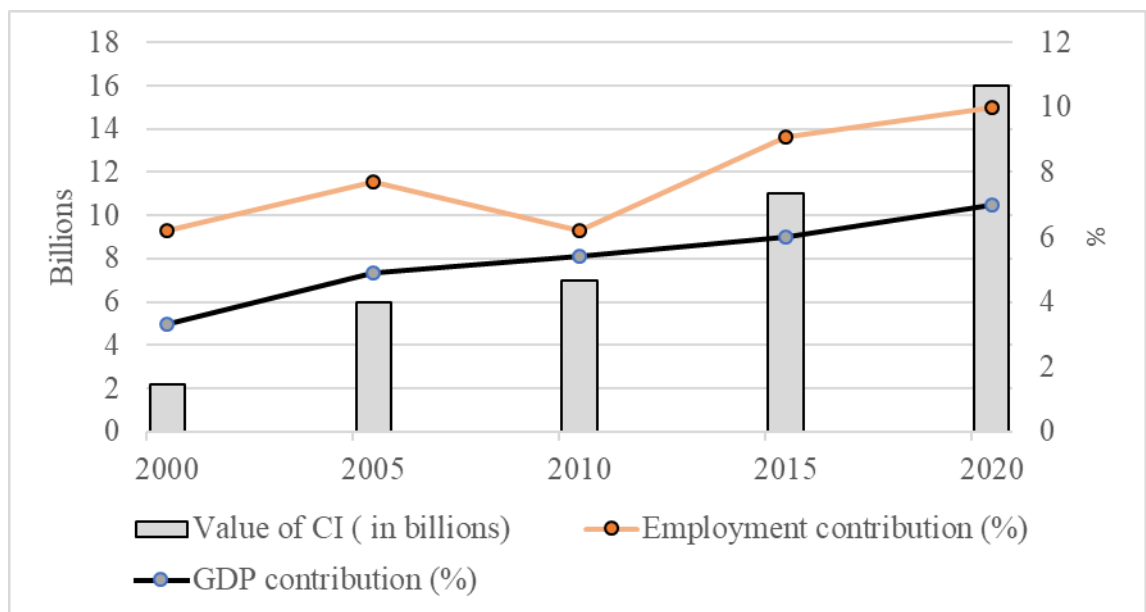


Figure 2.1: Contribution of New Zealand CI
(Stats NZ, 1980, 2000, 2006, 2010; MBIE, 2015, 2020b)

The contribution by CI increased gradually until the GFC hit NZ in 2008. Due to tax cuts and infrastructure investment from the NZ government, the CI saw growth but suffered from high unemployment. Almost 4870 jobs were lost during the GFC in the CI (MBIE, 2013). As a result of the GFC, housing construction fell in NZ (MBIE, 2013). Further, the Canterbury earthquakes happened in 2010-2012 worsened the situation for CI (RBNZ, 2016). Conversely, it was predicted that the overall construction cost of the rebuild was NZD 40 billion (RBNZ, 2016), which was a direct investment in CI. In 2010, the construction value of Canterbury region (without rebuild) was only NZD 2 billion (MBIE, 2013). Rebuilding increased a large number of

construction activities, and in 2014, CI contributed one-third to the total NZ's GDP (MBIE, 2015).

By 2020, for every 10-working people in NZ, 1 was a CI employee, with Auckland as the largest contributor (MBIE, 2020). The CI saw growth in all sectors (Residential, Non-residential and Infrastructure). Residential construction contributed 55% to the total national construction value and became the biggest contributor to national construction (MBIE, 2020a).

In the last 40 years, CI witnessed dramatic fluctuations and was expected to follow similar trends in the future. CI was predicted on a sharp fall to NZD 29 billion by 2023 from NZD 42 billion in 2020, due to Covid-19 (MBIE, 2020b). Further, the contribution of Auckland CI to the total national value was expected to decrease by 10% (MBIE, 2020a). However, Auckland CI's value fell by only 5% and predicted an increase of 11% by 2026 (MBIE, 2021).

2.5.1 Construction Industry in Auckland: An historical perspective

In 1841, one year after the Treaty of Waitangi was signed, Auckland became the colony's capital (McClure, 2016a). By the end of the 19th century, traditional Māori houses with European building techniques introduced a large number of new timber homes in and around Auckland (McClure, 2016b). The region made significant progress in the non-residential sector during a similar time. In addition to housing, other projects such as Grafton bridge, the Auckland town hall, ferry building, and the chief post office were completed (Heritage NZ, 2015).

Auckland's economy suffered a downturn during the 1930 global depression. It resulted in huge unemployment for the Aucklanders (Easton, 2010). The crisis introduced the first state housing estate construction by the NZ government (Ministry for Culture and Heritage, 2014). Many small construction firms were established in the post-depression period (Walrond, 2010). By the 1960s, more connectivity to the city was available with the help of new construction projects such as the Auckland Harbour Bridge (NZTA, n.d.).

It was 1984 when economic deregulation occurred, and Auckland's city centre reformed dramatically (McClure, 2016c). Banks and finance companies started investing in construction, and the industry became more vibrant (Tripe, 2013). An increase in investment started the new construction era for Auckland's CI (McClure, 2016d).

Auckland contributed more than one-third of total construction value in the 80s but reduced to almost half during the late 90s as the rise and fall of infrastructure demand continued (StatsNZ, 2019; Auckland Council, 2020a). Figure 2.2 shows the contribution of the Auckland CI to the NZ CI through its investment and employment.

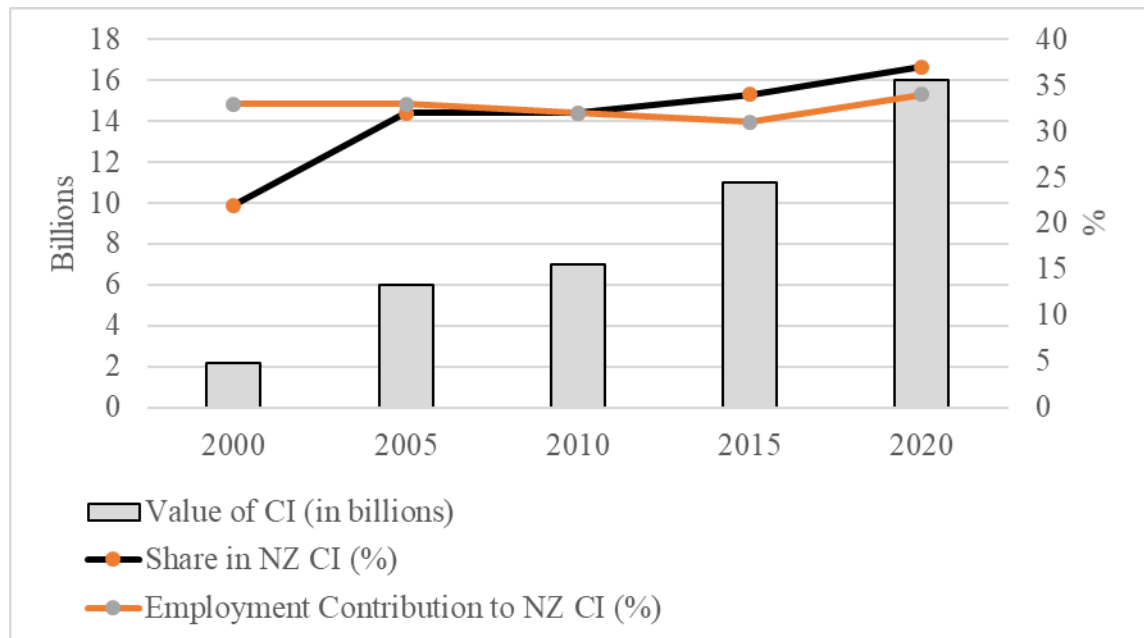


Figure 2.2: Contribution of the Auckland to NZ CI
(Stats NZ, 2000, 2006; MBIE, 2013, 2016; Auckland Council, 2020a)

In the early 2000s, the contribution of Auckland CI began to increase until GFC hit the industry. The CI did show growth after GFC, but it was marginal and less than predicted (StatsNZ, 2012). Residential construction in Auckland CI played a significant role in reversing the national slowdown that occurred due to GFC (MBIE, 2015). Due to high investments in construction after GFC, Auckland’s CI became the seventh largest industry in terms of gross regional product contribution (Auckland Regional Council, 2009). Auckland CI followed the pattern of the NZ CI. The 90s slump, 2000s boom, and GFC of 2008 were the key elements of the pattern.

The employment boom in Auckland’s CI happened in later years, and by 2020, 34% of the total construction employment of NZ was represented by Auckland (Auckland Council, 2020a). Auckland’s other industries such as Manufacturing (33%) and Health Care (31%) also had a significant employment contribution to NZ total Manufacturing and Health Care employment (MBIE, 2018; Infometrics, 2022). Construction investment in NZ for the year 2020 was NZD 43 billion, out of which NZD 16 billion was from Auckland (MBIE, 2020b). Further, 246,000 people were employed in NZ CI,

out of whom 86,000 worked in the Auckland Region (MBIE, 2020a). Auckland CI plays a vital role in the overall development of NZ by providing huge investment and a large amount of employment (MBIE, 2021)

The Auckland CI has drastically changed in the last few decades and has become a priority for contractors and homeowners (PwC, 2016b). In addition, Auckland had the highest number of building consents, GDP value, employment contribution, and consumer demand for infrastructure; overall, the Auckland CI led nationwide construction activities (MBIE, 2019; StatsNZ, 2019).

2.5.2 Construction Industry in Auckland: Present and future

In the last quarter of 2020, Auckland's CI grew significantly. The region topped in all building construction with the highest value of NZD 8 billion in residential buildings (MBIE, 2020b). In 2020, the total building construction value was NZD 16 billion and predicted to fall to NZD 14 billion by 2025 as a COVID impact (MBIE, 2020a). Residential construction is expected to remain the largest contributor to the national construction value as a result of peak in detached dwellings and multi-unit consents (MBIE, 2021). Figure 2.3 shows the contribution of residential, non-residential and infrastructure construction to the overall Auckland CI and gives predictions for the next five years.

As shown in Figure 2.3, the Non-residential sector value was predicted to decline from 2021 due to COVID impact and then increase from 2023 and maintain the growth by 2025 (MBIE, 2021). The infrastructure sector was estimated to grow gradually with no decline in the construction value till 2025. Further, the forecast for residential construction was predicted to decrease by NZD 2 billion by 2025 (MBIE, 2021). However, the contribution of residential buildings was predicted to be 45% of the total value of Auckland CI. Therefore, residential construction was expected to be the largest contributor to Auckland CI. As a result, the material consumption on residential activities was expected to increase in the Auckland CI (MBIE, 2021).

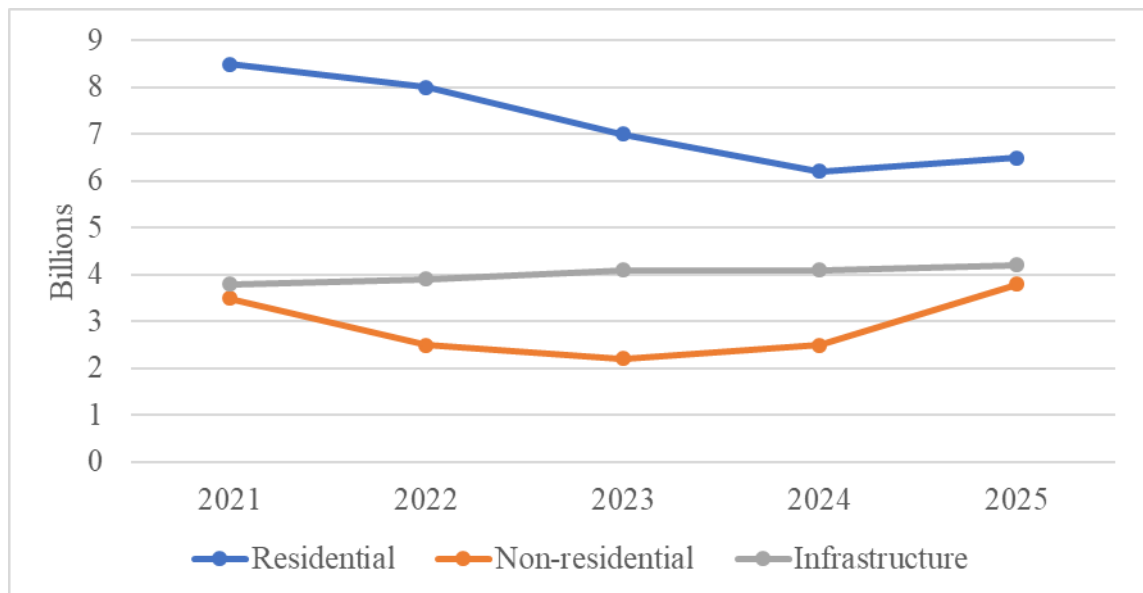


Figure 2.3: Value of Residential, Non-residential and Infrastructure construction in Auckland CI

(MBIE, 2021)

The CI in Auckland, and in NZ, serves almost all other industries by creating economic value or by creating infrastructure (PwC, 2016b). Unfortunately, the impact of industry was not solely positive. The industry suffered from some serious concerns including, but not limited to, high material consumption, carbon emissions, high energy consumption, and waste generation (Wilkinson et al., 2017). In Auckland, construction activities consume a large amount of natural resources and convert them into waste (Wilkinson et al., 2017). In 2017, Auckland CI generated 3 million tonnes of waste (Auckland Council, 2017). In addition, water use and recycling and contribution to Green House Gases (GHG) are some important concerns of Auckland CI (Thomas, 2018). Further, the high amount of C&D waste made Auckland CI one of the least sustainable industries in the Auckland (Auckland Council, 2020a), but adoption of Sustainable Construction (SC) can minimise the waste and improve social, economic, and environmental aspects of CI (Oke et al., 2019).

2.6 Sustainable Construction

This section presents the literature on the historical development of SC and discusses the various definitions of SC adopted in different parts of the world. Further, a worldwide overview of SC and Sustainability Rating Systems was reviewed. Similarly, the status of SC in NZ and Auckland was reviewed, followed by local Sustainability Rating Systems. The section concluded with SC challenges at the global and local levels.

2.6.1 Historical Development

The word ‘Sustainable’ implies something which can last for a long time with little or no damage to the environment, and the first modern-day use of the word appeared in 1924 in the context of resource consumption (Cambridge University Press, 2008). However, the concept behind ‘Sustainability’ had long roots in western philosophy. Aristotle introduced it back in 400BC in the field of household economics. His definition stated that a household had to be more self-sustaining and not just consumption focused (Stofleth, 2017). In other words, Aristotle suggested efficient resource utilisation of household products by considering the economic aspect of living.

The modern-day definition of ‘Sustainable Development’ was inspired by the 1973 oil crisis (Mogens, 2014). In 1973-74, six Middle Eastern countries lowered their export of oil which resulted into higher demand for oil in the international market (Aras & Crowther, 2013). The oil crisis introduced uncertainty about future demand and availability of oil. Hence, many countries chose to optimise their oil consumption to avoid the fall of the economy and maintain infrastructure growth (Mitchell, 2010). The oil crises added the environmental aspect to economic and social aspects of sustainability and drew everyone’s attention towards the Triple Bottom Line (TBL) approach of ‘Sustainable Development’ (Aras & Crowther, 2013).

In the next few years, ‘Sustainable Development’ was defined by different people and organisations with diverse perspectives, but the definition given by the UN in ‘Our Common Future’, became more realistic and practical. According to the Brundtland Commission, ‘Sustainable Development’ is defined as ‘Development that meets the needs of the present without compromising the ability of future generations to meet their own needs’(UN, 1987).

SC (Sustainable Construction Group UK) is considered as a subset of ‘Sustainable development’, which delivers building assets that enhance the quality of life and customer satisfaction (Goodhew, 2016). In the view of building construction, the present needs are focused on the use of energy, economic growth, social equity, resource consumption, and waste generation (Kibert, 1994). At the first International Conference on Sustainable Construction, Kibert (1994) defined sustainable or green construction as ‘a healthy creation of the building environment by minimising resource depletion and preventing environmental degradation’. The conference formally

introduced SC at the global level and laid the foundation for the environmental aspect of SC (Kibert, 2016).

SC is also defined as efficient use of resources in the pre-design, design and construction stages to avoid environmental damages and compromise with future generation needs (Construction Excellence, 2015). As construction activities began to grow, CI witnessed different challenges, and hence the definition of SC was updated as shown in Table 2.3.

Table 2.3: Definitions of Sustainable Construction

Definition	Reference
includes ‘cradle to grave’ approach that provides for the construction of building activities during its lifetime and eventual deconstruction and recycling of resources to reduce the waste associated with demolition.	Uher et al., 1997
a pathway which upholds and balances all the natural (environmental) and artificial (social and economic) aspects to improve quality of life.	UNEP, 2002
the creation and responsible maintenance of a healthy building environment based on resource efficient and ecological principles.	Merino et al., 2009
an investment in the future through saving of energy, water, and natural resources by Reduce, Reuse and Recycle (3R) to minimise waste and pollution to meet our own needs without compromising the needs of the future generation.	Sustainable Construction Group UK, 2010
represent projects that are designed, built, renovated, operated or reused in an ecological and resource efficient manner.	Akadiri et al., 2012
formation and management of a healthy building environment through the optimum use of resources with no environment damage.	Kibert, 2013
a practice of creating structures and using a lean process towards the environment to achieve resource efficiency throughout the life cycle i.e. design to deconstruction.	USEPA, 2016
the formation of a building environment with adaption to climate change and resource efficiency in construction with a specific focus on prevention and mitigation of future effects.	Yin et al. 2018
the term Green building (SC or Sustainable Building) used to describe planning to demolition stage of a project by considering environmental responsibilities and resource efficiency to reduce the waste and create a healthy and natural environment for people to live and work.	NZGBC n.d.

Various definitions of SC agreed on creating a healthy building environment through a life cycle understanding of the process. Table 2.3 shows that consideration of different aspects of SC leads to a sustainable future. Consideration of the environmental aspect in

SC became a frequent choice for researchers in the late 20th century (Merino et al., 2009; NZGBC, n.d.). The impact of CI on the consumption of natural resources was the largest of any industry (Sustainable Construction Group UK, 2010; Akadiri et al., 2012). Hence, most researchers and organisations have developed a definition of SC along the line of the same aspect (Uher & Lawson, 1997; USEPA, 2016; Yin et al., 2018).

UNEP suggested a balanced framework to promote SC as the interlinking of social, economic, and environmental aspects. It rooted the idea of optimum use of resources to create a liveable environment through the life cycle of a project (UNEP, 2002).

This research uses the definition of ‘Sustainable Construction or Sustainable Building or Green Building’ given by NZGBC as it is widely adopted in NZ. Most importantly, this research is focused on SC in the NZ.

2.6.2 Sustainable Construction: A worldwide overview

SC is a broad concept as it covers social, economic and environmental aspects in a single definition. As large quantities of natural resources are extracted for building construction activities, these activities give economic benefits by providing employment (Gan et al., 2015), and then these benefits improve the quality of life and health (Akotia, 2014). Ultimately, the economic and social benefits are achieved through environmental benefits (Zolfagharian et al., 2012). In other words, construction projects prove economically viable and provide good social standards of living when environmental factors are considered during the project's life cycle. The social, economic and environmental aspects are interdependent. Figure 2.4 shows all three aspects and their interdependency on each other.

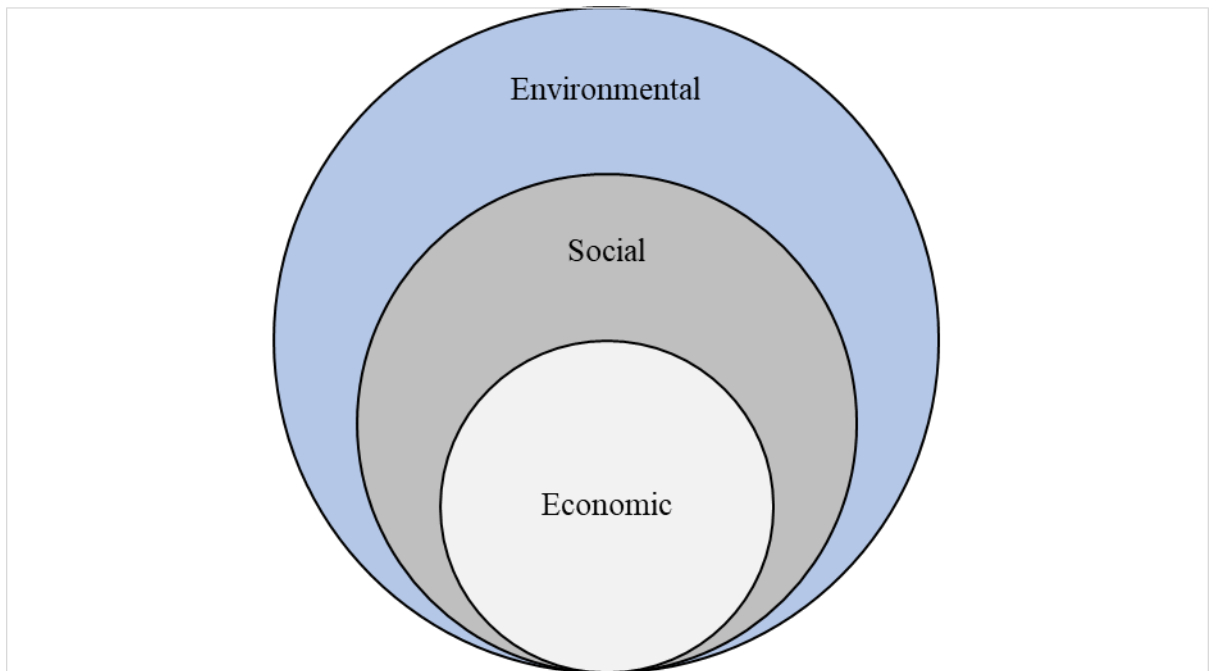


Figure 2.4: Sustainable Construction

(Gan et al., 2015)

It can be seen from Figure 2.4 that SC combines the social, economic and environmental aspects of the building environment. The economic contribution of building work promotes liveable social standards, which improves the environmental status of CI (Kibert, 2016).

In 1995, just after the first conference on SC, the concept of SC received attention from CI practitioners (Kibert, 2013). The International Council for Research and Innovation in Building Construction (CIB) decided to take sustainable development further in the building environment sector by considering all three aspects (CIB, 1999). The report published by CIB titled 'Agenda 21 for Sustainable Construction' stated that SC offers an effective approach to dealing with limited resources before and after their consumption to improve social and environmental benefits. The report created a global SC framework and laid the foundation for sustainable development in the building environment (CIB, 1999, 2002).

Further, the actions were expected to provide access to the funding for SC. Subsequently, creating a public-private partnership to balance SC's social, economic, and environmental aspects (CIB, 2002). In later years, the TBL approach became common in practice. Some of the important factors from each aspect are described in Table 2.4.

Table 2.4: Triple Bottom line approach for SC

Sustainable Construction		
Social	Economical	Environmental
Standard of living	Profit on investment	Natural resources
Education	Cost savings	Pollution prevention
Community	Economic growth	Innovation in design
Equal opportunity	Economic vitality	Water & land waste
Social responsibilities	Research & Development	Environment management

(Akotia, 2014; Kibert, 2016; Banihashemi et al., 2017; UNEP, 2018a)

The TBL approach states that to create and support the sustainable development in construction, not only the interlinking of the aspects, but also the impact of interlinking needs to be considered (Onat et al., 2014). Each aspect of SC holds responsibility to earn benefits from another aspect through the best possible combination of all available resources (people, material, and machinery) (UNEP, 2018a). Further, the benefits are obtained through the application of SC principles (Kibert, 2016):

- Reduce, reuse and recycling of resources,
- Protection of nature;
- Elimination of toxins;
- Life-cycle costing; and
- Focused on quality.

Some authors argue that SC should be more focused on the environment (Ding, 2008; Zolfagharian et al., 2012; Umar et al., 2014; Jalaei et al., 2019). The rationale behind this argument is that construction activities are the largest consumer of natural resources and the biggest contributor to landfill waste (UNEP, 2015b). It has also been argued that economic and social benefits together are responsible for saving the environment (UNEP, 2018a). From raw material extraction to the dumping of waste into landfill, the life cycle of a construction project starts and ends with the environment (Umar et al., 2013).

Almost 50 % of material extracted from the earth is converted into building material (World Economic Forum, 2016). The consumption accounts for 25-40 % of the world's total carbon emissions, 36 % of global energy and 2-3 billion tonnes of Construction &

Demolition (C&D) waste (UNEP, 2015b). The global statistics showed an urgent need to perform regional analysis of the environmental aspect of SC. Table 2.5 lists some of the important environmental concerns from each region.

Table 2.5: Different regions and their environmental concerns

Region	Environmental Issues	Reference
North America	Poor air quality Consumed 40 % total energy Poor resource management	Illankoon et al., 2017
South America	No SC policies in the region, except Colombia Contribute to 65% of total waste CI produced largest amount of carbon	Cesano & Russell, 2015
Europe	CI accounted for one-third of freshwater consumption CI consumed half of all extracted resources CI contributed to 50 % of carbon emission in the UK	UNEP, 2018
Asia	Pollution of air, water, and land Contributed to 50 % of the total C&D waste in the world Poor resource consumption and energy consumption crisis	Seadon et al., 2017
Africa	Energy and water depletion High consumption of non-renewable resource Poor environment management	Alagidede & Mensah, 2018
Australia	Harsh climate and scarcity of water Extraction of raw materials High carbon emission and energy consumption	Yu et al., 2017
New Zealand	Weather tightness building works Energy consumption and water recycling C&D waste contribute to half of the landfill waste	Auckland Council, 2018

Table 2.5 shows that building construction activities have a negative impact on the environment. All regions are struggling to optimise the consumption of resources (Cesano & Russell, 2015; Illankoon et al., 2017; Yu et al., 2017) . As a result, environmental degradation became a worldwide concern for the CI (Seadon et al., 2017). Further, poor resource consumption contributed to land and air pollution (Alagidede & Mensah, 2018).

The OECD published a brief policy for all OECD nations on achieving SC from an environmental perspective. The policy offered guidelines to tackle the issue of carbon emission, C&D waste, indoor air pollution, and high energy consumption through the use of eco-labelled building materials, imposing landfill taxes, separation of waste on-site, and introduction of building regulations (OECD, 2003a).

C&D waste is one of the key environmental issues in all the regions as it contributed significantly to environmental degradation and environmental pollution (UNEP, 2018a). The impact of C&D waste minimisation, results in less burden on landfills and improves air quality, and optimises resource consumption, ultimately leading to SC (Auckland Council, 2018b).

2.6.3 Sustainable Construction: An overview of NZ

The concept of SC was quickly adopted in NZ after its worldwide recognition. The NZ CI used 'Sustainable building or Green building' as a synonym for SC (NZGBC, 2015). However, at the beginning of sustainable development in construction, the CI used the term SC for many years until the concept of a green building became known in NZ. All three terms describe the balancing of the TBL approach in the building environment (Building Act, 2004).

Though the promotion and implementation of SC are supported by both government and private sectors now, it was the government sector who popularised SC at the time of its introduction (MfE, 2007). The SC agenda was later supported by the private sector through their contribution (MfE, 2007). The history of SC in NZ showed that the concept of protecting the environment has always been a topic of interest in NZ and after the Brundtland Commissions definition of sustainable development, the environmental agenda was reassured again (Waitaki District Council, n.d.). The NZ government took their first initiative towards SC by introducing the RMA (Resource Management Act) in 1991. Section 5 of the RMA states that the use of natural and physical resources has to be optimised and should allow social, economic and environmental well-being for everyone (RMA, 1991). The Act provided a sustainable framework towards resource consumption by considering the environment at the centre in the definition of SC (RMA, 1991).

Though the Act gave equal rights and responsibilities to every user towards protecting the environment, some believed that the Act was time-consuming, provided less

environmental benefits, and hindered overall (Parliamentary Commissioner for the Environment, 1998). This argument was formed because the Act allowed the district and regional council and sometimes the environment court to take all the important decisions related to the construction (Waitaki District Council, n.d.).

In 1991, the NZ government introduced the Building Act to address all sustainable aspects under one title (Buckett, 2014). The Act define important factors such as the definition of building, necessity of building consents, use of building, and importance of building certificates (Building Act, 1991). The Act established building regulations in 1992, and clause F5.3.1 from the building code promoted the sustainable construction agenda by covering range of areas from personal hygiene to energy efficiency. In addition, it also introduced guidelines on how to avoid construction and demolition hazards. Overall, the Act established social and economic equality along with the environmental aspect (Building Regulations, 1992).

In later years, government addressed each environmental issue with a separate regulation(s) (MfE, 2005). For example, Energy Efficiency and Conservation Act 2000 was introduced to promote national energy efficiency and conservation strategy by introducing energy efficiency, energy conservation, and renewable sources of energy. Clause 6 of the Act ‘Sustainability Principles’ assured the needs of the future generation and accommodated UN’s definition of ‘Sustainable Development’ (MBIE, 2000).

At a similar time, the private sector developed their interest in a sustainable building environment, and BRANZ produced their first report on ‘Building environment and climate change’ (Camilleri, 2000). The research identified different climate changing factors that can affect the building environment and concluded that the issue of flooding and house overheating needs to address quickly to make CI sustainable. In later years, BRANZ investigated different building environment issues, including leaky buildings, excess building energy consumption, fire-safety, construction waste etc and provided solutions to such issues (BRANZ, n.d.).

To promote SC awareness at district levels, the NZ government introduced the Local Government Act in 2002. The Act provided power to the local authority to deal with district level sustainability issues. Clause 181 of the Act promoted SC through addressing stormwater drainage, wastes disposal, and water waste issue (Department of Internal Affairs, 2019). In the same year, MfE introduced a guide to the management of cleanfills to tackle the waste issue. The guide mentioned that C&D waste was the

primary source of waste sent to landfills, and CI practitioners had a poor understanding of cleanfills and landfills. The guide provided waste acceptance criteria and the best possible methods to manage cleanfills. In addition, the guide suggested waste minimisation by considering the environmental and economic cost of waste (MfE, 2000b, 2000a, 2002a).

In 2003, the New Zealand Construction Industry Council (NZCIC) was established to bridge the government and the private sector. The NZCIC published their first document in 2003 on 'Understanding of SC'. The guidelines covered the project's life cycle, from its establishment to post completion check (NZCIC, 2016).

Meanwhile, the issue of leaky homes drew everyone's attention in NZ. In spite of different Acts and guidelines, the building environment proved less sustainable (Legal Vision, 2018). The Hunn report suggested that the Building Act 1991 was fundamentally sound but proved inefficient in construction of dwellings (Hunn et al., 2012). The government repealed the Act and drafted a legislative response to Hunn's report to address this issue. As a result, Building Act (2004) was introduced in NZ (Legal Vision, 2018). The Act introduced guidelines for construction, alteration, demolition and maintenance. It was drafted keeping the user's overall satisfaction from CI. Building code from the Act described how a building must perform in its intended use rather than describing how it should be designed and constructed (Building Act, 2004).

The Act introduced several amendments in the next few years by considering political drivers, social expectations, and adaptation of new construction technologies. The reformation strengthened the overall sustainability framework (Buckett, 2014). However, it has been argued that the Act still needs improvement. Section 18 of the Act mentioned that building works are not required to achieve performance criteria additional to building code. This allowed contractors to set a baseline for minimum expectations. Instead, the section should mention that any building work complies to sustainable building guidelines will have priority for resource consent. In addition, on validation of the building as a green building, the contractor may demand incentives from the client (Kirpensteijn, 2017).

The NZ CI formed their own GBC (NZGBC) in 2005 and collaborated with WorldGBC a year later ((WorldGBC, 2019). This started a new era for SC with a synonym of green building. A green building represents a home, an office, a hospital or any structure that

provides benefits to the environmental, social and economic aspects of construction (WorldGBC, n.d.). The term green building evolved constantly, and different countries have different definitions, depending upon their climate, culture, traditions, socio-economic benefits, and environmental impact. In other words, challenges faced by CI are introduced in the definition of green building, to convert them into opportunities (Mattoni et al., 2018).

2.6.3.1 Sustainable Construction: An overview of Auckland

SC in Auckland CI followed a similar timeline as SC in NZ CI. The increased in CI investment and growth of infrastructure in the last decade of 20th century seek researchers and practitioner's attention. The growth introduced the need for SC before the Auckland Council through the implementation of legislative instruments such as the RMA (1991) and Building Regulations (1992). In addition to central government Acts, to look for SC into more details at the regional level, the Auckland Council developed Auckland Unitary Plan (Auckland Council, 2013), Auckland Waste Management and Minimisation Plan (WMMP) 2012 (Auckland Council, 2012a) and 2018 (Auckland Council, 2018a), and Auckland Waste Assessment (Auckland Council, 2017).

The unitary plan aimed to make Auckland a quality place to live through effective management of the natural resources (Auckland Council, 2018b) and WMMP and Waste Assessment helps to divert the C&D waste from the landfill. The Auckland Council aims to achieve zero waste to landfill by 2040 (Auckland Council, 2018a). Similarly, Auckland Council has also published Energy Resilience and Low Carbon Action Plan with yearly goals (Auckland Council, 2014). The plan aims to reduce overall carbon emission by 40 % by 2040 based on 1990 emission levels by offering support to community centres and partnering with low carbon businesses. Further, Auckland Council leads the CI by promoting and practicing low carbon actions (Waitematā Local Board, 2015). In addition, private organisations such as BRANZ and NZGBC provide consulting, research and education on SC to CI practitioners (NZGBC, 2015). Overall, it seems that Auckland CI is in midst of adapting and promoting SC. Different SC indicators such as energy and waste are being addressed through regulations. In addition, public and private partnership is also contributing to SC in Auckland CI

2.6.4 Sustainability Rating Systems in the World

The sustainability rating systems are created to promote SC throughout the life cycle of a building (Varma & Palaniappan, 2019; Wu et al., 2019). The building projects are assessed for their environmental impact (Berry et al., 2019), profit on an investment (Doan et al., 2017) and a healthy ambience to live and work (Shan & Hwang, 2018). These rating systems have been in practice over the last three decades (GhaffarianHoseini et al., 2017; Vierra, 2019). Table 2.6 gives an overview of some of the prominent international rating systems.

As can be seen from Table 2.6, some of the rating systems are affiliated to the World Green Building Council (non-governmental), while others are designed by governing bodies. For example, LEED was developed by the US green building council and followed by more than 100 countries. In addition, LEED created a national and international impact in building assessment (Shan & Hwang, 2018). The need and impact of SC rating systems is acknowledged by government and private sector (Vierra, 2019). As a result, SC rating system have been practiced globally to achieve SC. European Commission (EC) published directives such as Energy Performance of Buildings Directive 2010/31/EU and Energy Efficiency Directive 2012/27/EU to optimise energy consumption and achieve SC (EC, 2020). In addition to these directives, the UK has developed its assessment system, CEEQUAL. The application of CEEQUAL has proved efficient to minimise design cost and deliver sustainable environmental solutions (Las-Heras-Casas et al., 2018).

In Africa, only South Africa, Nigeria, Kenya, Ghana, Rwanda, Namibia, Mauritius, and Uganda have developed a particular rating system (Masia et al., 2020; Alpin, n.d.). South African Green Building Council (SAGBC) is working actively with the world green building council to promote the rating systems for the other African countries (Masia et al., 2020). As a result, Ghana, Rwanda, Mauritius and Kenya showed interest in adopting rating system and also considered as prospective members of world green building council (Hoffman et al., 2020)

Table 2.6: Selected international sustainability rating systems

Region	Sustainability rating systems	Reference
North and South America	Building Environmental Performance Assessment Criteria	Shan & Hwang, 2018
Asia	Green Building Evaluation Standard Green Rating for Integrated Habitat Assessment, India Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), Japan	Varma & Palaniappan, 2019; Wu et al., 2019
Europe	Leadership in Energy and Environmental Design (LEED) Building Research Establishment Environmental Assessment Method (BREEAM), Energy Performance Certificates (EPC) Civil Engineering Environmental Quality Assessment (CEEQUAL)	Las-Heras-Casas et al., 2018
Africa	Green Star South Africa	Masia et al. 2020
Australia	Australian Building Greenhouse Rating Building Sustainability Index	Berry et al., 2019
New Zealand	Homestar and Greenstar National Australian Building Environmental Rating System New Zealand	GhaffarianHos eini et al., 2017
All regions in the World	Living Building Challenge International Green Construction Code (IgCC) Sustainable Building Tool (SB Tool) LEED	Doan et al., 2017; Vierra 2019

Table 2.6 shows that, in Australian and NZ, the governmental and non-governmental organisations have actively participated in developing building rating systems (Berry et al., 2019). It can be seen from Table 2.6 noted that some worldwide rating systems such as BREEAM (BRE, 2020), IgCC (International Code Council, 2018), WorldGBC (WorldGBC, 2016), SB tool (Vierra, 2019), and LEED (Shan & Hwang, 2018) have received a worldwide acceptance. BREEAM was developed in the UK, and is considered the oldest method of assessing, rating and certifying sustainability (BRE, n.d.). The IgCC, WorldGBC, SB Tool are adopted worldwide for rating building, especially for countries with no SC guidelines or rating system. In addition, the Living Building Challenge advocates SC through building performance assessment on seven

categories called Petals (Freilich & Popowitz, 2010; Castanheira & Bragança, 2014). Overall, the literature findings suggested that SC rating systems are considered crucial in achieving SC. Worldwide, use of SC rating systems is becoming a practice to optimise resources and minimise waste.

2.6.5 Sustainability Rating Systems in NZ

The promotion of green building is deemed insufficient and needs assessment and validation. The validation reveals the difference between theoretical and practical understanding of SC (NZGBC, 2014). Further, validation of buildings through a rating system helps policymakers and CI practitioners to practice SC effectively (Berry et al., 2019). As a result, from the collaboration of the public and private sectors, building rating tools to assess the sustainability were introduced. Some of the rating tools are listed in Table 2.7

Table 2.7: Building rating tools in NZ

Tools	Created by	Description
Home Star	NZGBC, BRANZ and Beacon Pathway Ltd	An individual homeowner can evaluate status of their home in terms of green building
Green Star	NZGBC and Building Industry	Greenstar has eight environmental impact categories from management to innovation to ensure sustainability in commercial buildings
The Green Home Scheme (GHS) and Green Office Scheme	MfE and BRANZ	Buildings are rated based on household energy consumption, use of sustainable materials, air quality, and water consumption
Tools for Urban Sustainability code of practice (TUSC)	MfE and Waitakere City Council	TUSC known as a web-based design and analysis tool used for assessing the sustainability of residential buildings
National Australian Building Environmental Rating System New Zealand (NABERSNZ)	Energy Efficiency and Conservation Authority (EECA) business and NZGBC	NABERSNZ considered as an energy rating tool used to improve energy efficiency and overall building performance of office buildings

(Auckland Council, 2012b; NZGBC, 2014)

As it can be seen from Table 2.7, Green star and NABERSNZ are the holistic rating system for commercial building certification, while Homestar, focuses on homes (Auckland Council, 2012b). Some of the examples of green star buildings from the

Auckland region are Deloitte centre and ASB waterfront (Mortan, 2017). The GHS and GOS are drawn from the UK rating system for homes and offices. These tools closely followed the national guidelines for SC in the UK (BRANZ, 2019b). In NZ, both the schemes produced effective results, but required more publicity and promotion to become a commonplace practice. (Jacques, 2004). A web-based tool, TUSC, helped to assess the building performance of residential buildings to encourage a sustainable building environment (Auckland Council, 2012b). The Australian government developed NABERS in 1998, and since its introduction, it produced positive results at the local and national levels in Australia. This allowed NZ to develop its version in 2013 to assess the environmental performance of NZ buildings (NABERSNZ, 2017).

In addition to the tools mentioned in Table 2.7, there are few other tools that promote SC in NZ. For example, SMART home initiative for homes, and software such as Annual Loss Factor and CarbonZero for assessment of energy and carbon (BRANZ, 2019b). The Living Building Challenge certifies buildings based on water, energy, materials, health & happiness, equity, beauty and place categories. The certification is based on industries response and aims to create clean, green, and efficient buildings (Building Excellence Group, 2017). Overall, it shows that NZ CI is acknowledging every aspect of SC (e.g. Energy, Waste, Water use) and promoting SC rating system to achieve SC.

2.6.6 Challenges in Sustainable Construction: Worldwide overview

The CI worldwide is envisaged to play a powerful role in any nation's growth, but the growth is only achieved when a sustainable agenda is implemented into practice during all stages of a project (World Economic Forum, 2019). However, achieving SC is difficult as different challenges occur during different project stages (Atombo et al., 2015). Some of the SC challenges include, but not limited to, high construction costs, waste generation, air and water pollution, poor consumption of resources, social equity and government regulations (Richer, 2014; Aigbavboa et al., 2017; Shan et al., 2017).

SC challenges drew everyone's attention in the last few decades since the investment to address them has increased worldwide. In 2010, Britain invested € 9.5 billion (NZD 15 billion) in the green and ethical retail fund (Auckland Council, 2013). Further, World Business Council for Sustainable Development advised China, India, and Japan to invest USD 150 billion (NZD 228 billion) annually to reduce their carbon footprint and improve building energy efficiency (Mohanty, 2012). It has been observed that

investment in green buildings results in necessary returns. For instance, between 2015-2018, LEED-certified buildings were estimated to have brought about USD 2.1 billion (NZD 3.2 billion) in energy, water, maintenance, and waste savings in the USA (McCadden, 2017). In Europe as well as in Australia and NZ, commercial buildings are the future of green buildings (WorldGBC, 2019). In NZ, green building construction provided different advantages to CI, such as high return on investment, reduced carbon risk, and improved offices to work in (NZGBC, 2015). In addition, green building construction provided more social and economic benefits such as a good standard of living and profit than conventional buildings (GhaffarianHoseini et al., 2017).

By 2050, the worldwide green building construction is predicted to make energy savings of more than 50 % compared to conventional buildings, and estimated to save up to € 410 billion (NZD 672 billion) (EC, 2015). In particular with NZ, the government has invested NZD 100 million to achieve the goal of ‘Sustainable low carbon NZ’ (NZ Treasury, 2018) and reduce the GHG emissions to 30 % below 2005 (Fernandez & Daigneault, 2020). The investment in green building, locally and globally, is predicted to grow rapidly, and the returns on these investments are only achieved if SC challenges are addressed properly from different perspectives (Atombo et al., 2015; McCadden, 2017).

Evaluation of SC challenges gives a better understanding of SC but collecting, analysing, and addressing all challenges under a single title itself is a challenge (Shan et al., 2017). Therefore, SC challenges are categorised under three major categories: social, economic and environmental (Elmualim & Alp, 2016). Table 2.8 lists SC challenges.

Table 2.8: Challenges of SC

Social	Economical	Environmental
Cultural value	Goods and services	Biodiversity
Population growth	Return on investment	Environment pollution
Political influence	Resource allocation	Energy consumption
Social equality	Economic growth	Resource consumption
Quality of life	Profit on recycling	C&D waste

(Shan et al., 2017; Kangwa, 2019)

Further, these challenges are occurred at different stages in a project such as pre-design, design, construction (refurbishment, repair, maintenance), and demolition (Atombo et

al., 2015). All the challenges are considered interdependently, and addressing one challenge directly or indirectly changes the status of others (Elmualim & Alp, 2016). If all challenges are addressed effectively as per their occurrence in the project's life cycle, then the best results of SC are achieved (Domingo, 2011). Table 2.9 provides an overview of SC challenges followed by a detailed discussion on each stage, i.e. Pre-design, design, construction, and demolition. Refurbishment/repair waste is often considered under the construction stage and hence challenges of repair/refurbishment stage are tabulated under construction stage.

Table 2.9: SC challenges in different stages

Pre-design	Design
Lack of demand	Feasibility reports
Capital cost	Project budget
Selection of green materials	Gender discrimination
Governmental policies	Material procurement
Poverty and social inequity	Biodiversity
Construction	Demolition
Workforce management	Deconstruction
Integrated knowledge	Waste levy
Material storage	Waste disposal charges
Environmental impact	Recycling infrastructure
Labour skills	Secondary market

(Elmualim & Alp, 2016; Ulubeyli et al., 2017)

2.6.6.1 Pre-Design

At this stage of a project, conceptual design and expected work outcomes are measured to set feasibility guidelines towards SC (Atombo et al., 2015). Lack of demand by clients and stakeholders was noted as the most commonly occurring challenge during the pre-design stage (Atombo et al., 2015). Table 2.9 shows that the design and impact of the actual construction process on nature, additional governmental policies, political situation, and legislation enforcement must be considered for better SC results (Djokoto et al., 2014). In particular, with developing countries, the challenge of deep poverty and social inequity due to the high population density are the prime SC concerns (Ulubeyli et al., 2017).

Government policies alone cannot be beneficial without good coordination between the government and the private sectors (Elmualim & Alp, 2016). Further, failure to implement good policies results in less return on investment, which affects the project's capital cost structure (Yin et al., 2018). To avoid such situations, an economic analysis of a project focusing on labour, materials, and machinery needs to be done (Windapo & Rotimi, 2012). This analysis helped overcome economic challenges such as lack of fiscal incentives and less support by investors due to high research and development costs (Yin et al., 2018).

In the context of the environmental aspect, 'use non-renewable resources only in case of no renewable substitute' requires special attention from CI (Atombo et al., 2015). In addition, availability of green materials and greenwashing hinder SC not only in the pre-design stage, but in later stages of a project (Elmualim & Alp, 2016). For example, giving extra careful consideration to green materials at the pre-design stage, allows recycling at the end-of-life stage (Richer, 2014).

2.6.6.2 Design

Designs and drafting of action plans are finalised in this stage. If the legal aspects enforced by governing bodies are not studied in the pre-design stage, it becomes difficult to check and validate its feasibility in the design stage (Elmualim & Alp, 2016). This stage calculates all project feasibility parameters as they appeared before the actual construction (Domingo, 2011). Table 2.9 shows, some of the important social challenges during design stage. If those challenges are not resolved, they lead to poor health and wellbeing and substandard quality of life (Oke et al., 2019).

The initial costs of SC are high, but the long-term impacts are positive. However, convincing clients to look for future impacts remains a difficult challenge while designing buildings (Onuoha et al., 2018). In addition, contractors only follow SC guidelines when clients demand it, or in most cases, perhaps no guidelines for environment protection are followed (Suhaida et al., 2013). Further, political interference plays a vital role while designing green buildings. Moreover, change in scope and design affect the investment cost, resulting in inefficient resource management (Atombo et al., 2015).

All the raw materials used for construction work are extracted from nature, which unbalance the nature (AlSanad et al., 2011). There are a few exceptions, such as wood

from sustainable forests. However, the majority of materials extracted from nature degrade the ecosystem (Opoku, 2019). Therefore, for effective implementation of SC, material resource estimates and procurement are required to be optimised, as resource consumption constitutes half of the project investment (Atombo et al., 2015).

A good resource management plan minimises waste cost by eliminating the waste through improving the time, cost, and quality performance of the project (Richer, 2014). A resource management plan is also referred as a construction management plan. The plan includes site conditions, material management, construction methodology, health and safety responsibilities and waste management (Hamilton City Council, 2019)

For an overall SC achievement, biodiversity and resource consumption needs to be attached with time, cost and quality to form an exemplary future of a sustainable paradigm (Opoku, 2019).

2.6.6.3 Construction

During construction, the problem of poor workforce management and cultural differences occurred regularly (Nayeem, 2020). As a result, productivity declines, and the growth of a project is stopped. Further, many construction projects failed due to a lack of binding guidelines to achieve SC and poor execution standards set in contract agreements (Hee et al., 2014). Though SC guidelines are available, contractors' unwillingness to follow the guidelines result in poor outcomes. In addition, a similar trend was noted with Health and Safety guidelines and their implementation (Hossain et al., 2018). Most importantly, solutions to such issues are easily available but rarely accepted by CI (Du Plesis, 2002). The ignorance to solutions often results into high waste generation, inadequate reuse of materials and the poor health and safety of labourers (Du Plesis, 2002).

In case of complex construction projects, critical task execution reduced the availability of skilled labourers, as the profit margin go low, and turnover of informal workers go high (Nayeem, 2020). Execution of critical tasks increases project expenditure and poor resource management (Nayeem, 2020). In addition, rapid infrastructure development involves high investment cost for the building environment., which brings financial risks such as inflation. Further, costs associated with social and environmental benefits decide the industry's economic growth (UNEP, 2016a).

Poor understanding of environmental issues and policies drawn from such understanding, generates high waste, pollute air and water, and consume more energy (UNEP, 2016a). Further, a lower supply of green resources and less environmental concerns from clients and contractors impact SC (Safinia et al., 2017). Moreover, ineffective managerial skills and a lack of integrated knowledge of the whole life cycle of the project causes damage to overall sustainability (Ofori, 2018). Once the construction work begins, it becomes difficult to change environmental policies, construction approaches and SC guidelines (Domingo, 2011). Hence, for better outcomes these challenges are required to be addressed at the earlier stages of the project (Säynäjoki et al., 2017).

The contractors often extend the life of a building through restoration or repair. The extension process is noted as refurbishment (Pombo et al., 2016). Refurbishment of a building includes painting, repair, renovation and cleaning activities. These activities are carried out by considering factors such as damage to a building, market condition, and return on investment (Pombo et al., 2016). The potential future use of a building decides SC guidelines for refurbishment. In addition, practising building refurbishment to reduce energy and waste, needs to become a commonplace consideration to achieve SC (Kylili et al., 2016).

Some of the important challenges of SC at refurbishment (and repair and renovation) are: environmental impact of waste; social assessment of new and old building materials; life cycle understanding of the refurbishment process; impact on the overall cost of the project due to poor resource allocation; and a structured approach to learn and implement refurbishment management (Baek & Park, 2012; Kylili et al., 2016; Pombo et al., 2016). Further, consideration of technical and political constraints such as public health, cultural heritage, and innovation play an important role to achieve a sustainable building environment (Kylili et al., 2016).

2.6.6.4 Demolition

During the demolition stage, the success to achieve SC, primarily depends on decisions made during pre-design stage and secondarily on upholding the decisions at design stage (Nielsen et al., 2017). Subsequently, implementation of such decisions during the construction stage plays an important role (Kibert, 2016). The selection and usage of green materials in earlier stages makes recycling or reusing possible during the demolition stage. For example, use of recyclable polymer to manufacture carpets result

in high value secondary materials from reusing and /or recycling the carpets (Safinia et al., 2017).

Achieving SC during the demolition stage has numerous challenges. Some of the regularly experienced social challenges of demolition are: less demand from stakeholders to reuse waste material; lack of governing guidelines; control over illegal disposal; and poor coordination between waste handling services (Kibert, 2016; Ghaffar et al., 2020). Further, traditional demolition practices and the unwillingness of contractors to adopt a deconstruction approach, contribute to an unsustainable building environment (Shan et al., 2017). Deconstruction is popular yet under practised due to its high cost. To perform deconstruction, the contractor requires additional time than demolition (Esa et al., 2017). Table 2.9 shows that educating people about recycled building materials, providing more understanding of benefits achieved against cost, and working alongside stakeholders' influence SC achievement (Esa et al., 2017).

Economic benefits from demolition are achieved by addressing challenges such as: cost of waste collection: resources required to maintain sorting and recycling facility and; cost optimisation and value analysis to increase Key Performance Indicators (KPIs) of SC (Griffiths, 2010). In addition, low cost virgin materials, lack of recycling infrastructure, and high cost of recycled materials impact on SC (Shan et al., 2017). Low-cost raw materials lead to poor resource consumption and increased natural resource extraction. Further, contractors dispose of the waste at the landfill instead of recycling due to less demand for recycled materials. As a result, achieving SC through economic benefits from demolition waste becomes difficult for CI. In addition, financial incentives on recycling of waste and cost analysis of different waste management practices required consideration from industry practitioners. Such analysis identifies demand and profit margin on recycled products (Griffiths, 2010). A low waste levy is considered one of the important challenges of this stage as it increases waste disposal (Bond & Perrett, 2012).

In addition to the social and economic challenges, demolition stage also has environmental challenges. Some of the noteworthy challenges are lack of advanced tools and expertise to demolish buildings; application of deconstruction to extract of reusable or recyclable materials; absence of resource recovery facilities and; C&D waste disposal guidelines (Henry et al., 2013; Ulubeyli et al., 2017). In addition, landfill capacity and poor waste handling techniques, require attention to promote SC

(Moradibistouni & Gjerde, 2017). Achieving SC during demolition requires waste management plan, the capacity of building to provide reusable or recyclable material, and environmental benefits of recycled material over virgin material (Yuan & Shen, 2011). Moreover, selling the recycled material in the secondary market drives SC success during the demolition stage (Mihai, 2019).

2.6.7 Challenges in Sustainable construction: NZ overview

In regard to NZ, the SC adaptation to climate change was one of the key challenges that CI needs to address (Thomas, 2018). The energy consumption in NZ has changed over the years, and as result, summer cooling required more energy than winter heating (Ade & Rehm, 2020). It also raised the question of thermal insulation quality in NZ building construction (Ade & Rehm, 2020). Similarly, there are different challenges the CI needs to address- some of them are listed in Table 2.10.

Table 2.10: SC challenges in NZ

Aspect	SC Challenges in different stages				Reference
	Pre-design	Design	Construction	Demolition	
Social	Lack of human well-being thinking	Lack of integrated urban design	Lack of client oriented approach	Less demand to reuse materials	IPENZ, n.d.
	Lack of mental health understating	Political influence and pressure	Lack of staff to promote SC	Secondary market for new products	
	Poor understanding of CI culture	Lack of Health and Safety guidelines	Traditional construction methods	Control over illegal dumping of waste	
Economic	Feasibility study and estimates	Quality of life and cost incurred	Labour cost and capital shortage	Waste sorting and collection cost	Raouf et al., 2019
	Industrial diversity thinking	Rising cost of land and construction	Expensive machines for construction	Low profit on recycled materials	
	Cost analysis of green materials	Cost of advanced designing software'	Use of modern technologies	Waste levy and disposal cost	
Environmental	Lack of cradle to cradle thinking	Poor understanding of material impact	High energy usage and climate change	Expertise to demolish buildings	Petrovic et al., 2017
	Poor resource management	Design for natural ventilation	Biodiversity, water use and recycling	Poor understanding of deconstruction	
	Lack of education and training of SC	Use of low embodied energy material	Climate change and rainwater harvesting	Resource recovery facilities	

It can be seen from Table 2.9 and Table 2.10 that, both globally and in the NZ, the SC challenges faced by CI are similar. Some of the common challenges are: health and wellbeing of society; lack of demand of eco-labelled materials from clients; adaptation to climate change; waste sorting and waste levy and; recycling of waste. As shown in Table 2.10, the noteworthy SC challenges in NZ are: demand of SC from clients; tracking TBL approach on a timely basis; economic growth; resource consumption energy efficiency; skill shortage; indoor quality; water use and recycling; leaky building and; C&D waste (Petrovic et al., 2017; Raouf & Al-Ghamdi, 2019; IPENZ, n.d.).

2.7 Construction and Demolition (C&D) Waste

This section outlines the C&D waste from its history to the present. It covers three main aspects of C&D waste. The first section discusses different definitions of C&D waste. Subsequently, the status of C&D waste at the global, NZ and Auckland level is reviewed. The section concluded with the identification of factors that influence C&D waste generation.

The word 'Waste' was derived from the Latin word 'vastum' which means empty or desolate (Petrák, 2016). In other words, waste means a product that contains no important element in the process (Amasuomo & Baird, 2016). However, current waste minimisation practices and secondary market for recycled products have turned waste into a resource; ultimately a new product (Gálvez-Martos et al., 2018).

The word got its current meaning in the 15th century (Barles, 2014). The current definition of waste varies from place to place as different regions include and/or exclude different materials to define waste. Waste can be considered as materials that are not prime products for which the generator has no further use for his purpose of production, transformation or consumption, and which he discards, or intends or is required to discard (UNSD, 2011). In the context of OECD countries, waste is defined as any 'unavoidable materials for which there is currently or no near-future economic demand and for which treatment and/or disposal may be required' (OECD, 2003b). In other words, any leftover resource after its consumption through the process is considered as waste.

2.7.1 Introduction

For waste minimisation policy formation, waste is generally divided into three broad streams i) Municipal Solid Waste (MSW), ii) Commercial and Industrial (C&I) Waste, and iii) Construction and Demolition (C&D) waste (UNEP, 2015b). These waste streams include different types of waste such as (Waste MINZ 2018):

- Clean fill material;
- Controlled fill material;
- Managed fill material;
- Household waste; and
- Hazardous waste.

Different types of waste are disposed at different landfills. For example, MSW landfills accept household and other waste. Managed fills accept lightly contaminated C&D waste, while C&D landfills accept only C&D waste. Clean fills accept any material which has no adverse effect on people and the environment and Industrial landfills accept industrial waste (MfE, 2021a). These landfills are subject to follow waste minimisation guidelines advised by MfE (MfE, 2009).

C&D waste has a significant contribution to total waste generated worldwide (UNEP, 2015b). Different countries calculate the contribution of C&D differently to formulate waste minimisation regulations. Some countries consider it part of MSW, while others calculate C&D waste separately (UNEP, 2018a). United Nations Economic and Social Commission for Asia and the Pacific (UNESCAPE) suggested that C&D waste should be considered under MSW (UNESCAPE, n.d.). Following the guidelines, countries such as India measure and landfill C&D with MSW. In addition, developed countries such as Canada measure C&D waste with respect to total MSW generated (Yeheyis et al., 2013). In contrast, in all OECD countries and the USA, C&D waste is measured as a separate waste stream rather than part of MSW (World Bank Group, 2012). The precise waste assessment helps to set achievable waste minimisation goals. Therefore, some countries choose to calculate C&D waste separately.

Understanding and knowledge about waste composition helps set achievable waste minimisation goals for each waste stream. Table 2.11 shows waste composition of MSW and C&I waste.

Table 2.11: Waste composition of MSW and C&I waste

Waste stream	Composition
MSW	Paper, plastic, metal, glass, textiles, and hazardous household organics
C&I	Food organics, soft plastics, cardboard, garden organics, tyres, and other rubber

(UNEP, 2015b)

C&D waste is often produced in all forms (solid, liquid, and gaseous). For example, in a landfill, rubble is considered solid waste, concrete slurry is considered liquid waste, and lead paint in its container is considered solid, liquid, and gaseous waste (MfE, 2002b). Thus, worldwide there are various definitions and category considerations for C&D waste (MfE, 2009).

In the context of C&D waste, before knowing its composition, it is important to understand the definition of C&D waste. Waste generated during construction, repair, reconstruction, and maintenance is described as construction waste, while waste generated during the end-of-life process is demolition waste. Demolition waste includes repair and maintenance if not included in construction waste (Lauritzen, 2019). Considering the life cycle of a building project, C&D waste are combined to assess and minimise the total waste. Table 2.12 summarises some of the definitions of C&D waste adopted from different organisations.

From Table 2.12 it can be seen that the European Council defined C&D waste and later introduced EU directives to address the issue of high waste generation. The directives encourage member states to reduce waste (article 3), practise integrated disposal (article 5) and prepare a waste management plan (article 18) (European Council, 1991). The European Council definition stated that C&D could be any material, while Statistics Canada (1999), mentioned a list of possible materials in C&D waste. The former approach was broad while the latter was specific, which helped CI to understand the composition of C&D waste and its assessment.

Table 2.12: Definitions of C&D waste

Definitions of C&D waste	Reference
The non-household and non-putrescible waste is generated from the construction, renovation, repair, and demolition of structures.	Waste MINZ, 2018
Any substance or object generated during the C&D process which the holder discards or is required to discard.	European Council, 1991
Materials from the possible waste list generated during C&D activities of roads, bridges, and buildings.	Statistics Canada, 1999
Waste produced by C&D work that includes excavation of soil, road, and rail construction and maintenance.	Department of Sustainability Environment Water Population and Communities, 2012
materials that are not prime products for which the generator has no further use in terms of purposes of production, transformation or consumption, and which the generator wants to dispose.	UNSD, 2015
material generated from the construction, renovation, and demolition of buildings, roads and bridges and other structures. It excludes debris generated from land-clearing activity or from natural disasters	USEPA, 2015
Waste generated during the construction, renovation or demolition of any building construction	UNEP, 2015
Any waste generated due to the activities related to the construction sector and falls under 'European list of wastes'	European Commission, 2016

Table 2.12 shows that, in the USA, debris generated due to natural disasters is not considered as part of the C&D waste, while countries such as Lebanon and Sri Lanka give special consideration to such debris in their C&D definition (Karunasena, 2012; Srour et al., 2013; USEPA, 2015). The USEPA (US Environment Protection Agency) consider building material debris generated due to natural disaster as part of 'Natural Disaster Debris Management' and manage accordingly (USEPA, 2019). It can be seen from Table 11 that, though UNEP uses 'any waste' term to define C&D waste, the focus of definition was on material waste only (UNEP, 2015b). To resolve which materials to be considered as the C&D waste issue, the EC drafted a European list of waste. The list considers all potential materials that can be considered waste (EC, 2016). The definition of C&D waste changes throughout Europe as different countries choose different materials from European waste list to define C&D waste (Iacoboaia et al., 2019)

Some countries, including NZ, Australia, and Germany, consider contaminated soil excavated during land clearance as C&D waste (Brennan et al., 2014), while the USA and Netherlands do not consider excavated soil as a part of C&D waste (USEPA, 2015; EC, 2016). The old construction methods from Europe suggest using excavated soil to fill the embankments for road construction and hence do not consider it waste (Correia et al., 2016). In addition, excavated soil is often taken to other sites as a construction material, considered a resource rather than waste (Williams, 2005).

Apart from the above definitions, some researchers have also defined C&D waste through different perspectives such as time and cost delays, quality, inefficient management, poor equipment selection and excess material consumption (Lu & Yuan, 2011; Chen et al., 2018). These perspectives are divided into three broad streams: labour, material, and machinery. All the perspectives aimed to consider C&D waste either by environmental or by productivity approach (Lu & Yuan, 2011). Both approaches introduce different perspectives to consider concerns that leads to C&D waste generation and factors that influence its minimisation.

The classification of C&D waste has been done differently worldwide. In countries like Canada, the USA, and some European countries, C&D waste is classified based on material, i.e. concrete, timber, and rubble waste (Statistics Canada, 1999; USEPA, 2015). In NZ, activities classify C&D waste, i.e. construction, renovation, and demolition (WMA, 2008). Perhaps the C&D activities involve a long list of material and hence instead of a number of different material types of waste, the materials are divided by their physical, chemical or biological reactivity, i.e. inert and non-inert materials or hazardous and non-hazardous materials to represent the classification of the C&D waste (UNSD, 2015; Tam & Lu, 2016). The chemically inactive materials are considered inert material, e.g. concrete, rubble, masonry, while chemically active materials are considered non-inert, e.g. treated wood, lead paint, and asbestos (Department of Sustainability Environment Water Population and Communities, 2012; WasteMINZ, 2018)

A typical composition of the C&D material waste includes concrete, wood, masonry, plasterboard, asphalt, plastics, mixed site debris, rubble, conduits, packaging waste, glass, insulation and gypsum board (Duan et al., 2015). On average, globally by weight, building rubble and concrete masonry contribute to more than 40 % of C&D waste (World Bank Group, 2012).

This research aims to analyse all project stages to understand challenges and remedial measures over the life cycle of building projects. Subsequently, the intention is to propose a waste minimisation framework, to achieve SC through C&D waste minimisation. C&D waste definition given by WasteMINZ, NZ covers life cycle of building projects. Hence this research uses the C&D waste definition given by WasteMINZ (Table 2.12).

2.7.2 Global Scenario

C&D waste has received acknowledgement in the last few decades as monitoring waste became a regular practice in different regions (UNEP, 2015b). Subsequently, waste monitoring shifted from weight measurement to volume measurement (Columbus, 2006). The volume measurement introduced visuals of the area covered by a landfill. If a landfill covers a larger area, it represents large quantities of waste, while a small area shows less waste. Visual representation of C&D waste raised environmental and public health concerns (Columbus, 2006).

During the 1970s and 80s, all C&D waste was landfill until the concept of Reduce, Reuse and Recycle, became common practice (UNEP, 2015b). The monitoring of C&D waste became common in the US after the 1990s and in Europe and Asia a few years later (Laquatra et al. 2011, pp.284).

Monitoring and assessing C&D waste helps to understand the consumption of resources, waste generation pattern, and factors influencing waste generation (Calvo et al., 2014). However, the national C&D waste data is often not explicitly documented in developed and developing countries such as Greece, Brazil, Nigeria and Ecuador. It is perhaps not considered as a challenge that hinders sustainable agenda. Further, a few countries, such as China and India, suffer from illegal dumping, making it difficult to evaluate the total waste (UNEP, 2015b). Thus, C&D waste generation statistics produced worldwide represent approximate estimates.

Some organisations, such as the World Bank Group, UN, European Council, and OECD, have done some approximate estimates of C&D waste produced worldwide considering different definitions of C&D waste. In 2015, worldwide, a broad group which includes, MSW, C&I waste and C&D, were estimated to be 7 to 10 billion tonnes per annum (UNEP, 2015b). In particular, with OECD countries, MSW, C&I, and C&D, waste generation for the year 2015 were 0.9 billion tonnes, 1.2 billion tonnes, and 1.3

billion tonnes, respectively (UNEP, 2015b; World Bank Group, 2018). Interestingly, C&D waste contributed 36 % of total waste, making it the largest waste stream. The increased waste quantities indirectly suggested the need for more resources to be extracted from nature, which made CI unsustainable (UNEP, 2015b).

In 2018, The global average of C&D waste generation was 1.68 kg/capita/day, and C&D waste accounted for 35 % of total waste (World Bank Group, 2018; Chen et al., 2019). For the same year, China was the largest C&D waste producer and generated over 2 billion tonnes of waste, while Bangladesh, with 1.28 million tonnes of C&D waste, was one of the smallest waste producers (European Council, 2018; World Bank Group, 2018). However, both countries suffered from negative environmental impacts due to significant waste disposal. In addition, in both developed and developing countries, C&D waste created concerns over resource consumption and waste disposal (Islam et al., 2019). Table 2.13 shows C&D waste generation in different regions.

Table 2.13: C&D waste generation in different regions

Region	Country	C&D waste generation (million tonnes/year)	Reference
North and South America	USA	700	Wu et al., 2019
	Canada	9	Akhtar & Sarmah, 2018
	Brazil	100	Rosado et al., 2019
Europe	UK	130	Bao et al., 2019
	Germany	209	UNEP, 2018a
	France	260	Tazi et al., 2020
Asia	China	2300	Wu et al., 2019
	India	112	Ram et al., 2020
	Japan	111	Tsukui et al., 2015
Africa	South Africa	5.9	Aboginije et al., 2020
Australasia	Australia	20.4	Wu et al., 2020
	New Zealand	3.6	MfE, 2021b

In 2015, the US generated 548 million tonnes of C&D waste, out of which demolition waste contributed 90% of total C&D waste (USEPA, 2015). It can be seen from Table 2.13 that in 2019, C&D waste generation in the USA increased by 20 % from 2015. The increase in C&D waste puts the environment in danger and lowers the social standards

of living (Laquatra & Pierce, 2011; Akhtar & Sarmah, 2018). The Waste Management Outlook for Latin America and the Caribbean mentioned that C&D waste monitoring and assessment were poor in the region. Thus, there are no available estimates of C&D waste in other parts of South America, except for Brazil (Hoornweg & Giannelli, 2017; UNEP, 2018b).

The UK, Germany and France were the frontrunners in Europe (Federal Ministry for the Environment Nature Conservation and Nuclear Safety, 2018). In 2018, Europe generated 900 million tonnes of C&D waste (European Council, 2018), double their waste generated in 2005 (Osmani, 2011). The C&D waste growth over the years has increased severe impacts on the environment and public health in Europe (Bao et al., 2019; Tazi et al., 2020).

Table 2.13 shows that India and Japan both produced over 100 million tonnes of C&D waste and suffered from the poor health of buildings. The Indian Ministry of Housing and Urban Affairs stated that actual C&D waste generation was more than documented as construction companies are not obliged to record the waste data (Ministry of Housing and Urban Affairs, 2018). In 2018, the Asian region contributed more than 50% of the total C&D waste produced worldwide, with China as the largest waste generator in the region (Ram et al., 2020). The growth in C&D waste generation had a negative environmental impact on the entire region (Tsukui et al., 2015; Wu et al., 2019).

The African region offers a limited body of literature on C&D waste. The waste monitoring and assessment are poor in most countries; however, countries such as South Africa have documented the recent growth of C&D waste (UNEP, 2015b). As shown in Table 12, in 2019, the construction sector generated 5.9 million tonnes of C&D waste and became the third-largest waste stream in South Africa (Aboginije et al., 2020). Interestingly, the country considers only non-hazardous or inert material under C& D waste definition (Department of Environmental Affairs, 2018).

Australia followed the world pattern in terms of C&D waste generation. In 2016, C&D waste stream became the largest waste stream in Australia and continued to be the largest waste stream till 2020 (Wu et al., 2020). In the context of NZ, the limited but growing body of the literature suggested that C&D waste contributed to half of the total waste landfill in NZ; resulting in high waste disposal cost and occupying half of the

landfills in the country (MfE, 2021b). Australia and NZ combined, reached 24 million tonnes of C&D waste- as shown in Table 2.13.

2.7.3 New Zealand Scenario

Waste generated due to construction and demolition from any building, includes excavated soil from contaminated land classified as C&D waste (MfE, 2015). The earliest record suggested that in 1973-74, the NZ government spent NZD 1 billion on construction, repair, maintenance, and demolition (StatsNZ, 1977). A total of 3,137 dwellings were demolished that year, which was the highest in the previous forty years. As a result, large quantities of demolition waste were generated (Housing New Zealand, 2017). The NZ government spends a significant amount of money on the disposal of demolished materials. The waste disposal established economic concerns for the government. (StatsNZ, 1977). The demolition data on other building types was unavailable because monitoring and costing of waste material were not common back then (Housing New Zealand, 2017).

The CI witnessed a construction boom in 1990s, but the boom was not entirely sustainable as it raised concerns about C&D waste. As a result of the construction boom, C&D waste emerged as the third largest waste stream after organic and paper (MfE, 1997). The rapid construction growth continued, and by the late 90s, C&D waste reached 1 tonne per capita per year (MfE, 1997). With the increase in C&D waste, the CI practitioners started diverting C&D waste from landfill and cleanfill to minimise the environmental burden (MfE, 2007).

In 2006, around 1 million tonnes of C&D waste was diverted, while 0.8 million tonnes were disposed of at landfills and 2.7 to 3.7 million tonnes were disposed of at cleanfills (MfE, 2007). Waste disposal kept surging steadily, and by 2010 C&D waste contributed to 40 % of total landfill waste (MfE, 2009). Further, a 10 % increase in landfill contribution was witnessed over the next five years (Wilson et al., 2017). In 2018, C&D waste became the largest waste stream in NZ, with 20 % of all waste going to landfill and 80% to Cleanfill (NZTA, 2019). A year after, in 2019, around 1.4 million tonnes of C&D waste was diverted, while 0.6 million tonnes were disposed of at landfills and 1.2 million tonnes were disposed of at cleanfills. In addition, 1.7 million tons were disposed of at C&D fills (MfE, 2019). The issue of C&D waste grows rapidly as the CI grows gradually (Auckland Council, 2019).

C&D waste disposal increased concerns about environmental stability, economic growth and living standards of society (MfE, 2009). To understand C&D waste critically, MfE published C&D waste list for NZ, similar to ‘European list of waste’ and ‘EPA list of Waste’. Section 17 of the list labelled all the potential C&D waste materials, which helped to categorise and learn about C&D waste (MfE, 2015). The composition of C&D waste typically includes concrete, plasterboard, wood, steel, brick, cardboard, metal, plastic, and glass.

2.7.3.1 Auckland Scenario

Landfill waste has been monitored in Auckland since 1983 (MfE, 1997). However, the trend of monitoring C&D waste was uneven for a few years as it was not a concern back then (MfE, 1997). During the 1990s construction boom, C&D waste received attention from the NZ government (MfE, 1997). The Auckland CI contributed significantly to C&D waste generation during the construction boom as it had the largest share in the infrastructure growth of NZ (Stats NZ, 2000).

The earliest records suggested that in 1995, Auckland produced 821,000 tonnes of total waste, double that in 1983, and C&D waste contributed to 35 % of total waste (MfE, 1997). It was an alarming sign for the Auckland CI and the beginning of the environmental pollution due to increased C&D activities. The growth of Auckland CI and high C&D waste generation continued through the late 90s to early 2000. The concerns on C&D waste generation increased rapidly in recent years. In 2011, C&D waste contributed 700,000 tonnes to landfills and 540,000 to cleanfill in similar quantity to managed fills (NZ Ecolabelling Trust, 2019). Disposal of C&D waste introduced public health and wellbeing concerns. It also contributed to environmental pollution (Wilkinson et al., 2017).

In 2018, C&D waste became the largest waste stream in Auckland and contributed 40 % to landfills (Auckland Council, 2018b). The landfill contribution created an environmental hazard and eliminated recycling opportunities of waste. The approximate estimate suggested that Auckland produced 570,000 tonnes of C&D waste in 2018 and it is predicted to grow by 3 % every year (Thiele, 2019). In addition, the Auckland CI spend NZD 100 million to dispose of C&D waste. Interestingly, the disposal of waste was cheaper than waste recycling. Waste disposal put an economic burden on CI. Further, the growth in C&D waste was accountable for the additional extraction of natural resources (Roberts, 2019).

In Auckland as well as in NZ, the CI consumes a high amount of renewable and non-renewable resources and later turned them into landfill or cleanfill waste; creating social, economic and environmental issues (Auckland Council, 2018b). The poor consumption of material is a greater concern in NZ and hence, this research focuses on material waste.

2.7.4 Factors influencing C&D waste generation

A worldwide argument suggested that factors influencing C&D waste are estimated, from different perspectives (Islam et al., 2019), including political, economic, cultural, environmental, technical, legal, and socio-culture factors (Ali et al., 2019). Life cycle assessment covering pre-design, design, construction, maintenance, refurbishment, and demolition provides a better understanding of factors that influences waste generation at each stage (Ali et al., 2018). The following subsection reviews factors that influence C&D waste generation at different project stages.

2.7.4.1 Pre-Design

Consideration of preventive measures in the early stage helps later stages to minimise waste generation (Islam et al., 2019). Preventive measures assess budget, policy impact, and contract documents for waste generation (Ali et al., 2019). The pre-design stage promotes industrial diversity thinking, such as waste produced from C&D activities converted into a resource for other industries, e.g. recycled wood to furniture (Dajadian & Koch, 2014). A concept based project draft plan considering; environmental regulations, the overhead cost of material and machinery, and prefabrication, plays a vital role in minimising C&D waste during construction (Yuan, 2017).

2.7.4.2 Design

Key factors influencing the generation of the C&D waste in the design phase include: change in scope; design; and design faults (Islam et al., 2019). The change in scope and/or design often occurred due to lack of understanding between stakeholders, poor estimates of project cost, and misleading material specifications and leads to high waste generation (Yuan, 2017). In addition, the selection of poor materials and ordering of such materials in bulk increases the risk of waste. Thus, identification and elimination of such materials are important (Calvo et al., 2014). During the design stage, C&D waste needs equal consideration along with other technical specifications. Giving C&D waste a priority at this stage reduces waste generation during construction. Along with

the priority, interdepartmental views on waste, government guidelines on waste and community engagement also needs to be considered while designing out the waste (Ali et al., 2019).

2.7.4.3 Construction

Construction, repair, maintenance, and refurbishment of a building generates physical waste, and the amount of waste primarily depends upon actions made in the previous two stages. For example, lack of innovation during the pre-design stage and poor designers' decision-making during the design stage often results in high waste generation during the construction stage (Calvo et al., 2014). The construction stage shows the difference between the predicted amount of waste and the actual amount of waste (Domingo, 2011). The prime factors that can influence the actual amount of waste are lack of material storage facility, material damage due to on-site transportation, malfunctioning of machinery, poor construction techniques, and unwillingness to practice regulations made in pre-design and design stages (Calvo et al., 2014; Islam et al., 2019; Ali et al., 2019). Introduction of 3R (Reduce, Reuse, and Recycle) during the construction stage significantly minimises C&D waste generation rate (Mihai, 2019).

2.7.4.4 Demolition

Demolition of a building results in a large amount of physical waste, mostly heterogeneous (Vieira & Pereira, 2015). Demolition waste is significantly influenced by almost every factor, from the conceptual design to physical monitoring of demolition activities (Islam et al., 2019). The geographical location, building category and usage, and demolition budget impact the demolition waste generation (Zheng et al., 2017). Further, demolition time, on-site sorting of waste, cultural resistance to divert demolition waste and illegal waste dumping, increases waste generation (Menegaki & Damigos, 2018). The use of green construction materials reduce demolition waste as the materials are easily recyclable (Ali et al., 2019); however, the composition of demolition waste plays a vital role in recycling and reducing waste. For example, heterogenous waste requires more resources for recycling compared to homogenous waste (Chen & Lu, 2017).

In addition, disposal cost, recycling cost, and landfill charges influence C&D waste generation (Ali et al., 2019). Application of deconstruction decides the amount of demolition waste that goes into the recycling facility (Calvo et al., 2014), and waste

management and resource recovery plans influence the amount. Further, an increase in waste generation implies a need for financial support from the government to establish additional recycling facilities to divert waste from landfill (Chen & Lu, 2017). The economic viability of recycled products i.e. profits on the investment considered as one most influencing factors in minimising demolition waste (Ali et al., 2018). In addition, the secondary market for recycled products needs to perform well. Thus, industry-council engagement is needed to minimise demolition waste (Ali et al., 2019).

2.8 C&D waste minimisation

This section presents different definitions of C&D waste minimisation to understand various perceptions of waste minimisation. The section then discusses C&D waste minimisation challenges that occurred during different project stages and explains the co-relation between C&D waste minimisation and SC.

2.8.1 Introduction

C&D waste minimisation is often guided by the need for a sustainable building environment and considered a subset of waste management (Domingo & Luo, 2017). There are different perspectives to define C&D waste minimisation, and all are considered under two broad categories: i) at source; and ii) by recycling. The on-site reuse, reuse and recovery are part of the recycling category (Gálvez-Martos et al., 2018; Ma et al., 2020). Some of the definitions of waste minimisation from both perspectives are listed in Table 2.14.

It can be seen from Table 2.14 that ‘source’ waste minimisation deals with materials before they become physical waste, while ‘recycling’ deals with materials after they become physical waste (Ma et al., 2020). The ‘reuse’ of material is considered under ‘at source’ waste minimisation, as materials do not go under any process before their next use, while ‘preparing for reuse’ is considered under ‘at recycling’ as the material needs inspection and reprocess before their next use (EU, 2008). Both the steps are based on the same principle of waste elimination and are considered part of a waste management hierarchy (Gálvez-Martos et al., 2018). The benefits of these steps depend upon how effectively the challenges of waste minimisation are addressed.

Table 2.14: Definitions of C&D waste minimisation

By Source	By Recycling	Reference
by source technique design out, reduce or eliminate waste in the process so there will be no waste to manage in further stages	Activity that can replace the consumption of new resources through recycling of old resources	Gálvez-Martos et al., 2018
eliminating the production of waste in the design stage	A technique that allows reuse or recycling of materials to manage the waste generated	Ma et al., 2020
any technique or task that reduce or eliminate the waste generation at the source, usually within a process	recovery and/or reuse of waste generated during and/or after the process.	Begum et al. 2007

2.8.2 Challenges in C&D waste minimisation

Several studies mentioned that effective planning at the design stage or at source, reduces one-third of the total waste generated during the project (Osmani et al., 2008; Yu et al., 2013). On the other hand, if source reduction appeared to be impossible, on-site sorting and recycling of waste at the construction stage diverts more than half of the waste from landfill (Islam et al., 2019). Despite both approaches, C&D waste is noted as the largest waste stream in most countries, due to the variety of challenges that arises during different project stages (Esa et al., 2017). All the waste minimisation challenges need to be analysed separately to advocate SC through C&D waste minimisation. Thus, Table 2.15 overviews C&D waste minimisation challenges occurred during different stages of a project.

Table 2.15: Challenges in C&D waste minimisation

Pre-design	Design
Eco-labelling of materials	Material specification writing
Lack of innovation and motivation	Change in scope and design
Early involvement of stakeholders	Waste management plan
Construction	Demolition
Material storage and handling	Regular waste audits
Prefabrication and standardisation	Lack of deconstruction
Waste collection and sorting	Secondary market

(Esa et al., 2017; Islam et al., 2019)

2.8.2.1 Pre-Design

The pre-design stage of the project gives a rough estimate of the project and approximate statistics on consumption of both renewable and non-renewable resources (Poon et al., 2004) . Table 2.15 shows that eco-labelling and material selection are a common concern during this stage (Esa et al., 2017). In addition, lack of building standards and design faults negatively impact selected material and result in poor consumption and high C&D waste generation (Huang et al., 2018). Further, lack of innovation and motivation may be caused by political pressure and technical guidelines influence on waste generation. Moreover, stakeholders' early involvement in drafting a conceptual waste management plan plays an important role in minimising waste at this stage. In addition, the conceptual waste management plan laid the foundation to prepare a comprehensive waste management plan in the design stage (Ajayi & Oyedele, 2018).

2.8.2.2 Design

The design stage is identified as a phase in which ideas are converted into reality, and hence precise and specific designs of buildings are prepared (Gupta et al., 2020). Lack of detailed specification of materials and poor quantity surveying of such materials are some of the prime concerns for this stage. These concerns result in the over-ordering of material and eventually contribute to waste generation (Ajayi et al., 2018). The estimates and designs made, based on poor regulations (environmental, technical, and governmental) result in poor material selection. Also, a specification without considering the precise regulations, increased the risk of high C&D waste generation (Won & Cheng, 2017). Despite having material specifications and precise regulations, waste is still generated due to unavoidable circumstances such as climate change, machinery failure and on-site accidents Thus, materials with high recycling value need to be selected at this stage (Wu et al., 2019). In addition, a detailed draft of waste management and resource recovery plans and other technical plans are also required. However, contractors often neglect these plans due to non-binding guidelines, unwillingness to protect the environment, and lack of demand from stakeholders (Ajayi et al., 2018).

2.8.2.3 Construction

This stage deals with physical waste resulting from design waste. Construction, repair, maintenance, and refurbishment produce a large amount of physical waste, and the waste generation rate mainly depends upon guidelines set in earlier stages (Domingo,

2011). Construction work needs proper guidance on material storage and handling, which is often considered simple work but performed with poor standards (Esa et al., 2017). In addition, issues such as ordering wrong materials, time and cost delays in execution, inefficient management, and lack of waste identification and quantification, play an important role in failure to reduce waste (Wu et al., 2019). Further, manufacturing defects in windows, doors, frames, and roofing steel also contribute to physical waste (Ajayi et al., 2018).

During this stage, the physical waste generated needs guidance on waste sorting and collection. Inadequate guidance often leads to lower productivity and a high C&D waste generation (Huang et al., 2018). In addition, consideration of social and environmental values related to waste disposal needs attention from industry and governing authorities (Domingo et al., 2017). In the context of maintenance and refurbishment activities, CI needs to address challenges such as material selection, building condition, availability of tools, labour skills, contractor's behaviour, budget and time (Ali et al., 2019).

2.8.2.4 Demolition

Buildings at their end of lives are deconstructed or demolished, which result in demolition waste. During this stage, challenges are classified under three categories; pre-demolition, demolition, and post-demolition (Menegaki & Damigos, 2018). Pre-demolition challenges assess decisions and actions made in previous stages. Further, the precise waste audit is considered a key challenge during pre-demolition, which often fails to become part of the demolition due to poor environmental legislation (Ali et al., 2019). The waste audit covers some of the important factors such as type of building, demolition plans, and cost of demolition. Each factor becomes an individual challenge if not considered during the pre-demolition phase (Esa et al., 2017).

Traditional demolition practices and understanding and implementation of deconstruction require special consideration (Esa et al., 2017). The systematic extraction of resources will guide on-site and/or off-site reuse and recycling. Such extraction mainly depends on the availability of machinery, skilled labour, and application of advanced tools such as Building Information Modelling (BIM) (Liu et al., 2015).

The post-demolition phase is influenced by outcomes of earlier stages, i.e. pre-demolition and demolition. The pre-demolition stage includes site surveys to identify

recoverable material, while the demolition (or deconstruction) stage extract recoverable materials. Materials obtained after deconstruction need promotion to reuse and recycle as a common practice (Ajayi et al., 2018). Further, creating a secondary market for such materials is difficult as industry practitioners often reject recycled products (Huang et al., 2018). Despite efficient reuse and recycling, waste is still generated, which needs to be disposed of at the landfill. Hence, in addition to aforesaid challenges, waste disposal charges and waste levy also influence C&D waste generation (Nikmehr et al., 2017).

A case study done in China on a standard multi-storey residential unit showed that 80% of demolition waste can be diverted through reuse and recycling (Zhang & Tan, 2020). In UK, studies have shown that organised resource extraction during demolition stage of a timber-framed house divert 65% material through reuse and 35% through recycling (Akanbi & Oyedele, 2019). Further, in NZ, findings of residential unit demolition showed that deconstruction and material reuse prevent carbon emission of around 27kg (CO₂e) (Zaman et al., 2018).

2.8.3 Importance of C&D Waste minimisation to SC

The CI raised the social, economic, and environmental standards of society by considering the needs of SC (Manowang, 2012). As all the aspects are interlinked and addressing one can improve the other two, the environment needs such optimise resource consumption, less use of energy, less waste generation, and disposal, and promotion of recycled materials are important to address to achieve SC (BRANZ, 2014). The C&D activities are prime contributors to environmental depletion through high consumption of resources and environmental pollution through large landfill contributions (World Bank Group, 2018). Hence, C&D waste minimisation must be considered as a primary environmental need as it contributes to SC in different ways such as to:

- Reduce the environmental burden by minimising waste at source or at recycling (Cruz et al., 2019);
- Minimise greenhouse gas emissions and adopt the effect of climate change through the consumption of renewable material over non-renewable material (Nižetić et al., 2019).
- Provide effective resource management, client satisfaction, and good community connections. In addition, C&D waste minimisation introduces new job

opportunities and promotes advanced technologies to make SC a common practice (BRANZ, 2014)

In most countries, including NZ, SC is advocated through C&D waste minimisation. C&D waste minimisation is considered an opportunity to practice a circular economy through circulating resources (Purchas & Ainsworth, 2019). The circular economy promotes cradle to cradle thinking, creates job, and save cost and the environment. For example, in 2018, the USA and South Korea saved USD 7 billion (NZD 10 billion) and USD 2 billion (NZD 3 billion), respectively, through C&D waste minimisation (EC, 2016). C&D waste minimisation has become a need for SC, and a better understanding and application of C&D waste minimisation approaches help to advocate SC.

2.9 Approaches for C&D waste minimisation

This subsection describes different approaches used by CI to minimise C&D waste. The subsection begins with the introduction of the waste management hierarchy and then overviews its worldwide status. Subsequently, different guidelines and regulations on waste management made worldwide are discussed. The subsection concludes with different C&D waste minimisation tools developed and practised by CI researchers and practitioners.

2.9.1 Waste Management Hierarchy

Waste is generated at any stage (design to demolition) of a project and hence needs more than one option to deal with it. This introduces waste minimisation or management through stages generally known as ‘waste management hierarchy’ (MfE, 1997). The waste management hierarchy is considered the origin of waste minimisation and is widely used in different industries, including construction.

The history of waste management suggested that, in 1975, the European Union introduced the concept of waste management hierarchy in Waste Framework Directives. This was the first attempt by any organisation to consider waste minimisation through a policy (EU, 1975). The hierarchy covered the life cycle and aimed to promote resource efficiency and waste minimisation. In addition, the Directives promoted the health and wellbeing of workers and environmental responsibilities through Article 4 (Williams, 2015).

The USA recognised the need for efficient resource utilisation and waste minimisation during the mid-80s, and by the early 90s, the USEPA introduced the waste management hierarchy in the USA (USEPA, 1986). The USEPA waste management hierarchy had similar features to the EU hierarchy and it was developed to deal with MSW, particularly MSW generated due to the consumption of hazardous materials. In the USA, It was common to measure C&D waste with MSW (United States Congress Office of Technology Assessment, 1989). In 1992, UNEP established International Environmental Technology Centre (UNEP-IETC) to guide developing countries on waste management. In addition, UNEP published the waste management hierarchy for MSW management (UNEP, 1996). Over the years, the waste management hierarchy was introduced in various countries in their national and state policies and in 2013, UNEP took the initiative to promote the hierarchy globally (UNEP, 2013). The reason for this, is that half of the world's population at that time did not have the waste assessment and management understanding. The UNEP promoted waste management hierarchy in countries with no waste minimisation policies and set review and reform guidelines for countries with waste minimisation policies (UNEP, 2013). All waste hierarchies follow a common pattern of steps with the aim of maximum environmental benefits and minimum waste generation. Table 2.16 shows Waste hierarchies in different regions.

Table 2.16: Waste hierarchies in different regions

Region/Country	Waste Management hierarchy	Reference
New Zealand	Reduction, reuse, recycle, recover, treat, dispose or residual dispose	MfE, 2015
USA	Prevention, reuse, recycling, recovery, disposal	USEPA, 2018
South America	Prevention, minimisation, reuse, recycling, recovery, landfill	UNEP, 2018b
Europe	Prevention, preparing for reuse, recycling, recovery, disposal	European Commission, 2016
Asia	Reduction, reuse, recycling, recovery (energy), treatment, disposal	UNEP, 2015
South Africa	Avoidance and reduction, reuse, recycling, recovery, treatment, and disposal	Republic of South Africa, 2009
Australia	Avoid and reduce, reuse, recycle, recover, treat, disposal or residual disposal	Australian Government, 2018

The waste management hierarchy is considered a practical and feasible step by step guide to minimise waste (Australian Government, 2018; USEPA, 2018). The first step of the guide is preferred mostly to increase sustainable standards, while the last step is preferred to avoid degradation (Republic of South Africa, 2009). It can be seen from Table 2.16 that, in the NZ version of the waste management hierarchy, all the steps have a similar sequence as compared to other waste hierarchies. The waste management hierarchy started with a reduction at the top and dispose or residual dispose at the bottom (MfE 2015). Like the Australian version, the NZ version added ‘Treat’ before disposal or residual disposal (MfE, 2021a). Next subsections discuss different steps (actions) of waste management hierarchies in details to enhance understanding of waste minimisation.

2.9.1.1 Prevention or Source Reduction

As the name suggests, source reduction deals with reducing the source before the material progresses towards waste (Ferrari et al., 2016). The process of minimising waste (in product state) before it becomes physical waste is referred to as prevention or source reduction (EU 2008, Waste Framework Directives 2008/98/EC, Article 9). Source reduction is considered the first step into material progression and is highly favourable to attain environmental benefits. Even if the reduction at source is preferred and practised, it still has limitations that allow waste generation (UNEP, 2013).

2.9.1.2 Reuse

Reuse is a process in which material is used again for the same purpose it was aimed to serve. During reuse, the product requires no additional process (and inspection) and hence it is considered material rather than waste (EU, 2008). On the other hand, 'preparing for reuse' required cleaning (on-site) and quality check before reuse and hence considered as waste (DEFRA, 2011). Reuse proves more efficient when efficient utilisation of resources, redesigning the product and rethinking the process, are given special consideration (UNEP, 2013).

2.9.1.3 Recycle

Recycling is preferred when reduction and reuse prove insufficient (WRAP, 2011). Recycling and reuse are similar approaches as both suggest the use of material either for the same or different purposes. However, recycling consumes more resources than reuse and offer more options to minimise waste (WRAP, 2013). In recycling, the waste is reprocessed and used again for the same or other purposes (Zero Waste NZ, n.d.). Recycling consists of three steps, i) collection of waste through sorting, ii) conversion of the waste into new products through the necessary process, and iii) purchase of recycled products (UNEP, 2013). Recycling often produces lower quality products. The success of this stage depends upon decisions made during the design stage. In addition, negative perceptions about recycled products also influence the effectiveness of recycling (UNEP, 2013).

2.9.1.4 Recovery

Recovery is a method of processing the non-recycled materials and sometimes defined as a subset of recycling (WRAP, 2013). Recovery is considered the last stage of material progression as no economic and/or social benefits can be extracted from waste beyond this stage (WRAP, 2011). However, successful attempts have been made to make the waste less hazardous, e.g. neutralising solvent acids and transforming asbestos into non-toxic material to gain environmental benefits (Gillham, 2018). Article 10 of the EU Waste Framework Directive 2008/98/EC suggested that to achieve benefits through the recovery of materials, each waste should be collected separately for best end results (EU, 2008). Recovery offers less benefits than 3R (Reduce, Reuse, and Recycle), but is still considered a favourable option over disposal (UNEP, 2013). One reason is that disposal needs a large space of landfill for the waste, while recovery through incineration converts waste into ashes and requires less space to landfill the waste (EU,

2008). In addition, recovery offer an interdisciplinary approach, i.e. carpet waste as a fuel to a cement kiln, and not destroying the resources without benefits (Van Ewijk & Stegemann, 2016). However, waste to energy is not recommended because it destroys innovation, hindering a circular economy, releasing harmful substances and reducing employment (Seadon, 2019).

2.9.1.5 Disposal

The last step of the waste management hierarchy is disposal. Waste disposal is defined as a process of storing unwanted materials after the end of their life cycle; considered to be exactly the opposite of recovery (UNEP, 2013). Waste that cannot be Reduced, Reused, Recycled, and Recovered (4R), such as asbestos, solvents, and lead paints, need to be disposed of (WRAP, 2011). Disposal is considered the least preferred method, and disposal facilities have their hierarchy to deal with waste. For example, contaminated soil is sent to Class 1- landfill, while masonry waste sent to Class 5-landfill (WasteMINZ, 2018). Rather than providing benefits, disposal negatively impacts the environment and hence strongly is opposite to all waste hierarchies (UNEP, 2013).

To avoid environmental pollution and achieve SC, the CI practitioners contributed to the waste management hierarchy through innovative thinking (Abella, 2016). Refuse and rethink are practised to minimise C&D waste. The former offers use of sustainable material, while the latter allows redesigning the process with a sense of responsibility (Abella, 2016). In addition, remanufacturing and repurposing were introduced. Remanufacture suggested manufacturing new products from the old product to serve the same function and repurpose offered new product from the old product to serve a different function (Kirchherr et al., 2017).

2.9.2 Guidelines and regulations for C&D waste minimisation: A worldwide overview

The earliest records suggest that around 500 BC, the first municipal dumpsite, with regulations, was developed in the western world (in Athens). The regulations stated that the waste should be disposed of at least 1.6 km from away from the city of Athens (Columbus, 2006). Though the regulations were made for household waste, it was the introduction of landfilling of the waste (Bouazza & Kvazanjan, 2001).

Even in modern times, the disposal of waste into landfill was the best-known method to deal with C&D waste until the 1980s (UNEP, 2015b). Over the years, the number of landfills increased worldwide. The negative impact on the environment due to heavy

disposal of contaminated soil changed everyone's perception about landfilling the waste, which introduced need for waste handling and disposal guidelines and regulations (Huang et al., 2018).

International organisations such as UNEP and EU have published guidelines for C&D waste minimisation. The UNEP guidelines target both developing and developed countries, while the EU guidelines are dedicated to European countries. The UNEP provided Cleanfill guidelines for waste acceptance and management. Cleanfills needs to avoid non-inert material to lower the environmental impact of disposal (UNEP, 2016b) . In addition, UNEP published Product Stewardship Guidelines to promote circular economy. Some of the key features of the guidelines are: efficient inventory control; providing return allowance on unused materials; and using multiple containers on-site to store reusable and recyclable waste (UNEP, 2016b). The EU Circular Economy Package provides an action plan to minimise waste from its manufacturing and consumption to recycling and selling into the secondary market. Some of the key areas of guidance were recycled content requirements, integrated life cycle thinking and material recovery targets and material specific quantification (EC, 2022). Table 2.17 shows the guidelines and regulations used around the world for C&D waste minimisation.

The North American region focuses on the procurement of materials. The regulatory tools guide waste efficient procurement in the region (Government of Canada, 1990; Waste Reduction Act, 1990). One of the benefits of efficient procurement is that it allows suppliers to encourage a reduction in packaging. In addition, efficient procurement constitutes timely delivery of quality-checked products within allotted budget. As a result, on-site material waste is reduced by 10% (CIB, 2001). In addition, efficient procurement eliminates secondary transportation and storage costs (CIB, 2001). Regulations analyse the impacts of construction materials on the environment and inform on responsibilities to minimise the impact (National Zero Waste Council, n.d.).

Table 2.17: Guidelines and regulations for C&D waste minimisation in different regions

Region	Country	Provision for waste minimisation	Regulatory tools
North America	USA	Effective procurement of resources	Waste Reduction Act, 1990
	Canada	Promotion of environmental responsibilities	Canada's Green Plan, 1990
South America	Brazil	Generators responsibilities from design to disposal	Waste Management Resolution (307/2002), 2002
Europe	Europe	Technical guidance for selecting construction products	Construction Product Regulations (305/2011)
	UK	A mandatory waste management plan during the design stage	Site Waste Management Plan Regulations, 2008
Africa	South Africa	Guidelines on material selection and procurement	National Environmental Management Act, 1998
Asia	China	Optimise resource consumption to reduce off-cuts	Construction waste disposal technical specifications
	India	Ecological design standards for building materials	National Housing and Habitat Policy, 2007
	Japan	Guidelines for selecting construction materials	Ministry of the Environment 2004
Australasia	Australia	Sustainable procurement of building materials	Framework for material Procurement, 2008
	New Zealand	Sustainable management of resources	RMA, 1991

Similar trends for waste minimisation are found in the South American region; however, the regulations explicitly focus on the waste generator (National Environment Council, 2002). As a result, responsibilities for waste minimisation are not equally shared among all stakeholders. For example, in Brazil, when Resolution 307 was enacted by the National Environmental Council in 2002, the industry began to find viable solutions to the problem of C&D waste. However, a case study done by the Ministry of Education on a seven-story residential construction tower revealed that construction waste generated from the project was double what was planned. The failure to minimise waste was due to lack of a waste management and control system, absence of waste management plan, poor control over resource consumption, and lack of reuse (Maciel et al., 2016).

In Europe, the EU created regulations to promote the circular economy through construction waste minimisation. The Construction Products Regulations provides common technical specifications and uniform assessment methods to assess construction materials' performance (Sundström et al., 2013). The materials must meet the fundamental requirements, including resistance and stability, health and environment, energy economy, and optimisation of material consumption (Henrotay et al., 2016).

In the UK, all construction projects above £300,000 tender value must have the Site Waste Management Plan (SWMP) before the execution of work (DEFRA, 2013). Although the UK's legislative requirement to carry out SWMPs has been repealed, in all cases, the contractual arrangements between contractor and client continued to require them to be completed (Rose & Stegemann, 2018).

In the African continent, countries like South Africa have shown interest in waste minimisation. The South African government published guidelines on selecting sustainable building materials to achieve environmental benefits (National Environmental Management Act, 1998). As a result, practices such as Green star certification, eco-labelled materials, and optimised resource consumption increased in the region (Simpeh & Smallwood, 2015).

In Asia, particularly China and India, it is common to have regulations on building materials standards and their efficient procurement (Ministry of Housing and Urban Rural Development, 2010). The regulations help both countries to promote sustainable construction (Ministry of Housing and Urban Affairs, 2018). The Japanese CI has regulations on recyclable materials, standards, and environmental impacts of construction materials (Ministry of the Environment, 2004). The regulations offered a selection of sustainable materials and raised the recycling rate of construction waste from 42% in 1995 to 97% in 2011 (Liu et al., 2020). Other Asian countries such as Indonesia (National Action Plan), Singapore (Sustainable Singapore Blueprint), Malaysia (Waste Regulations), Thailand (Public Health Act) and Myanmar (Sustainable development Strategy) also have strategies and regulatory framework for sustainable development through waste minimisation (UNEP-IETC, 2017)

The Australasian Procurement and Construction Council published a sustainable material procurement framework for Australia and NZ (Australian Procurement and

Construction Council, 2007). The framework allows organisations to meet their needs for products, services and works and achieve value for money without any negative impact on the environment (Australian Government, 2009). The sustainable material procurement framework optimises resource consumption, introduces innovation in sustainability and adopts ethical practices (Australian Government, 2009). As a result, the Western Australian Government, the New South Wales Government and Queensland Government aligned their procurement goals with the framework (Tomossy & Alam, 2017). In contrast, in NZ, the framework was criticised for its lack of social aspect. The Auckland Council's Procurement Strategy and Group Procurement Policy explicitly refer to social procurement to promote community economic development and reduce poverty (Menzies 2018).

The New Zealand Government enacted the RMA (1991) to promote the sustainable management of natural and physical resources (RMA, 1991). In addition, the WMA (2008) was enacted to offer Product Stewardship Schemes to promote good design, which allows materials to be recycled via reusing or recycling (WMA, 2008). Further, WMA (2008) promotes waste assessment and waste management plan for C&D waste minimisation. Though the implementation of Acts by CI practitioners has not been satisfactory, the Acts can help to minimise waste and advocate sustainable construction.

2.9.3 Tools for C&D waste minimisation

The distinct perspectives introduce different C&D waste minimisation tools and their unique benefits to CI. Different tools and approaches are used to minimise waste, predict quantities of waste, and forecast recyclable content. For example, the DoWT-B (Designing out waste tool for buildings) helps contractors identify opportunities to DoW, record design solutions and calculate their impact on waste (Gupta et al., 2020). Further, the Net Waste Tool focuses on environmental and commercial costs of waste and calculates the potential waste quantities throughout the project. It also predicts quantities of recyclable material and optimises its consumption (Akinade et al., 2018).

Design out waste encourages design for deconstruction, accurate design documents and efficient material procurement. The design for deconstruction or design for disassembly approach allows efficient resource recovery of materials through reuse and/or recycling and/or recovery (Akinade et al., 2017). A building's design requires flexibility, and the selection of components has to be with industry standards to enable easy diversion from

landfill. This flexibility advocates optimal resource consumption, which ultimately minimises waste (Ajayi et al., 2015). Buildings that adopt the design for deconstruction generate end-of-life materials that are 65% reusable and 35% recyclable (Akanbi et al., 2019).

Role of design documents also plays an important role in waste minimisation (Ajayi et al., 2017). The clarity and comprehensiveness of design documents enhance buildability and avoid reworks (Osmani et al., 2008). The design documents, for example, drawings and Bill of Quantities, together form a good source of information for estimating the construction waste volume, to plan waste management upfront before construction starts on site (Lam et al., 2019). However, due to lack of communication, construction projects sometimes suffer from design change and faults that result in a significant amount of waste (Wang et al., 2015).

Waste efficient procurement eliminates waste by selecting, ordering, delivering and storing the materials efficiently to avoid damage (Li et al., 2015). The four important features of efficient waste procurement are suppliers' commitment, low waste purchase management, timely delivery, and waste efficient Bill of Quantities (Ajayi et al., 2017). Waste efficient procurement increases labour productivity by 30% and reduces waste disposal cost by 20 % (Liu & Lu, 2018).

Apart from these tools and approaches, several other tools have been used in different parts of the world to minimise C&D waste. Table 2.18 present some of the widely used tools, followed by a discussion of their application and benefits.

Table 2.18: Tools for C&D waste minimisation

Tools	Remark	Reference
Lean Tools	Lean tools such as Value stream mapping and Just in Time are commonly used to control the inventory	Vinodh et al., 2011
Supply Chain Management (SCM)	Controls inventory and creates a smooth flow of information which helps to procure sustainable building materials.	Vrijhoef & Koskela, 2000
Building Information Modelling (BIM)	Present a virtual copy of a project and expected physical issues before actual execution. It is used to design the buildings for deconstruction	Soltani, 2016 Moayeri, 2017
Linear Programming (LP)	LP deals with a single objective function such as minimisation of waste. LP model gives optimised resource consumption	Maués et al., 2020
Vector Optimisation (VP)	Target multiple objective functions but can only be considered as a supportive tool for managing the project.	Rudloff et al., 2017
Dynamic Programming	Future decisions are made based on the previous decision. DP required a large amount of coding work.	Zhou et al., 2013

i. Lean Tools

Lean is defined as a set of techniques to identify and eliminate waste. Lean tools such as Value Stream Mapping (VSM), Kanban and Just-in-Time (JIT) deliveries are practised widely to reduce waste (Polat et al., 2017). VSM provides systematic identification and minimisation of on-site activities leading to waste (Vinodh et al., 2011). Application of VSM reduced the lead time by 30 % and the total cost of a project by 20 % (Gunduz & Naser, 2019).

The JIT tool controls inventory and minimises waste (Gunduz & Naser, 2019). JIT eliminates the lead time, mishandling of material, and transportation damage to materials through just in time deliveries (Vinodh et al., 2011). Further, reductions in the quantities of stockpiled materials reduce pollution, resource consumption and give time savings and cost savings (Vilventhan et al., 2019).

ii. Supply Chain Management

The Supply Chain Management (SCM) tool originated from the manufacturing industry and was later adopted in the CI (Vrijhoef & Koskela, 2000). SCM provides equal responsibilities among all stakeholders and effective control over resource flow (Ahmed et al., 2002). Further, this flow advocates sustainable awareness and its integration

through waste minimisation (Shooshtarian et al., 2020). Application of SCM reduced waste by 10% for perfect order fulfilment and 20% for overall value at risk (Papadopoulos et al., 2016; Wibowo et al., 2017). To achieve such results, SCM focuses on design, management of material, workers, and recycling (through eco-label materials) (Papadopoulos et al., 2016).

Application of SCM in material procurement, often termed as 'Green SCM'. Green SCM allows smooth flow of material from its extraction to consumption (Beldek et al., 2016). Green SCM techniques promote cradle to cradle approach and focus on reverse logistics to improve waste minimisation (London et al., 2013). In addition, green SCM focuses on strategic procurement, supplier development, senior management support, and effective organisational communication to advocate sustainable construction (Benny & Joy, 2018).

iii. Building Information Modelling

Building Information Modelling (BIM) is defined through three main dimensions: i) a product to define a building, ii) a process of information, and iii) a system to enhance efficiency and quality of a structure (Soltani, 2016). These dimensions give numerous analytical outcomes for visualised design and contribute to predicting and reducing waste (Moayeri, 2017).

BIM is frequently used to: find drawing inefficiencies; optimise resource consumption; and promote reuse of resources (Baros, 2016). For example, two case studies for waste management in South Korea were performed to understand BIM. The first case involved two residential units, and the second case involved a sports complex comprising a baseball facility and a clubhouse. In the first case, BIM identified and categorised design errors such as discrepancies between drawings which accounted for 47.8% of design errors, followed by omission (35.4%) and illogical design (16.8%). In the second case, illogical design (57.4%) was the first cause of design errors. Further, BIM reduced construction waste by 15.2% in case 1 and 4.3% in case 2 compared to estimated waste quantities. The identification of design errors, i.e. efficiency of BIM models, depended on the understanding of BIM, interpretation skills, and resource availability (Won et al., 2016).

The DoW principle 'design for deconstruction' is often explored through BIM models (Akinade et al., 2015). BIM uses a mathematical modelling approach based on the

building designs' Bill of Quantity. The model predicts types and quantities of materials which can be reused or recycled or recovered. To achieve maximum recovery of materials, BIM promotes pre-fabrication and demountable connections (Ge et al., 2017).

iv. Linear Programming

Linear programming (LP) is a single objective mathematical model of solving practical problems such as optimisation of resources or minimisation of waste (Salim, 2010). LP models are often used to minimise the projects' time and cost by focusing on material selection, procurement and handling, and workforce management. A case study of 10 projects revealed that labour stability and workforce management saved 29.8% on total project cost (Florez et al., 2013).

LP models predict waste generation and provide key decision-making information to minimise waste. A case study was conducted on 23 residential buildings in Brazil. The model obtained an accuracy of 64.29% in the development phase and 66.67% in the validation phase, showing that the results are largely acceptable. With these results, the waste manager drew a baseline graph to indicate the waste volume to be reuse or recycle. The baseline estimate allows the prediction of the possible volume of construction waste to be generated in future and devise interventions accordingly (Maués et al., 2020).

v. Vector Programming

Vector Programming (VP) is a multi-objective mathematical model used to optimise a process (Kucukvar et al., 2016). The VP models optimise project decision-making results through precise constraints formulation (Rudloff et al., 2017). The constraints are formed based on material procurement, financial resource management, and the social impact of work (Dobrovolskienė & Tamošiūnienė, 2016).

VP models optimise building design by providing essential information for decision-makers. A case study done on a residential project showed that VP models reduced the total number of sheets required to construct a building component and minimise waste. For instance, for a homogenous panel, such as with plasterboard, it is desirable to reuse the offcuts to cover irregular regions at other places. VP model provided multiple solutions to minimise scrap area, i.e. off-cuts with a maximum shared edge. The optimise solution reduced scrap area by 17.73 m² and maximised the shared edge by

512.18 m. VP models optimise resource consumption to maximise the reuse and minimise waste (Connor & Siringoringo, 2017).

VP models provide an optimisation-based decision support framework, to reuse and recycle materials at the construction stage (Kucukvar et al., 2016). A case study was conducted on the Physical Science Building project at the University of Central Florida. The VP model first calculated total environmental impacts of various waste management options: recycling, conventional landfilling and incineration. Then a compromise programming model was utilised to determine the optimal recycling strategy considering environmental and economic impacts. The findings predicted that cardboard waste could be reduced by 100% through recycling and plasterboard by 90% (Kucukvar et al., 2016).

vi. Dynamic Programming

Dynamic Programming (Mokhtaiani) is defined as a mathematical optimisation method used to solve a complex problem with nonlinear constraints (Zhou et al., 2013). DP breaks the single problem into several subproblems and then solves the subproblems just once and stores their solution to save time and cost of recomputing if a similar problem arises (Wirahadikusumah, 2003).

DP models are used to improve project economic efficiency through construction waste management over the life cycle (Zoghi & Kim, 2020). The University of Alabama, USA, conducted a case study on a 12-storey commercial building to optimise construction waste and quantify the costs and profit. The model was simulated via four iterative steps: (1) model description (identification of variables); (2) development of a causal loop diagram; (3) development of a stock-flow diagram; and (4) model test and validation. The model's findings offered better decision-making information on material sorting and deconstruction procedure. Further, the DP model maximised the reuse, recycling and selling of salvageable material. As a result, construction waste management cost was reduced by 57%. In addition, the landfill cost was reduced by 85%, and profits from selling the materials were recorded at USD 1.1 million (NZD 1.6 million) (Zoghi & Kim, 2020).

2.10 C&D waste minimisation approaches in NZ and Auckland

This subsection describes C&D waste minimisation approaches used in NZ. The subsection starts with the introduction of the waste management hierarchy adopted in

NZ and then overviews national regulations and guidelines on C&D waste minimisation. The subsection then describes the waste minimisation related responsibilities and contribution of territorial authorities, in particular, with Auckland followed by C&D waste minimisation tools used in NZ.

2.10.1 Waste Management Hierarchy

The waste management hierarchy was introduced in NZ in the early 1990s. In 1990 the NZ government introduced National Waste Management Policy to minimise solid waste through the application of reduction techniques (MfE, 1997). The policy promoted recycling at the local level, and in 1992 it was revised to add a waste management hierarchy for achieving the best possible waste minimisation results (Auckland Regional Council, 2009). Worldwide, the waste management hierarchies are similar (Table 2.16, section 2.10.1). Figure 2.5 shows the NZ version of waste management hierarchy.



Figure 2.5: Waste Management Hierarchy (MfE, 2019)

As shown in the Figure 2.5, the waste management hierarchy describes possible environmental impacts of waste through different steps, e.g. reduction- fewer consequences, disposal- more consequences (MfE, 2022). In addition, the hierarchy represents the order of preference of action, e.g. reduction-most preferred, and disposal-least preferred (MfE, 2019).

2.10.2 Guidelines and Regulations

The conservation of the environment through guidelines and regulations has been an interest of the NZ government for decades (Nathan, 2007). Some of the earliest examples of such interest are for Nelson to manage wastewater (Nelson Waterworks Act, 1863) and Dunedin to address the issue of fish waste (Dunedin City Fish-Markets And Empowering Act, 1918). Further, timber was put under regulation with the Forests Act (1949) to minimise timber waste. The indigenous timber provisions in the Act required any business or work performed with the use of timber to be environmentally sustainable (Forests Act, 1949). During the early 90s, the government increased its concerns over resource efficiency and legislated the RMA (RMA, 1991) and building regulations (Building Act, 1991).

Further, between 2000 - 2008 different waste management Guidelines were published to achieve the SC, landfill guidelines in 2000 (MfE, 2000b) and Cleanfill Guidelines in 2002 (MfE, 2002a). In addition, the NZ government introduced Zero Waste Strategy in 2002 to manage and minimise waste effectively and move NZ towards zero waste (MfE, 2002b). Though the landfill guidelines were specifically designed for MSW, they included managing inert materials from C&D waste. The cleanfill guidelines guided to avoid site contamination and leachate generation, as cleanfills received C&D waste in voluminous amount. The landfill and cleanfill guidelines were replaced in 2016 with 'Technical guidelines for disposal' to provide detailed technical guidance to design, operate and monitor: MSW landfill; C&D waste landfill; Managed fill; Controlled fill; and Clean fill (WasteMINZ, 2018).

In 2008, the NZ government legislated the WMA to encourage waste minimisation and reduce waste disposal. Before the WMA, the government had promoted waste management hierarchy under different regulations and guidelines, but through the WMA government established a legislative framework specially dedicated to waste minimisation and management (WMA, 2008). The highlights of the Act were the introduction of the waste levy, product stewardship, establishment of the Waste Advisory Board, role of territorial authorities to promote waste minimisation, enforcement on waste minimisation and monitoring of waste. Clause 43 of the Act required territorial authorities to have a Waste Management and Minimisation Plan (WMMP), and clause 51 required waste assessments. Waste assessments track progress

on the goals set previously. In addition, it was a guide on setting achievable waste minimisation targets for future.

NZ has 67 territorial authorities, which includes 13 city councils and 53 district councils and the Chatham Islands Council (localcouncils.govt.nz, 2019). In addition, five territorial authorities, including Auckland, are considered unitary authorities. The construction growth and C&D waste were higher in city councils compared to other NZ regions. Table 2.19 discusses C&D waste minimisation actions set by city councils in their WMMP and waste assessment of those actions.

Table 2.19: The WMMP with C&D waste minimisation actions for different city councils (in the order they published their first WMMP)

Territory/ Region/ Council	First WMMP (year)	Waste Assessment (year)	Second WMMP (year)	C&D waste actions set in the first plan	C&D waste actions assessment	C&D waste actions in the second plan
Tauranga	2010	2016	2016	Set regulations for recyclable materials Encourage Reuse of materials	Partly achieved	Set up waste minimisation learning units Optimise resource consumption
Wellington	2011	2016	2017	Set regulations for cleanfills Provide support to businesses practicing SC	Not achieved	Set up resource recovery units Rethinking on manufacturing building products
Auckland	2012	2017	2018	Set up resource recovery units Promote REBRI guidelines	Partly achieved	Promote Redesign and repurpose Practice of deconstruction
Hamilton	2012	2017	2018	Monitoring of WMMP Improve landfill diversion	Not achieved	Implement requirements of DoW Stakeholder collaboration
Hawkes Bay	2012	2017	2018	Promote management hierarchy Maximise resource recovery	Unable to measured	Set guidelines for recycled materials Develop community awareness on waste and their impacts
Palmerston North	2012	2018	2019	Set up recycling units Efficient waste collection and landfill diversion	Partly achieved	Community engagement and education on waste streams Precise waste quantification

Territory/ Region/ Council	First WMMP (year)	Waste Assessment (year)	Second WMMP (year)	C&D waste actions set in the first plan	C&D waste actions assessment	C&D waste actions in the second plan
Nelson	2012	2017	2019	Promote REBRBI guidelines and Homestar programme Practice source reduction	Partly achieved	Financial support for community-led sustainable projects Promote circular economy
Christchurch	2013	2019	2020	Set regulations for cleanfills Promote Reuse of materials	Partly achieved	Application of deconstruction to improve resource recovery
Dunedin	2013	2018	2020	Set up resource recovery units	Partly achieved	Promoting C&D waste minimisation practices via an online toolkit

Table 2.19 shows that Tauranga City Council was the first council to publish the WMMP (Tauranga City Council, 2010) and Christchurch and Dunedin city councils were the last (Christchurch City Council, 2013; Dunedin City Council, 2013). However, the Christchurch City Council published a waste management bylaw in 2009 (Christchurch City Council, 2009), but no C&D waste goals were set in that plan. The Invercargill City Council did not publish any WMMP, but the Solid Waste Activity Management plan published in 2017 considered C&D waste as a growing concern. Similar to the Christchurch waste management bylaw, the Invercargill City Council did not mention any timeline and/or goal to minimise C&D waste (Invercargill City Council, 2017). Most city councils partly achieved the targets set in their first WMMP, but the targets remained unachieved or unable to measure for a few city councils (Tauranga City Council, 2010, 2016a, 2016b). Some of the reasons the city councils were unable to achieve the targets were less control on waste generation than industry, collaboration with stakeholders, resource recovery infrastructure, and poor quantification of C&D waste (Palmerston North City Council, 2018, 2019). The future targets of all city councils are focused on precise waste quantification, expansion of resource recovery networks, and promotion of circular economy (Auckland Council, 2012a, 2017, 2018b).

The NZ government imposed a waste levy (Part 3 of WMA, 2008) to collect revenue for promoting and achieving waste minimisation. Local councils have advocated an increase in the waste levy to get stronger financial incentives and support innovative waste minimisation businesses (Auckland Council, 2018b). The NZ government plans to change the waste levy in the future. With new regulation waste levy from 1 July 2023 will be (MfE, 2022):

- Municipal landfill: \$50 per tonne;
- C&D waste landfill: \$20 per tonne; and
- C&D cleanfill: \$10 per tonne

Currently, the government is getting the waste data from Transfer stations from solid waste analysis protocol. The aim is to improve the waste assessment through the waste levy and use the levy fund to support innovative waste minimisation businesses (MfE, 2022).

The Auckland Council is using a waste levy as a funding mechanism to support businesses (Auckland Council, 2018b). The Waste Minimisation and Innovation Fund (WMIF) is allocated to innovative initiatives that minimise waste. In 2020, the Auckland Council funded 51 waste minimisation initiatives and spent NZD 650,000. C&D waste stream received 20 % of the total funds for five initiatives (Auckland Council, 2020b). The initiatives were intended to minimise waste from design, construction and demolition stages. Importantly, waste minimisation at these stages was identified as an important action in the 2018 WMMP (Auckland Council, 2020b).

2.10.3 Tools

In addition to the guidelines and regulations enforced by governmental organisations, there are few non-governmental organisations, such as BRANZ and NZGBC which have their own C&D waste minimisation guidelines and goals dedicated to helping industry and community (BRANZ, 2014). The Auckland council and BRANZ collaborated to resolve the C&D waste issue and formed the Resource Efficiency in the Building-Related Industries (REBRI) programme in 1995 (BRANZ, n.d.).

The REBRI published template of SWMP to guide contractors. In addition, the NZGBC is promoting SWMP by awarding up to 5 credits where the following are demonstrated during construction and /or refurbishment (NZGBC, 2021):

- SWMP adhered to REBRI guidelines: 1 point
- SWMP with a target waste of:
 - 15-20 kg per m² 1 point
 - 10-14.99 kg per m² 2 points
 - under 10 kg per m² 3 points
- SWMP includes provisions for on-site waste sorting, with a minimum of 3 sorting stations: 1 point

The SWMP template is advantageous to CI practitioners as it allows them to set achievable goals and required objectives for waste avoidance or reduction for each waste stream. In addition, the template advised on: use of salvaged materials; waste sorting; prefabrication; and reduce packaging to promote circular economy (NZGBC, 2021). NZGBC also had set goals that encourage contractors to practice waste minimisation. The goals are (NZGBC, 2016, 2021):

- 100% diversion of clean soil;
- 90% diversion of C&D waste from landfill;
- 30-40% reuse when demolishing a building; and
- Application of deconstruction instead of demolition

The REBRI programme has grown over the years and published waste minimisation guidelines from project tendering to the deconstruction stage (BRANZ, 2014, 2019a). The guidelines offered C&D waste minimisation over the entire life cycle of a project through early involvement of stakeholders, uses of Just in Time for material procurement, early identification of market for recycled material, on-site sorting of waste, and morning tea shouts (incentives on waste minimisation) (BRANZ, 2014). In addition, source separation, efficient resource consumption, and resource recovery are some ways to reduce waste (Easton, 2012).

The REBRI programme adopted life cycle understanding and provided different tools for waste minimisation such as resource routing calculator, waste management plan, recycling directory, and waste transfer form (BRANZ, n.d.). LCA's application helped quantify waste and understand how the product converts into waste over the life cycle (NZ Ecolabelling Trust, 2019). The use of LC and SCM for minimising C&D waste was not a common practice in NZ. However, few validated case studies suggested that the application of lean tools helped to minimise C&D waste through source reduction and on-site sorting (Vilasini, 2014), and the practice of SCM for material procurement promotes environmental benefits (Samarasinghe, 2014).

The use of BIM for C&D waste minimisation has been in practice worldwide for long, and in NZ it has been around for a decade. BIM integrates the entire process from design to demolition and improves resource consumption, communication between stakeholders, and replacement of non-value adding activity by value-adding activity; resulting in less waste and more profit (Akinade et al., 2018). However, the uptake of BIM in NZ CI was slow due to a lack of understanding, difficulty in implementation, and low interest from researchers and industry practitioners (Doan et al., 2020).

Techniques like LP, VP and DP are not common in practice due to their complexity. Similarly, simulation in construction was also avoided. However, few studies see simulation as a future of NZ CI. It tracks the origin of the waste and provides better decision-making choices by understanding the real-time process (Zaeri, 2017).

2.10.4 Deconstruction

Deconstruction in a building context is defined as ‘activity performed at the end of the life cycle that allows efficient resource recovery of materials through reuse and/or recycling and/or recovery’ (Ajayi et al., 2017). Deconstruction aims to replace demolition with the objective of efficient use of resources with minimum waste. Further, deconstruction promotes circular economy thinking that eliminates the ‘make, use and dispose’ approach of a linear economy (Akanbi et al., 2019). In other words, deconstruction suggests protecting the environment and optimising natural resources consumption (Raghuwanshi, 2017).

Deconstruction is an effective approach to minimise C&D waste and advocate SC efficiently through a systematic process (Queheille et al., 2019). A result of deconstruction, is that it diverts a significant amount of C&D waste from landfills and creates jobs in the recycling industry (Sanchez et al., 2019). The financially poor class avoid using new materials and replace them with low-cost materials obtained through deconstruction, resulting in lower waste generation and less disposal cost (Akinade et al., 2017).

Thus, deconstruction is practised in many countries to provide a resource efficient environment (Sanchez et al., 2019). Although this was the scenario, demolition often dominates deconstruction and produces a large amount of waste (Sanchez et al., 2019). Selection of demolition against deconstruction or vice versa is influenced by different factors. Table 2.20 lists some of the important factors.

Table 2.20: Factors influencing Demolition and Deconstruction

Factors	Demolition	Deconstruction	References
Time	Required less time and less labour intensive	Required more time and need skilled labours	Ajayi et al., 2017; Raghuwanshi, 2017
Cost	Less cost for demolition, but high disposal cost	High deconstruction cost and low disposal cost	
Environment	Increase the environmental burden through the disposal	Reduce the environmental burden through recovery	
Demand	High demand from clients, but less benefits	Low demand from clients, but more benefits	
Building Materials	Building material knowledge is not required	Building material knowledge required	Akanbi et al., 2019; Sanchez et al., 2019
Construction	Suitable to any type of construction method	Not suitable to in-situ and chemical bonding method	
Information and Design	Specific design and detail information are not required	Specific design and detailed information are required	
Health and Safety	Traditional health and safety guidelines are sufficient	Specific health and safety guidelines are required	

Deconstruction of buildings requires more resources (time, cost, and machinery) than demolition (Akinade et al., 2017). However, the long-term impact obtained from deconstruction covers the costs ; making the resource investment feasible. Deconstruction promotes resource recovery and creates job opportunities at reuse and recycling facilities to advocate SC (Queheille et al., 2019; Sanchez et al., 2019).

In NZ, the application of deconstruction to minimise C&D waste has received interest from industry practitioners in recent years. In particular, with Auckland, waste minimisation through deconstruction received considerable interest (Auckland Council, 2017). The Auckland Council led by example and applied deconstruction to council-led projects. In the Ranui community centre project, through deconstruction, the council managed to divert 99 % of demolition waste from landfill and saved \$ 33,000 (Auckland Council, 2018b).

Auckland Council performed deconstruction all over the Auckland region and managed to save NZD 800, 000 through reusing and recycling timber, metals, concrete, glass, plasterboard, and door and window frames (Auckland Council, 2018b, 2019). Moreover, the Auckland Council supported the contractors involved in the City Rail

Link project to develop waste minimisation and resource recovery plans (Auckland Council, 2018b). Deconstruction proved effective than demolition and provided social, economic and environmental benefits. Therefore, it was considered as an alternative to demolition for the Auckland region. In the Auckland region, by 2030, 7000 homes are estimated to be demolished and replaced with 22,000 new homes. It was predicted that the Auckland Council would save NZD 25 million through the application of deconstruction by 2030 (Auckland Council, 2019).

2.11 Theoretical Waste Minimisation Framework

The literature findings helped to prepare a theoretical waste minimisation framework. The framework had identified key challenges in waste minimisation and provided remedial measures. Figure 2.6 shows the theoretical waste minimisation framework.

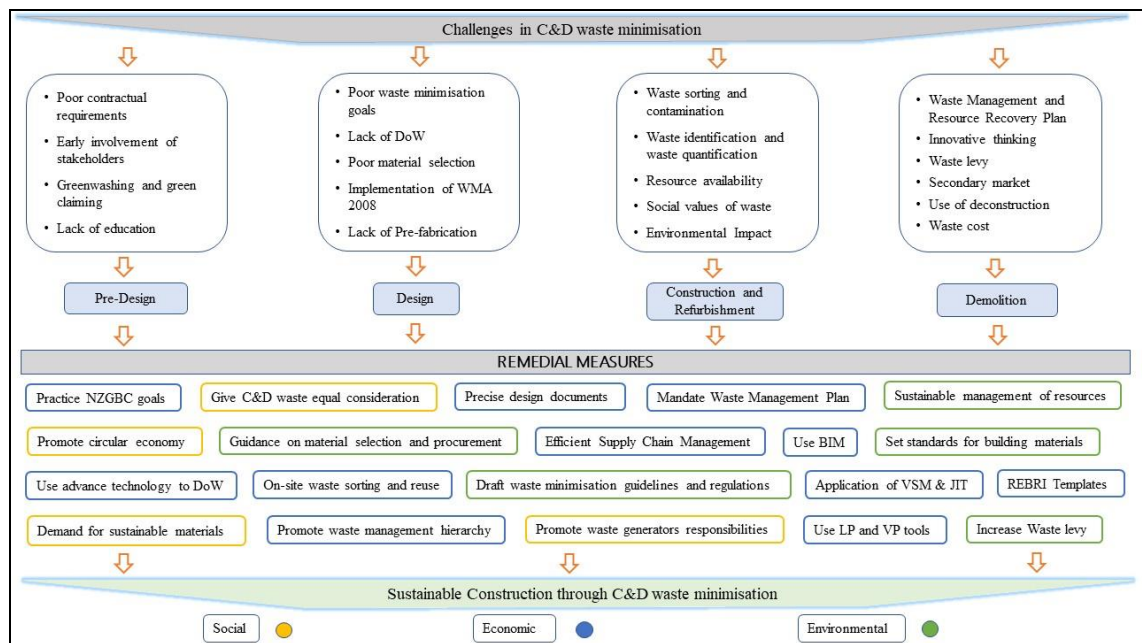


Figure 2.6: Theoretical waste minimisation framework (developed from literature review)

Waste minimisation is considered a collective responsibility, and all the project stakeholders need to contribute their share to achieve SC through waste minimisation (Domingo, 2011). Construction projects suffers from waste minimisation challenges at every stage over the life cycle of building projects (Elmualim & Alp, 2016). The theoretical waste minimisation framework divides all challenges into four broad stages, i.e. pre-design, design, construction (and refurbishment) and demolition. Pre-design stage challenges such as greenwashing, can be addressed through efficient procurement, precise design documents and demand for sustainable building materials (Atombo et al.,

2015). Subsequently, successful application of waste management hierarchy can solve design stage challenges such as poor material selection (UNEP, 2013). In addition, advanced techniques such as BIM can help to DoW (Won et al., 2016). Further, REBRI guidelines and use of templates, can minimise the waste reporting related challenges (BRANZ, n.d.). Remedies for the refurbishment stage challenges, such as social values of waste, is promotion of circular economy and education on social benefits of waste minimisation (Raghuwanshi, 2017). On-site sorting and reuse helps to achieve social benefits of waste minimisation (Vilasini, 2014). Application of lean tools, deconstruction, LP and VP induce innovative thinking and minimises waste handling cost (Sanchez et al., 2019; Maués et al., 2020). In addition, mandatory waste management and resource recovery plans create secondary markets for waste materials (Rose & Stegemann, 2018). The theoretical waste minimisation framework shown in Figure 2.6 laid the foundation for proposing a practical framework for the Auckland CI.

2.12 Summary

The literature review was conducted to understand the state of the art of C&D waste minimisation to advocate SC. The sections discussed in this chapter build a direct relationship between C&D waste and SC. In addition, importance of C&D waste minimisation to achieve SC was analysed.

This chapter reviewed the literature that compared NZ on the global scale on themes such as the economic contribution of CI, the status of SC, C&D waste and its extent, and C&D waste minimisation approaches. The literature review suggested that, worldwide, CI is envisaged playing a more significant role in GDP contribution and employment. In NZ, infrastructure demand has significantly increased in recent years, and CI has grown rapidly. The growth of CI introduced the need for SC and established social, economic, and environmental challenges, and these challenges lead to: i) imbalance between social, economic and environmental aspects; ii) high waste generation and high energy consumption due to increases in the population and infrastructure demand; and iii) financial fatalities due to cost overrun at any stage.

The literature review showed that in many countries, C&D waste was not well documented. However, the vast body of literature suggested that C&D waste is reflected as one of the biggest environmental concerns. For example, at the time of this research, C&D waste was the third largest waste stream in the world (behind MSW and C&I) It

is also the largest waste stream in all OECD countries, one of the priority waste streams in NZ, and the largest waste stream in Auckland with 50 % landfill contribution. Some of the factors that influence C&D waste include, but are not limited to, change in scope of the project, poor specification writings, lack of waste management plan, and secondary market for recycled products. The minimisation of C&D waste has been considered a means to advocate SC.

Although there are remarkable benefits of C&D waste minimisation, the adaptation of waste minimisation approaches has been arduous and challenging for CI practitioners. In addition, the current waste minimisation practices in NZ are distant in advocating SC. Further, C&D waste minimisation through life cycle thinking has not been studied in the Auckland CI, which shows a knowledge gap in the literature. Hence, the next chapter described methodological options and research design used in the study to fill that gap.

Chapter 3 Research Methodology

3.1 Introduction

The broad explanatory review of literature emphasised the need for C&D waste minimisation to advocate SC. The literature also examined the available waste minimisation approaches and noted the knowledge gap. This chapter introduces a methodological argument on the research process to fill the knowledge gap, i.e. the process of finding answers to the research questions.

The chapter begins with a general definition of research and research methodology, followed by a scientific meaning. Subsequently, the philosophical stance of the research was determined and assumptions were made to collect, analyse, and validate the data. Thereafter, different research approaches and techniques are analysed with a supplement of approach and technique adopted for this research. The chapter then outlined several research strategies and suitable strategy adopted for this study. Subsequently, data was collected with ethical considerations. Further, the chapter provided commentary on data analysis and explained the reliability and validity of the research findings. These steps led to proposing a waste minimisation framework. Finally, the chapter concluded with a summary

3.2 Overview of Research Method and Research Methodology

During Middle Ages in France, the word ‘research’ referred to a process of seeking closely. In later decades the rational thinking aspect was added which introduced scientific seeking, notable as scientific investigation or inquiry (Harper, 2020). The modern-day definition describes research as a systematic process that produces new knowledge or creatively uses existing knowledge to find answers to the questions of interest (OECD, 2013).

In the context of ‘methodology’, the word ‘method’ is made from a combination of the Greek words ‘meta’, i.e. desire and ‘hodo’, i.e. road, together becomes a road that fulfils the desire. Further, the word ‘logy’ demonstrates a subject's doctrine (Harper, 2020). The scientific version expresses methodology as a structured framework prepared to solve the problem by applying suitable methods (Goundar, 2012). In addition, a methodology referred to an investigation performed to collect, examine and validate data in the most efficient way (OECD, 2004).

A research method is a part of research methodology and regarded as a tool to collect data, while research methodology is a guide that offers multiple methods to collect and analyse data and produce the findings (Igwenagu, 2016). A scientific investigation has a structured framework to solve the research questions. The framework is often built on inductive and/or deductive approaches. The former is applied to generate a new theory, while the latter validates the existing theory (Burney & Saleem, 2008).

It has been argued that research methodology has an impact on the quality of the research. It allows the researcher to gather knowledge through multiple perceptions and enhance the understanding of the subject matter (Abutabenjeh & Jaradat, 2018). In addition, it guides selecting a suitable research strategy and approach that justifies the outcomes (Goundar, 2012). Moreover, it offers the validity of the outcome and improves the overall performance of research. However, understanding the research problem, knowledge of research methods, and philosophical assumptions, often influences research outcome (Kothari, 2017). The next subsections cover all these subjects in detail.

3.3 Philosophical stance of the Research

Philosophical stance or research philosophy is considered as a cornerstone of research methodology. Knowledge of research philosophy helps researchers establish, control and enhance the research approach and strategies to generate knowledge (Creswell, 2018). In addition, research philosophy explores existing theories to confirm scientific findings, through multiple viewpoints based on multiple philosophical assumptions (Sapkota, 2019). These assumptions play a vital role in selecting a research paradigm as they question ‘what is reality?’ and ‘what is knowledge?’ (Sapkota, 2019). The next subsection discusses the three most common research paradigms and their philosophical assumptions. Further, the subsection concludes with the research paradigm and philosophical assumptions considered for this research.

3.3.1 Positivism

A paradigm describes a way of seeing the world through a spectrum of narratives with a set of beliefs. In early 18th century Comte, founder of Positivism, introduced sociology (Lenzer, 2017). Positivism in sociology is defined as a system that includes scientific investigation to collect the data and exclude metaphysical speculations (Whewell, 2017). Positivism is also described as a paradigm or philosophical position that upholds

logic and rational thinking with empirical data, to find answers to research questions (Creswell, 2018). Positivism has a two-fold tenet: generalise scientific notions and enhance understanding of social life (Allwood, 2019). To perform research with clarity, positivism is required to have philosophical assumptions (Yvonne Feilzer, 2010).

Ontology and Epistemology are arguably the most important philosophical assumptions. The word 'onto' refers to 'being real' and 'episteme' means 'knowledge' (Harper, 2019b, 2019a). The positivism paradigm considers one single reality and measures the knowledge obtained through that reality (Alharahsheh & Pius, 2020). In addition, positivists consider social and physical reality the same with an objective approach. Further, positivism uses a quantitative approach for data collection, as the researcher ought to be distant from the research (Hasan, 2016). However, some authors argue that the social world is created through individuals' perception and discards the single reality concept (Alharahsheh & Pius, 2020). In addition, positivists find answers of the 'what' question but cannot find answers to 'why' (Dananjoyo, 2018).

3.3.2 Interpretivism

In the late 18th century, Dilthey emerged as the first documented critique of positivism (Hodges, 2013). The argument presented and later accepted was a reality (ies) discuss the objectified expression of human minds and cannot be separated from the world. In addition, the natural world cannot be explained without considering human actions and to understand the subject matter clearly, these actions need to be interpreted logically (Hodges, 2013). Interpretivism is defined as a philosophical position that acknowledges the existence of multiple realities and considers the researcher as a part of it (Alharahsheh & Pius, 2020). The ontological assumption allows the researcher to consider the truth or reality as a socially constructed phenomenon because facts are subjective (Hasan, 2016). The epistemological assumption offers an interpretation of data to find hidden effects or underlying findings (Ryan, 2018). However, the generalisation of findings is not recommended if the sample size is small (Dananjoyo, 2018). Further, interpretivism often uses a qualitative approach to gather data through in-depth interviews (Alharahsheh & Pius, 2020).

3.3.3 Pragmatism

Pragmatism refers to a perception that offers a practical viewpoint to collect, analyse and validate the data (Parvaiz et al., 2016). As the name suggests, pragmatists envisage

social life with practical relevance and are free to adopt the best-suited research approach to get the findings (Dananjoyo, 2018). In other words, pragmatists consider pragmatic or practical issues concerned with the study by neglecting all constraints enforced by a positivist or an interpretivist (Yvonne Feilzer, 2010).

The pragmatists' ontological assumption considers that the current truth constantly changes, hence, the epistemological assumption deems knowledge a temporary phenomenon; no ultimate truth exists (Maarouf, 2019). Further, a pragmatist considers that reality remains negotiable, debatable and interpretable through multiple views. Subsequently, the views should be examined via a combination of different methods rather than considering one specific method (Dananjoyo, 2018). Moreover, pragmatists hold no specific position and often consider both subjective and objective data collection approaches depending on the research questions (Parvaiz et al., 2016). Therefore, it has been argued that research should adopt a pragmatist research approach that provides practical outcomes for the research (Yvonne Feilzer, 2010).

3.3.4 Research Paradigm for this study

Positivists collect knowledge objectively, while interpretivists involve themselves in the research to collect the knowledge (Alharahsheh & Pius, 2020). Further, a pragmatist considers that knowledge should be obtained through the best possible paradigm (Parvaiz et al., 2016). Positivism and interpretivism are extreme ends of philosophy, while pragmatism offers flexibility to adopt any or both research paradigms (Tran, 2016). Table 3.1 compares all three research paradigms on different themes to assist selection of a research paradigm for this study.

Table 3.1: Comparison of different research paradigms

Themes	Positivism	Interpretivism	Pragmatism
Reality	Reality is concrete	Realities are abstract	Changes constantly
Truth	One single truth	Multiple interpretations	No ultimate truth
Approach	Deduction	Induction	Abduction
Facts	Facts are objective	Facts are subjective	Adopt the best possible tools to solve the research questions
Researcher findings	Distinct	Interactive	
Sample size	Generalise	Specific and unique	
Approach	Large in number	Small in number	
	Quantitative	Qualitative	

(Al-Ababneh, 2020)

It can be seen from Table 3.1 that pragmatism paradigm offers intermediate thinking or practical thinking to collect and validate the data. A paradigm shift is considered a natural phenomenon because researchers prefer to see the world through different perspectives (Dananjoyo, 2018).

Positivism often solves natural science problems, and interpretivism deals with social science problems (Ryan, 2018). The construction management-related research is often positioned between natural science and social science, and hence pragmatism is recommended for data collection and interpretation; to get practical solutions (Love et al., 2002).

The construction work involves humans, and hence the researcher faces obstacles for being distant from the process. In addition, construction projects include many stakeholders, allowing the existence of multiple perceptions resulting in multiple realities (Scott, 2016). However, these realities are debatable as truth changes depending on the perception. A commonplace practice found that architects often highlight poor workmanship if construction projects fail, while the site engineer believes that the lack of standardised drawings from architect causes the failure (Kovac, 2018).

This research aims to develop a waste minimisation framework to advocate SC. The research identified the factors that influence high waste generation and the causes and effects of such factors. To do this, the researcher collected in-depth data by becoming a part of the research and then observing the construction process objectively or

subjectively or using both approaches to validate the data. Therefore, this research adopts the pragmatism paradigm to collect, analyse and validate the data.

3.4 Research Approach

A research approach is a way forward or a procedure that guides data collection, analysis, interpretation and validation for reliability (Gaus, 2017). The research approaches cover broad aspects of research work and are considered a general pathway to achieve the research's overarching aim (Bryman, 2017). Before adopting the research approach(es) for a study, the researcher should understand 'Theory' and 'Data' as these factors are cornerstones of approaches (Domingo, 2011). 'Theory' in a scientific context is defined as a set of logical statements that establish a link between variables to describe a phenomenon (Abend, 2008). In addition, theory interprets observations to prove the existence of a phenomenon. Further, information collected to prove a theory is labelled as 'data'.

The academic literature divides research approaches into three broad categories: deductive, inductive and abductive approaches (Awuzie & McDermott, 2017). In the deductive approach, a theory/hypothesis is developed and later tested by collecting data. Conversely, in the inductive approach data is collected to develop a theory (Leavy, 2017). The abductive approach is considered to be similar to the inductive approach. The researcher collects enough (limited) information to develop a theory. Unlike the inductive approach, the abductive approach gives the most possible answers as the process of abduction eliminates all non-possible solutions (Awuzie & McDermott, 2017). All three approaches offer benefits depending upon the nature of work and research questions. Table 3.2 overviews the approaches on different themes.

Table 3.2: Research approaches

Themes	Deductive	Inductive	Abductive
Logic	Theory to observation	Observation of theory	Theory-observe-theory
Generalisability	General to specific	Specific to general	Specific/general
Future	Certainty	Probability	Most certain
Theory	Verify and test	Design and generalise	Generate and modify

(Edmonds & Kennedy, 2016)

Table 3.2 shows that the deductive approach verifies the existing theories and predicts the certainty of outcome for a specific phenomenon. In contrast, the inductive approach develops a theory with probable futuristic results to generalise the findings (Woo et al., 2017). All the approaches are logically correct and prove viable in the different study areas, i.e. social science and natural science; hence no comparison can be made. Building environment-related studies often require a combination of approaches to produce a viable outcome (Awuzie & McDermott, 2017).

This study adopted the abductive approach. It has collected enough data by reviewing the literature on C&D waste to develop a hypothesis on the need for waste minimisation. In addition, the CI already practices waste minimisation approaches, and through this study, such practices were observed to propose a new framework with specific findings. Research approaches are categorised as quantitative, qualitative, and mixed-methods.

3.4.1 Quantitative, qualitative and mixed methods

Research approaches are often classified based on the nature of the information they offer to the researcher (Leavy, 2017). Quantitative research approach is defined as a method to establish a relationship between variables through deductive reasoning, based on cause-and-effect phenomena. In addition, quantitative research uses statistical methods to test a hypothesis to confirm an event (Creswell, 2018). Quantitative studies mostly collect numerical data and adopt a positivist viewpoint to resolve social phenomena. The researcher often remains distant from the research, hence the quantitative approach collects objective knowledge (Edmonds & Kennedy, 2016).

In qualitative research, a researcher understands human behaviour through participants' experiences, ideas, and thoughts on the subject matter (Leavy, 2017). The researcher involves themselves in the research and collects the data from a subjective viewpoint. In addition, the researcher often discusses and debates this data with participants, and hence qualitative research adopts open-ended questions to examine an inquiry. Further, the collected data is interpreted carefully to develop a theory (Creswell, 2018). Overall, qualitative research uses inductive reasoning to achieve the aim of the research (Creswell, 2018).

In the mixed-methods approach, the researcher often uses both quantitative and qualitative methods in parallel or sequence. The former executes both methods

concurrently with no relationship with each other, while the latter performs one method after completing the other (Granikov et al., 2020). The researcher combines the features of both methods to develop and validate the hypothesis (Creswell, 2018). The mixed-methods approach uses multiple perceptions of the subject matter, a complete understanding of phenomena, and critical validation of results (Tashakkori et al., 2020).

The selection of a research approach is influenced by research questions and the nature of the inquiry, i.e. explanatory or exploratory or convergent (Creswell, 2018). The explanatory inquiry is a two-phase mixed methods design. The first phase starts with collecting and analysing the quantitative data, followed by collecting and analysing qualitative data. Conversely, in exploratory inquiry, qualitative data is collected, followed by quantitative data. In both inquires, findings of the first phase are used to design or develop the second phase. In the convergent inquiry, the researcher collects quantitative and qualitative data concurrently and analyses it separately. Subsequently, the results of both phases are merged to interpret the research findings (Creswell, 2018). In addition, different factors need to be considered before selecting a research approach. Table 3.3 lists some of the factors and their interpretation under all three approaches.

Table 3.3: Different research approaches

Factors	Research approach		
	Quantitative	Qualitative	Mixed- method
Paradigm	Positivism	Interpretivism	This approach combines quantitative and qualitative approach with the philosophical paradigm of pragmatism
Knowledge	Objective	Subjective	
Examine	Variables	People	
Logic	Deductive	Inductive	
Findings	Statistics	Narrative	

(Creswell, 2018)

Table 3.3 shows that the researcher examines different variables in quantitative research by acquiring numerical data to publish statistical findings. On the other hand, in qualitative research, the researcher explores concepts and ideas to publish narrative findings. The mixed-methods approach allows the researcher to generate a theory and validate it through reliability (Creswell, 2018).

The quantitative approach focuses on validating theory without being part of the research, resulting in abstract findings. Such findings are general and require a detailed exploration of the topic through discussion and debates (Kumar, 2018). Though discussion provides valuable information, time and resources required to conduct and interpret them remain one of the limitations of qualitative investigation (Creswell, 2018). The mixed-methods approach gives the researcher flexibility to adopt both approaches to overcome individual weaknesses and obtain benefits from both methods (Daniel et al., 2018).

3.4.2 Approach suitable for this study

Construction-related research requires the development of theory and validation of findings (Love et al., 2002). This research investigates how C&D waste generates over the life cycle of building projects and propose a better waste minimisation approach through a waste minimisation framework. To develop the framework, factors influencing waste are considered for data collection. Further, industry practitioners' experience, thoughts, and expertise were documented.

In addition, to validate the findings, the researcher needs to observe the process without being part of the research. Therefore, this research adopts the mixed-methods approach for data collection, analysis and validation.

The data collection includes qualitative investigation (literature review and in-depth interviews) to determine the factors contributing to waste generation over the life cycle of project. Further, a quantitative approach (structured on-site observations) was adopted to validate the findings. The combination of both approaches provided generalisability and reliability of the findings.

3.5 Research Techniques

A research technique is defined as a procedure adopted to collect, analyse, interpret and report the research data (Goundar, 2012). To select a feasible research technique, the researcher should have a clear purpose of research, philosophical assumptions, and research approaches (Ernst, 2019). In addition, resources allotted for the study and timeframe for research also influence on the research technique selection process (Berkwits & Inui, 1998). Several studies have been done in construction management, and various research techniques were employed (Fellows & Liu, 2015). Table 3.4

presents the commonly adopted research techniques for the mixed-methods survey approach.

Table 3.4: Research techniques

Technique	Approach	Strength	Weakness
Interviews	Exploratory	Allows participants to share opinions	Time-consuming and expensive
		Allows researcher to control questionnaire	Responses are biased and require validation
Questionnaire	Explanatory	Easy to interpret and analyse	Low response for complex questionnaire
		Inexpensive and have a quick turnaround	Poor interpretation of questions
Focus group	Exploratory	Provides a diverse set of response	Difficult to analyse and interpret data
		Allows exploration of the topic in detail	Bias atmosphere due to groupthink nature
Observation	Exploratory and explanatory	Gives real-time data of project activities	Bias due to researchers' manipulation
		Provides detail assessment of a topic	Behavioural change in participants
Document review	Exploratory and explanatory	Easy to collect and analyse data	Limited access to data and poor readability
		Contain accurate details of an event	Bias interpretation if insufficient data

(Creswell & Creswell, 2017)

Table 3.4 shows that different research techniques provide different benefits, along with their weaknesses. It has been argued that one technique cannot be superior to others, depending on its implementation and circumstances (Creswell 2018). A combination of techniques, i.e. more than one technique to collect data, is often recommended to improve research quality and reliability (Creswell & Creswell, 2017).

i. Interview

An interview is defined as a process of social interaction organised to gather information on the topic of interest (Creswell & Poth, 2016). Interviews explore participants' viewpoints on industry practices, challenges in the process and opportunities for improvement (Saunders et al., 2003). In addition, participants'

experience and emotions help the researcher establish a relationship between variables and their impact (Saunders et al., 2009). Interviews are taken in-person, telephonic, or via video conferencing and classified under three broad categories: structured; semi-structured; and unstructured (Leavy, 2017). Structured interviews are rigid, while unstructured interviews give the researcher very little control over participants' responses. Semi-structured interviews offer a degree of freedom to the researcher to control the discussion with basic interview structure (Kumar, 2018). The semi-structured exploratory interviews use open-ended questions, while the explanatory interviews are conducted with closed-ended questions (Kumar, 2018). Further, in-depth semi-structured interviews offer flexibility and enable the researcher to collect detailed information by asking probing questions. Overall, in-depth semi-structured interviews guide the researcher to understand social phenomena of concern and their remedial measures (Creswell, 2018). Although such interviews are often targeted for biasness, researchers ability to conduct the interview and interpret the collected data gives unbiased findings (Qu & Dumay, 2011).

ii. Questionnaire

A questionnaire is a research tool that includes a series of questions to collect information from participants. A questionnaire survey generally targets a large population when the interviews are not feasible (Yin, 2017). Questionnaires are sent to participants via paper, telephonic and online surveys, requiring less resources to collect the data. Questionnaires are often organised in a standard explanatory structure to get similar responses (from given choices) to validate a hypothesis (Kumar, 2018). However, an exploratory questionnaire can be also designed if the research questions and research design requires exploratory data (Creswell, 2018). As shown in Table 3.4, the response rate for the questionnaire remains low due to long and complex questions. Hence, a well-designed questionnaire with a pilot study is recommended for a large group of participants (Creswell, 2018).

iii. Focus group

A focus group is a group of people discussing a specific issue to seek different opinions to solve it (Webb & Kevern, 2001). Focus groups generate textual information rather than numeric and therefore are well suited for qualitative research with open-ended questions. The textual information shows individuals' behaviour, attitude, and perceptions (Rosenthal, 2016). These individuals are experienced people or experts in

their field. Focus groups are conducted in one or multiple sessions depending upon the complexity of the research questions and the quality of data (Guest et al., 2017).

iv. Observation

A research instrument that observes activity or events to understand the process (or behaviour) and its impacts referred to observation research technique (Corbin & Strauss, 2014). A researcher chooses to observe a process or a participant or both, to gather knowledge (Creswell, 2021). The observer collects data through different observation positions. For example, i) complete participants-researcher is fully involved in the activity; ii) complete observer - the researcher is not visible to participants and confidentially collects data; and iii) observer as a participant-researcher is neither a complete participant nor complete observer and acts as an outsider of the group and takes notes from a distance without direct involvement in an activity (Takyi, 2015).

v. Document review

A process of collecting, documenting, analysing and interpreting a set of documents labelled as document review (Kothari, 2017). It can be seen from Table 3.4, that document review provides a detailed description of processor events. A review of documents helps the researcher understand the research's theoretical underpinnings and gather information on processes, problems, and existing solutions (Kumar, 2018). Further, the review offers a possible solution or a methodological approach to get the solution for the research questions (Creswell, 2018). However, before finding the solution, the researcher often suffered from accessibility and readability of data (Creswell & Poth, 2016). As a result, solutions are difficult to interpret and seems biased, for their validity. It is, therefore, suggested that document reviews need to be done effectively by dividing them into themes and keywords during the analysis and interpretation phases (Aberdeen, 2013).

There has been a notion and proven studies that show the application of more than one technique to collect the data, offers reliability and validity of information, generally referred as data triangulation (Creswell, 2018). In NZ, at the time of this study, there have been limited documents available on C&D waste minimisation through life cycle assessment. Further noted, is the fragmented CI of NZ and growing but limited awareness (and participants) of C&D waste minimisation to achieve SC discard questionnaire survey technique.

The focus group technique was ruled out because the research aims at finding individual perceptions without social pressure from fellow participants. In addition, the research technique should not be based on the groupthink concepts as it results in poor data collection; it is also difficult to generalise the findings. Data interpretation from focus group audio-visuals and notes often consume more resources than individual interviews during the data analysis.

This research adopts an in-depth semi-structured interview approach with open-ended questions to explore the subject matter. Interviews offer broad perspectives and provide substantial knowledge. This knowledge helps the researcher to identify factors influencing C&D waste in the Auckland CI. Further, this research also adopts an on-site structured observations technique to validate the identified factors. The researcher was not involved in the construction activities and observed the process from a distance. The interviews and observations helped the researcher to propose a waste minimisation framework

3.6 Research Strategies

A research strategy is described as an overall plan of action to execute and monitor the research study (Schutt, 2018). The research strategies guide the researcher in selecting the research technique that fits the philosophical stance of the research and research approach (Creswell, 2018). It has been argued that the nature of the research question, the researchers' control over behavioural events and the degree of inclination towards contemporary events influence research strategy selection (Kumar, 2018). In addition, a researchers' field experience, resources required to implement strategy and the audience should also be considered when choosing a research strategy (Schutt, 2018).

Several authors classified the research strategies in different categories considering the aforementioned criteria (Creswell, 2018; Kumar, 2018; Schutt, 2018). Table 3.5 presents some of the commonplace strategies used to investigate scientific inquiries.

It can be observed from Table 3.5 that different research strategies are suitable for different scientific investigations. In addition, research criteria such as behavioural control and consideration to contemporary events, also plays a vital role in selecting a research strategy. The different strategies are discussed in detail below.

Table 3.5: Research strategies and their suitability

Strategy	Type of question	Control over behavioural events	Focuses on contemporary events	Suitable for
Experiments	How, why	Required	Yes	Exploratory and explanatory
Survey	Who, what, where, how many, how much	Not required	Yes	Descriptive, exploratory and explanatory
Archival analysis	Who, what, where, how many	Not required	Yes/No	Exploratory and explanatory
Grounded theory	How, why	Not required	Yes/No	Exploratory and explanatory
Case study	How, why	Not required	Yes	Descriptive, and exploratory
Ethnography	How, why	Required/Not required	Yes	Descriptive, and exploratory
History	How, why	Not required	No	Exploratory
Narrative study	How, why	Not required	Yes	Exploratory
Phenomenology	How, why	Not required	Yes	Exploratory
Action research	How, why	Not required	Yes	Explanatory
Delphi method	How, why	Not required	Yes	Exploratory

(Creswell, 2018)

i. Experiments

The experiment strategy establishes a cause and effect relationship between a factor and an observed outcome (Kothari, 2017). Experiments are conducted in a controlled laboratory environment to explain or explore a phenomenon (Creswell, 2021). This strategy is mostly suited for the validation of hypotheses (or theories) in the field of natural science (Kumar, 2018). In the social world, experiments often suffer from ethical issues as they involve the recruitment and management of a group of people in a controlled environment (Creswell, 2018).

ii. Survey

The survey strategy is defined as a process of collecting responses from a group of people (Creswell & Creswell, 2017). Surveys often recruit a large number of people and

study their behaviour to get ideas and thoughts for process improvement (Kothari, 2017). Thus, the survey strategy is often practised in social science and psychological studies (Ponto, 2015). Surveys collect data through a variety of methods such as interviews, observation and review of documents. One of the challenges in data collection and validation, is sampling and generalising findings from the samples (Kumar, 2018).

iii. Archival analysis

In the archival analysis, a scientific investigation is carried out by collecting manuscripts, documents and textual material (Ventresca & Mohr, 2017). In addition to the archive, contemporary events and documents are also studied to get insights into the current practices (Rahi, 2017). The findings of such strategies are heavily influenced by the availability of data, accessibility of data and nature of data. In addition, modern-day studies often require compatible solutions offered by currently available technologies rather than data collected in the past with then available technologies (Creswell & Creswell, 2017).

iv. Grounded theory

To develop a grounded theory, data is collected from the ground, rather than exploring available literature on the subject matter (Rahi, 2017). The strategy requires empirical data to generate a theory, but it also allows the researcher to study contemporary events to enhance the research findings (Chun Tie et al., 2019).

v. Case study and Ethnography

In-depth exploration of an event, a programme or one more individuals in a specific timeframe is referred to as case study strategy (Creswell & Poth, 2016). This strategy is suitable for different types of inquiries, i.e. descriptive, exploratory and explanatory. However, it requires a lot of resources and extensive data collection techniques from multiple resources to achieve the aim of the study (Yin, 2017). Unlike case studies, ethnographic research studies an entire group of people who share common interests (generally cultural) (Hammersley, 2018). The researcher observes a pattern in the participants' everyday behaviour to find themes for the conclusion (Creswell & Poth, 2016). Similar to the case study, an ethnography strategy is considered a laborious task (Fetterman, 2019).

vi. History

A history strategy explores the events that happened in the past to establish a sense of similarity and correlation to the present problem (Meyers et al., 2016). The researcher does not consider contemporary events, and hence the findings are not suitable for studies where specific problems haven't been studied in the past (Kumar, 2018). In addition, a lack of understanding of current practices gives outdated solutions (Leavy, 2017).

vii. Narrative inquiry and Phenomenology

Both of these research strategies seek individual perception and participants' personal experience (Williams, 2007). The data collection deals with how participants sense reality and construct the social structure around them (Hickson, 2016). The scientific credibility of both strategies remains a principal challenge in their implementation. In both strategies, the researcher discards theoretical assumptions and consider experiences shared by participants to obtain the conclusions (Creswell & Poth, 2016).

viii. Action research

In contrast with experiments, an Action research strategy involves a real-life environment rather than a controlled laboratory environment (Stringer & Aragón, 2020). The researcher goes beyond observation, theorises phenomena, and solves real-world problems of participants that they experience in their everyday practices (Coghlan, 2019). One of the limitations of improving such practices is a generalisation of the findings. As the research tangled with a specific group of people, it often requires repetition of the process with different participants under different situations (Creswell, 2018).

ix. Delphi method

Similar to action research, the Delphi strategy also targets a specific group of people in this case, experts in the field (Okoli & Pawlowski, 2004). In Delphi method, a questionnaire is sent out to experts, followed by a discussion. Further, the experts receive feedback in the form of 'group response' to adjust their responses for the next round of discussion (Avella, 2016). Several rounds of questionnaires and discussions are conducted to get validated opinions to solve the problem (Avella, 2016).

The current research investigates through ‘how and what’ type of question. The research develops a waste minimisation framework by understanding the relationship between factors influencing waste and waste minimisation approaches.

The experiment strategy would not be suitable as this research falls between natural and social science. In addition, participants cannot be controlled and manipulated in the process of data collection. The archival analysis was also eliminated as the body of literature on C&D waste minimisation through the life cycle approach was limited. In addition, this research aims to analyse contemporary achievement in C&D waste minimisation to develop a waste minimisation framework. Grounded theory was also overruled as it consumes more time and produces a large amount of data, often difficult to manage.

Case study and ethnographic strategies are time-consuming and require a lot of resources. Further, history analysis was rejected due to lack of historical data and constantly improving NZ construction practices. The narrative and phenomenology strategies are not best suited for the study as the research aims to generalise the findings with scientific validation. Further, Action research and the Delphi method were not suitable because of similar concerns.

This research aims to recruit an exploratory and explanatory strategy that consumes optimal resources. A strategy that allows scientific rigour and offers pluralistic findings that can be validated and generalised for the Auckland CI. Survey strategy provides all the essentials and hence is selected for this research to achieve its overarching aim. This study adopts two approaches of the survey strategy: semi-structured interviews and on-site structured observations.

3.7 Data collection

This study began with the researcher finding a broader area of interest focusing on CI in NZ. An extensive literature review enabled the researcher to develop an argument towards the importance of SC. After narrowing the interest to C&D waste minimisation, the researcher discovered a knowledge gap. Subsequently, the impact of the knowledge gap was determined to articulate research questions with the aim. The knowledge gap instigated the process of comprehensive data collection to achieve the aim of the study. The data collection was done in three phases: preliminary data collection; semi-

structured interviews; and on-site observations to propose a waste minimisation framework. The next subsection briefly discussed these phases.

3.7.1 Phase 1: Preliminary data collection

The preliminary data collection consisted of a literature review and conducting a pilot of semi-structured interviews. The literature review covered a broad area of research and identified the research gap. Further, pilot interviews helped the researcher get insight into CI in NZ, especially Auckland CI. The pilot interviews were conducted from December 2020 to February 2021, followed by the ethics approval in November 2020.

The literature review is defined as a process of understanding the state of the art of the area of interest by examining multiple sources of information (Kumar, 2018). In this study, a review of literature began with a background study of the CI and its impact. Subsequently, different keywords such as ‘SC, C&D waste, C&D waste minimisation, and different C&D waste minimisation approaches in NZ’ are used to broaden the search. These keywords emerged as different themes that identified the issue of C&D waste and advocated its minimisation to achieve SC.

To confirm the literature findings and establish a position of Auckland CI and its C&D waste issue, the researcher conducted a pilot study that included six semi-structured interviews. Semi-structured interviews with open-ended questions allow the participants to express their emotions, ideas, and opinions about the subject matter (Kumar, 2018). These expressions helped the researcher to understand participants’ knowledge on research questions and the way forward to develop the solution (Leavy, 2017). In this research, interview participants represented different stakeholders, including client representatives, contractors, policymakers, and policy influencers. Each category of stakeholders had different participants:

- Client representatives- Architects, Engineers and Project Managers;
- Contractor- Site Engineers and Construction Managers;
- Policymakers- City Council and MfE employees; and
- Policy influencers- Research organisation’s employees, waste collectors and recyclers.

The researcher interviewed two participants from each category to conduct the pilot study. The in-depth interviews with industry experts provided rich and experiential data

which confirms the theoretical existence of a knowledge gap into practice. This step gave the confidence to explore the topic in detail and conduct the second phase of data collection.

3.7.2 Phase 2: Semi-structured interviews

The in-depth semi-structured interviews provide high level and deeper understanding of the subject matter. This research adopted a qualitative approach to collect the data through survey technique. In this data collection stage, similar to the pilot study, semi-structured interviews with 31 industry experts were conducted from March 2021 to July 2021. It has been argued that the quality of a questionnaire influences the research outcome and hence it was articulated considering:

- Research aim and objectives
- The complete life cycle of projects, i.e. design to disposal
- The flow of questions - Starting with background information of participants to C&D waste challenges followed by best waste minimisation practices

The focus of the questionnaire was broad, which eventually narrowed down to a specific subject. The questionnaire was then revised multiple times to improve the readability and eliminate complexity.

The interview participants were recruited after finalising the questionnaire. The researcher established a physical network of contacts in Auckland CI through conference attendances and volunteering research-related technical events. In addition, the researcher also participated in regional-level competitions to present the research and collect information on potential participants. As a member of the Waste Management Institute of New Zealand and New Zealand Green Building Council, the researcher managed to interact with industry frontrunners and policymakers. Moreover, the researcher also adopted the snowball technique for recruiting participants when required. Selection of participants was made rigorously by considering their:

- Level of experience in the CI (International & NZ);
- Level of experience in dealing with C&D waste (International & NZ); and
- Level of experience in dealing with C&D waste (NZ and Auckland)

The participants represented a broad spectrum of CI practitioners. Table 3.6 shows different categories of participants and their average work experience.

Table 3.6: Participant information

Category	Number of participants	Average work experience (in years)
Client representatives	10	17
Contractors	12	8.5
Policymakers and influencers	9	12.5
Total	31	

Table 3.6 shows that client representatives, contractors, and policymakers and influencers were interviewed to collect the data. The client representatives had the highest average work experience while the contractors had the lowest. The minimum experience in each category, i.e. client representatives, contractors, and policymakers and influencers was eight years, five years, and eight years respectively. In contrast, the maximum experience was 40 years, 25 years and 20 years.

As presented in Table 3.6, the researcher conducted 31 semi-structured interviews for the data collection. It has been argued that most PhD studies find a sense of data saturation within 28 interviews if not within 31 interviews (Mason, 2010). The mode of the interview was in-person, telephonic and video conferencing. Most participants preferred video conferencing due to multiple nationwide lockdowns, and hence 19 out of 31 interviews were conducted through MS teams and Zoom. Further, 9 out of 31 interviews were conducted in-person as per the participants' convenience (time and location). In addition, 3 out of 31 participants were interviewed by telephone.

The average time for the interview was 45 minutes, and all the interviews were digitally recorded with participants' consent. In addition, hand-written notes were taken to add probing questions. The recordings and notes helped the researcher to perform: data analysis and interpretation, acquire direct quotes and provide an interview summary to participants.

3.7.3 Phase 3: On-site observation and waste minimisation framework

The literature review, preliminary data collection and semi-structured interviews discovered 36 critical (influential) factors accountable for high waste generation over

the life cycle of a project. The identified factors were validated for their generalisability through on-site observations. The on-site observations gave a realistic view of process and offered a better understanding of how activities are executed in a real-life environment. In addition, observations determined the difference between theoretical underpinnings and practical execution. The on-site observations caused a behavioural change in construction site workers, however multiple observations and efficient interpretation help the researcher to get impartial findings.

In this study, direct on-site observations of nine sites, including three from each; construction, refurbishment and demolition was conducted from July 2021 to December 2021. The sites were chosen by considering: location of the site, nature of work and the willingness of organisations to understand and practice waste minimisation. Figure 3.1 shows a graphical representation of on-site data collection process.

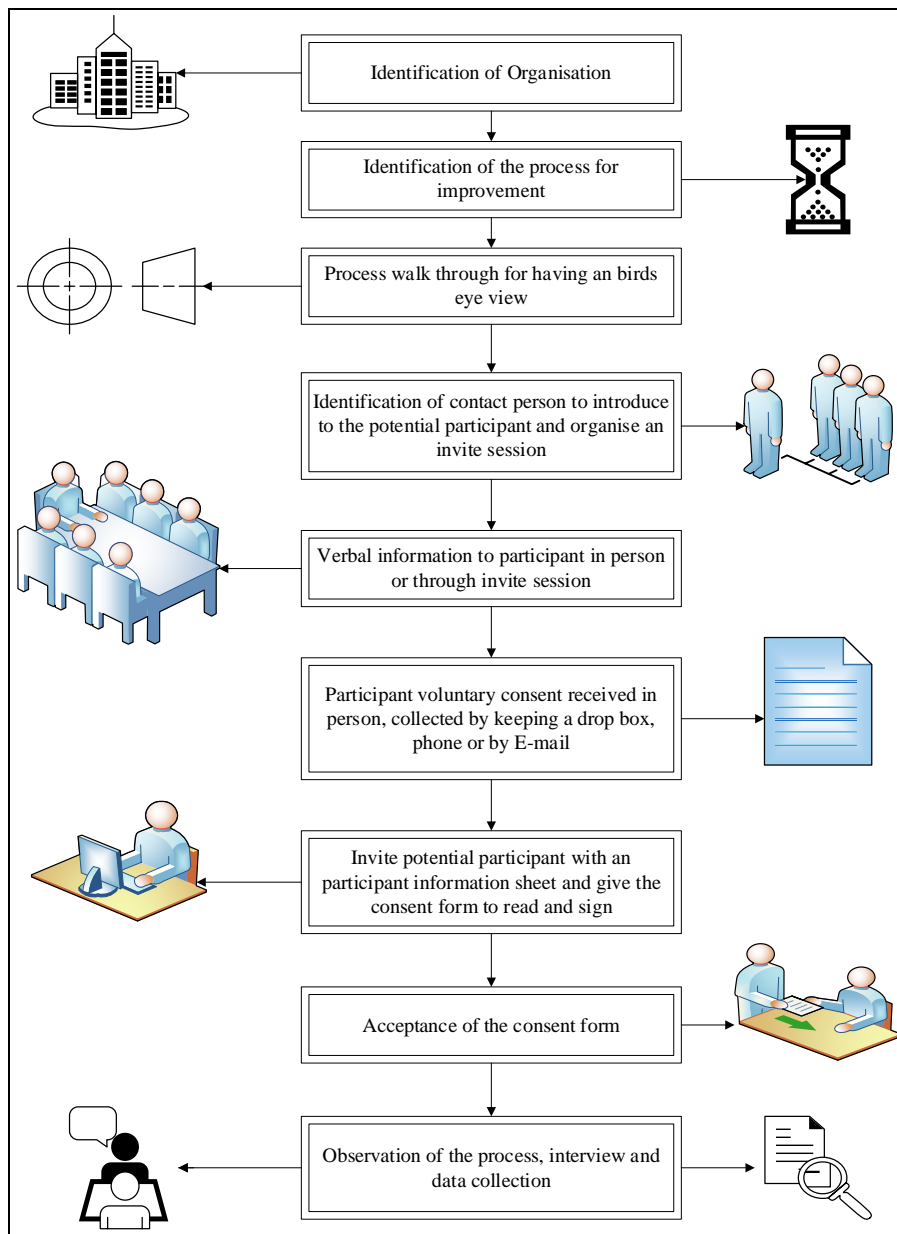


Figure 3.1: Process of on-site data collection

The on-site observations included the process and participant observation. The researcher observed the daily on-site activities for 30-60 minutes after getting consent from participants. The Participant-as-observer technique was adopted. The researcher collected data from a distance without interacting with site workers. The data collected through observations was quantitative, because only the waste generation factors and their frequency of occurrence were observed without interacting with participants. However, informal discussions with site managers were done on nine sites which added value to the findings. These findings were qualitative and hence analysed by using a thematic analysis technique. The informal discussions provided external validity to the waste minimisation framework. The waste minimisation framework was developed in four stages: i) identifying factors influencing a high waste generation, ii) understanding

waste minimisation practices in Auckland, iii) finding opportunities and challenges in waste minimisation, and iv) discovering remedial measures to challenges.

3.8 Ethical Consideration of the research study

Research ethics is defined as moral standards set to conduct a scientific investigation while protecting participants' dignity, privacy, and rights (Israel & Hay, 2006). Ethical standards promote the purpose of the research, collaborative work, generalisation of study, and moral and social values (Wiles, 2012). The researchers must maintain these standards by showing good behaviour towards the research participants (Smith, 2003).

This research adopts an ethical code set by Auckland University of Technology Ethics Committee (AUTEK). Two ethical approvals were sought from the committee before the beginning of data collection. The first ethics approval (19/418) was to perform the pilot study while the second was to conduct semi-structured interviews and on-site observations.

The Participants for the research were volunteers who gave consent to record their responses. The researcher strictly categorised the participants into different segments (client representatives, contractors and policymakers and influencers) without making identifiable remarks. The researcher also practised three 'Treaty of Waitangi' principles to make the ethics process robust. The next subsection discusses the principles in detail.

3.8.1 Principle of Partnership

The principle of partnership promotes the principle of working together. The researcher and participants (interview participants and on-site observations participants) worked together by giving feedback to each other. During the interviews, the researcher asked open-ended questions and the participants gave their feedback by answering the questions. Further, the researcher provided research findings to participants and feedback to participants to add value to their knowledge.

The research design adopted for the study helps the researcher understand the value of the knowledge obtained from participants. Conversely, the researcher's findings increase participants respect in their community. At the end of the research work, all participants were thanked for contributing to the study.

The research design introduced the utmost good faith in the researcher and participant. Further, the interview questions and on-site observation introduced mutual advantages and benefits to both parties. The researcher was also aware of the AUT code of conduct and practised it during the data collection period. Through the collected data, the researcher gained knowledge and expertise of the diverse people, and this collaboration introduced mutual respect between researcher and participants.

3.8.2 Principle of Participation

The principle of participation was accomplished through mutual understanding. The interviewed participants were expected to interact and respond to interview questions. In contrast, the direct observation participants needed to do their on-site activity, so that the researcher could observe and record notes. Both categories of participants were informed about the research methodology and their role in the research. In addition, participants did not have any formal role as stakeholders; rather, they were recruited from a broad range of client representatives, contractors and policymakers and influencers.

The research design wanted to achieve participants' positive involvement to strengthen the relationship between the researcher and participants. The researcher guided participants on how their participation and contribution helped the researcher to achieve the research aim. Conversely, the research findings helped participants understand current waste minimisation issues.

The research design allowed the researcher to understand participants' communities and their engagement with the issue of C&D waste. Further, by understanding the contribution of participants' communities to waste minimisation, the researcher gained knowledge of state-of-the-art of C&D waste minimisation.

3.8.3 Principle of Protection

The research design was intended to protect participants' knowledge, interest, and values by the researcher. The interview questions and direct observations did not deliberately deceive or harm participants' values. In addition, none of the data collection techniques involved harmful and inducing incidents socially or culturally. Further, the researcher did not label any participant during data collection and research publication stages.

Moreover, the researcher did not share any personal or professional (organisational) data with anyone without prior consent from the participant. Further, the researcher did not share any personal information about themselves and requested participants to avoid discussing any conflicting subject to protect both parties.

The researcher strictly respected the privacy of all participants during all stages of data collection. In addition, the researcher acknowledged the ethical factors such as protection of rights, benefits, and possessions. The interview sessions and direct observations gave rich data to the researcher, and the data was handled confidentially.

3.9 Data Analysis

Data analysis is defined as an organised process of examining the data through logic and reasoning to provide research findings (Creswell, 2021). Data analysis is also referred to method(s) used to describe claims, discover patterns, develop explanations, and invent or validate hypotheses (Kothari, 2017). Data analysis often included data examination, cleaning, sorting, categorisation, comparison, and synthesis (Kumar, 2018). The data analysis process benefited the researcher to establish a relationship between variables. Subsequently, this relationship proves or disproves hypotheses made by the researcher (Creswell & Creswell, 2017). This research collected data through a qualitative and quantitative approach. The next subsection discusses the data analysis procedure for both approaches.

3.9.1 Qualitative data analysis

Qualitative data analysis is a process of arranging interview transcripts, finding patterns and understanding the phenomena (Kumar, 2018). The procedure to perform qualitative data analysis consists of five steps:

- Transcription;
- Organisation of data;
- Familiarisation;
- Coding; and
- Themes.

These steps helped the researcher to build and test a theory (Lacey & Luff, 2001). The data gathered through in-depth interviews consists of unstructured textual information as the researcher aims to collect participants' ideas, thoughts, and opinions. This data was

organised by date or context. Further, multiple readings of organised data were performed to summarise initial understanding. The data was then coded and categorised under different titles. Subsequently, the titles developed themes and then from themes, developed a hypothesis. There are several techniques to analyse the qualitative data such as (Lacey & Luff, 2001):

- Thematic analysis;
- Content analysis;
- Narrative analysis;
- Discourse analysis ;
- Phenomenological analysis;
- Semiotic analysis;
- Ethnographic analysis; and
- Grounded theory analysis.

Thematic and content analysis are similar to identifying patterns and themes (Creswell & Creswell, 2017). However, the content analysis is partially quantitative as most findings represent numerical data. Conversely, the thematic analysis offers considerable attention to the qualitative aspects of the study (Joffe & Yardley, 2004). The narrative, discourse and phenomenological analysis deal with people and stories and how they are connected (Wertz, 2011). Further, semiotic analysis is defined as the study of signs significant to research. The signs exist in different forms such as pictures, objects, behaviour, metaphor or actions (Radford, 2000). The ethnographic analysis focuses on culture, family and education-related studies, while grounded theory deals with all studies performed on the ground.

Research questions influence the selection of a data analysis technique, and the researcher often uses multiple techniques to get precise findings (Leavy, 2017). In this research, qualitative data was collected through in-depth semi-structured interviews. Table 3.7 shows the details of the interview participants.

Table 3.7: Interview participants

Category	Code	Phase 1	Phase 2	Total
Client representatives	A	2	10	12
Contractors	B	2	12	14
Policymakers and influencers	C	2	9	11
Total		6	31	37

As shown in Table 3.7, this research collected qualitative data through 37 in-depth semi-structured interviews considering phase 1 and phase 2 of data collection. The client representatives, contractors, and policymakers and influencers are coded by alphabets A, B, and C. In total, 12 client representatives were interviewed, and hence interview participants are coded as A1-A12. A similar pattern was followed for the remaining two categories, i.e. contractor: B1-B14 and policymakers and influencer: C1-C11.

All interviews were audiotaped, and hand-written notes were also taken during some of the interviews. Software such as Express Scribe and Audext were used to prepare the transcripts. Further, the transcripts were coded under four different categories (stages): pre-design; design; construction; refurbishment and demolition. The pre-design stage involved a feasibility study and elementary solutions to the waste minimisation challenges. In addition, the pre-design stage involved early discussions of stakeholders on C&D waste, while the design stage had consideration of C&D waste. The construction stage included commentary on physical waste. It also included details of factors influencing refurbishment waste. Further, the demolition stage involved deconstruction and demolition of buildings.

The qualitative data analysis was conducted from February 2021 to March 2022 (phase 1 & 2 of data collection). The study adopted the combination of constant comparative analysis and thematic analysis. The former provided comparison between interviews to acquire a sense of data saturation, while the latter helped to develop themes from the saturated data. These themes were further converted into factors that influence waste.

The researcher compared transcripts of all semi-structured interview with each other. Subsequently, repetitive statements and keywords were identified. For instance, need of industrial diversity thinking to use waste as a resource was repeated in several

transcripts. As a result, industrial diversity thinking was labelled as one of the themes and subsequently as a waste influencing factor.

3.9.2 Quantitative data analysis

Quantitative data analysis refers to converting numeric into meaningful data with the application of logic and rationale (Bryman & Cramer, 2009). The quantitative data analysis is performed through data cleaning, organising, coding and transformation (Kothari, 2017). The data is examined for omissions and consistency. Further, non-numerical information is replaced with symbols to organise the data. The data is then coded as per numerical scores or classifying symbols and converted to analysed by computer software (Creswell, 2018).

The commonly used quantitative data analysis techniques are descriptive analysis and inferential analysis (Leavy, 2017). In the descriptive analysis, findings are described through percentage (proportion), frequency (occurrence), range (scale) (Meyers et al., 2016). In addition, the central tendency of data, i.e. mean, mode, and median, is also discussed in the findings. Since descriptive analysis deals with a single variable, it is also referred as univariate analysis (Meyers et al., 2016).

In the inferential analysis, general claims are rendered for a group by selecting a specific number of samples from the same group (Kuhar, 2010). The inferential analysis shows a cause-and-effect relationship through estimation and prediction (Schoonenboom & Johnson, 2017). The inferential analysis uses different methods to predict future phenomena. Some of the methods are: Co-relation: establish a relationship between two variables; Regression: predict the relationship between variables; T-Test: comparing average performance between two groups; Analysis of variance: measure the extent to which these groups differ from each other (Bryman & Cramer, 2011).

The volume of data often influences the use of statistical software to perform data analysis (Clayton & Pett, 2008). Software such as Microsoft Excel, Statistical Package for Social Sciences (SPSS), Statistical Software Analysis (Las-Heras-Casas et al.), Analysis of Moment Structures (Dobrovolskienė & Tamošiūnienė), and Liberal Structural Relations (LISREL) (Jung, 2019) are used to perform statistical analysis. The quantitative data collected from on-site observations were analysed by descriptive analysis to discover the existence and occurrence of the factors influencing C&D waste.

The descriptive analysis helped to identify the occurrence(s) of a factor in real-time. For example, poor on-site sorting of waste was observed on all sites which guided researcher to see the pattern and subsequently validate the influence of on-site sorting on waste generation. Due to the small data size, MS Excel was used for the data analysis instead of SPSS or AMOS. The data analysis was conducted from November 2021 to June 2022.

In this research, themes generated from qualitative data are converted into factors that influence C& D waste. In total, 36 factors were identified and labelled from F1- F36. These factors were validated through direct on-site observations. Table 3.8 shows details of sites chosen to collect the quantitative data.

Table 3.8: On-site data collection

Site	Code	Number of sites
Construction	Alpha	3
Refurbishment	Beta	3
Demolition	Gamma	3
Total		9

As shown in Table 3.8, a total of nine sites were selected to validate the qualitative findings. Three sites from each category, i.e. construction, refurbishment, and demolition, were chosen and labelled Alpha, Beta, and Gamma. Further, individual construction sites were labelled Alpha 1, Alpha 2, and Alpha 3. A similar pattern was adopted for refurbishment and demolition sites, i.e. Refurbishment: Beta 1, Beta 2, and Beta 3 and Demolition: Gamma 1, Gamma 2 and Gamma 3. The on-site observations confirmed the status of 36 factors identified in the qualitative data collection.

The qualitative and quantitative findings guided the researcher to recognise opportunities and challenges in C&D waste minimisation in the Auckland CI. In addition, the findings offered remedial measures and helped the researcher to develop the waste minimisation framework. For the generalisability of findings, the next section briefly discusses research findings' reliability and validity (internal and external).

3.10 Quality for the Research Findings

The credibility and trustworthiness of research depend on the research findings (Creswell & Creswell, 2017). The research design needs to be robust and should offer reliability and validity to generalise the research findings with confidence Kothari 2017. The quality of research often influenced by research ‘bias’ occurred during different research stages, regardless of method and approach used in the research Noble et al. 2015. In addition, sample selection and data collection also play a vital role in making research findings reliable Kumar 2018. The following subsections briefly explain the reliability and validity of the research findings and discussed actions taken to achieve them.

3.10.1 Reliability

Reliability is defined as an ability to replicate similar research findings by any researcher at any period of time using similar research design (Creswell & Creswell, 2017). In addition, reliability is considered as a process of eliminating errors to achieve standardisation in the data collection (Kothari, 2017). Reliability offers consistency in the research findings through well-documented research design. There are different forms to assess the consistency: test-retest, alternate-form and internal consistency (Leavy, 2017).

The test-retest suggests collecting data at two different periods of time to check the similarities in the findings. The alternate-form suggests comparison of two different test findings obtained through different data collection at two different periods of time (Creswell & Creswell, 2017). Further, the alternate form literally means alternative (second) questionnaire form used to collect data, keeping all the data collection parameters similar to previous questionnaire form (Creswell, 2018).

Unlike an alternative form, the internal consistency is assessed by comparing multiple items in the same findings (test), and hence repetitions of the test are not necessarily advised (Kumar, 2018). The internal consistency checked the consistency of responses received during the data collection stage and then established a co-relation between those responses (Gravesande et al., 2019). Internal consistency adopts the principle of ‘greater the degree of co-relation better the research findings’, and hence the researcher often preferred internal consistency check on their research findings (Creswell & Poth, 2016).

This research adopted a well-documented procedure to formulate the research design. In addition, special consideration was given to develop a robust framework for data (Creswell & Creswell, 2017) collection and analysis. The indicative questions for interviews were derived after reviewing the worldwide literature on the research area. The questions were further revised multiple times before the commencement of the pilot study.

The interview participants were recruited based on their expertise in C&D waste minimisation. The average experience of interview participants was 11.25 years. Before the interview, all the participants were guided through the Project Information Sheet (Pisani). After the interview, participants received a summary of the interview to allow transparency; ultimately enhanced the research findings. The interviews' responses were compared to establish a co-relation between variables, which helped to identify factors that influence C&D waste. Further, on-site observations were conducted on construction, refurbishment and demolition sites to confirm the identified factors. All nine sites represented typical residential houses in the Auckland CI.

3.10.2 Validity

Validity is defined as a logical and rational process that analyses how accurately a method measures what it is supposed to measure (Creswell & Creswell, 2017). In other words, validity shows the theoretical and practical difference between the achievements of the research findings (Leavy, 2017). Subsequently, validity offers the generalisability of findings by understanding the patterns from outside the research environment (Golafshani, 2003). A broad classification of research validity includes internal validity and external validity. In addition, construct validity also received interest from researchers' as it provides evidence and reasoning to form a conclusion (Abowitz & Toole, 2010). Table 3.9 discuss different types of validity with their phase of measurement.

Table 3.9: Different types of validity

Type of Validity	Phase	Definition
Internal validity	Data analysis	A method of establishing a cause-and-effect relationship between variables.
Construct validity	Data collection	A process of inferencing the findings from previously studied data.
External validity	Research design	A process of examining the research findings for generalisability

(Creswell & Creswell, 2017)

Table 3.9 showed that internal validity establishes a relationship between variables. Further, variables' performance depends upon documentation and data collection techniques (Abowitz & Toole, 2010). Further, the quality of collected data, influences inferences offered by research findings and hence a rigorous research design is often promoted. Such research design understands the commonplace practices and generalises the research findings (Creswell & Creswell, 2017).

In this research, the interview questionnaire was aligned with the research aim and objectives as the first step towards validity. Further, the study adopted multiple data collection methods to eliminate research bias. The collected data were examined and coded accurately. Further, data were analysed to develop themes most relevant to research questions. Different sites (construction, refurbishment and demolition) were observed to validate these themes by collecting quantitative data. The data was then analysed through descriptive analysis to find the common patterns and generalise the research findings.

3.11 Chapter Summary

This research aims to propose a C&D waste minimisation framework considering the life cycle of a project to advocate SC. This chapter outlined the overall research methodology adopted to achieve this aim. First, the philosophical position of this research was found in pragmatism, and a hypothesis was developed using the abductive approach. Subsequently, a mixed-methods approach was adopted to discover a hypothesis. This research used a survey technique to collect qualitative data through in-depth semi-structured interviews and quantitative data through on-site observations. Further, ethical considerations given to research participants over the entire research process are discussed. Further, qualitative and quantitative data analysis methods are

reviewed. The qualitative data was analysed through a combination of constant comparative analysis and thematic analysis. Further, MS Excel was used for the quantitative data analysis. Finally, the chapter concluded with the quality of the research findings through reliability and validity.

Chapter 4 Results

4.1 Introduction

The data collected through qualitative and quantitative methods were analysed to produce the research findings. This chapter presents the findings of the qualitative data collected during the preliminary data collection phase (pilot study) and semi-structured interviews. The qualitative data identified factors influencing C&D waste over the life cycle of a building. Subsequently, the identified factors were authenticated through on-site observation conducted on construction, refurbishment and demolition sites (Alpha, Beta, Gamma, respectively). Finally, the chapter concluded with a summary covering the influential factors in C&D waste minimisation in the Auckland CI.

4.2 Qualitative data analysis

This section presents the findings of the semi-structured exploratory interviews with client representatives (A), contractors (B) and policymakers and influencers (C) in the NZ construction industry. In total, 12 client representatives were interviewed, and their responses were labelled as A1- A12. Similarly, the contractors' responses were labelled as B1-B14 and policymakers and influencers as C1-C11.

First, the qualitative data collected during the preliminary data collection phase (pilot study) and semi-structured interviews were analysed to identify the factors that influence C&D waste. Next, the identified factors were categorised under different project stages such as pre-design, design, construction (and refurbishment) and demolition. The next sub-section offers an understanding of the factors that influence C&D waste during the pre-design stage.

4.2.1 Pre-design

The pilot study and semi-structured interviews provided knowledge and understanding about factors influencing C&D waste in the pre-design stage. The responses of client representatives (A), contractors (B), and policymakers and influencers (C) listed seven factors. Table 4.1 tabulated these factors from highest to lowest number of responses received by a factor from interview participants. The number of responses represents the number of people considering that factor influencing C&D waste minimisation.

Table 4.1: Factors influencing C&D waste in the pre-design stage

Code	Factor	Number of responses by category			Total responses
		A	B	C	
Number of participants in each category		12	14	11	
F1	Contractual requirements	10	14	11	35
F2	Green washing and green claiming	10	12	11	33
F3	Early involvement of stakeholders	9	11	10	30
F4	Education and innovation	10	12	8	30
F5	Eco-labelling of building materials	8	10	10	28
F6	Industrial diversity thinking	8	8	9	25
F7	Conceptual waste minimisation plan	7	8	10	25

As shown in Table 4.1, contractual requirements were the most influencing C&D waste minimisation factor in the pre-design stage. In contrast, the least influencing factors were industrial diversity thinking and the conceptual waste minimisation plan. In total, 35 out of 37 interview respondents mentioned that contract requirements for waste minimisation would significantly impact C&D waste minimisation as it covers the life cycle of a project. Further, all contractors (14 out of 14) and policymakers and influencers (11 out of 11) expressed that the introduction of waste minimisation is one of the essential requirements in the contract that allows stakeholders to achieve a circular economy. It also makes the contract a strong document to think about sustainability through compliance.

Further, 33 out of 37 interview respondents recommended using sustainable materials to avoid greenwashing. All the policymakers and influencers believed that though building materials are procured considering environmental sustainability, the selected green materials are often non-recyclable or non-recoverable. As a result, construction projects generate high quantities of C&D waste. It can be seen from Table 4.1 that 30 out of 37 interview participants considered the early involvement of stakeholders, as one of the influencing factors. In total, 9 out of 12 client representatives mentioned that early involvement of stakeholders makes a significant difference in C&D waste minimisation. Further, most policymakers and influencers (10 out of 11) stated that early involvement

of stakeholders creates awareness about the responsibilities of clients, contractors, sub-contractors and waste handling services related to waste minimisation.

In total, 30 out of 37 participants mentioned that education for CI practitioners is important to understand the international waste minimisation practices and their feasibility in NZ to achieve SC. A client representative argued that education is required to produce high-value second life at the local recycling facilities (A-09). Further, 12 out of 14 contractors and 8 out of 11 policymakers and influencers supported the argument and stated that education induces innovative thinking to minimise waste.

Table 4.1 shows that 28 out of 37 interviewees considered that Eco-labels are important to promote sustainable materials. In total, 10 out of 11 policymakers and influencers stated that eco-label building materials provides social, environmental and economic benefits due to ease of recycling. The recycled building materials can be used to serve other industries (C-10). In total, 25 out of 37 participants mentioned that industrial diversity thinking connects the CI with other industries. In addition, if building materials are evaluated for industrial diversity at the pre-design stage, they can be reused and recycled at the demolition stage to use in other industries. For instance, plasterboards are recycled to make soil conditioners (A-01).

As it can be seen from Table 4.1 that 25 out of 37 interview participants considered the conceptual waste minimisation plan an effective waste minimisation approach. Further, 8 out of 14 contractors mentioned that the concept base plan can be further converted into a robust document (waste management plan) to deal with waste. Moreover, 10 out of 11 policymakers and influencers stated that the conceptual waste minimisation plan helps contractors identify potential waste streams.

4.2.2 Design

This sub-section shows the factors that influence C&D waste during the design stage of the project. The interview respondents mentioned nine influential factors from the design stage that influence C&D waste. Table 4.2 shows these nine factors.

Table 4.2: Factors influencing C&D waste in the design stage

Code	Factor	Number of responses by category			Total responses
		A	B	C	
Number of participants in each category		12	14	11	
F8	Circular resources and circular economy	12	14	11	37
F9	Waste minimisation goals	12	12	11	35
F10	Material selection and overordering	10	14	11	35
F11	Design out waste	11	12	10	33
F12	Use of Waste Minimisation Act 2008	12	9	11	32
F13	Standardisation and Prefabrication	8	10	10	28
F14	Waste management plan	9	9	10	28
F15	Specification writing	8	9	8	25
F16	Equal consideration to C&D waste	6	6	8	20

It can be seen from Table 4.2 that the circular economy was considered the most influential factor by all interview participants. Further, 20 out of 37 interview participants considered equal consideration to C&D waste as the least influencing factor. Table 4.2 shows that all interview participants (37 out of 37) considered circular economy as a need for SC. Further, all participants stated that the Auckland CI practitioners acknowledge the circular resources concept. Some of the practices of circular resources include, but are not limited to: reducing material consumption; reusing timber formwork; refusing unsustainable carpet fibres; repurposing polystyrene; recycling of cardboard and steel to sell into the local and international market; shredding of treated timber for waste to energy; use of untreated timber for landscaping and animal farm and; plasterboard to make soil fertilisers.

It can be seen from Table 4.2 that all the client representatives and contractors agreed on setting waste minimisation goals to increase the desire to achieve SC through C&D waste minimisation. In total, 12 out of 14 contractors stated that waste minimisation goals generate a need for waste minimisation and incorporate innovative approaches. A policymaker from the Auckland Council argued that putting waste minimisation goals as a legislative or voluntary requirement in a contract document, is one of the options to encourage waste minimisation in NZ (C-02). The legislative requirement mandates the

contractors achieve the goals, while the voluntary requirements are not mandatory but preferable (C-02). Most interview participants (35 out of 37) supported the inclusion of waste minimisation goals in contract documents.

In total, 35 out of 37 participants consider poor material selection and overordering responsible for high C&D waste generation (Table 4.2). All the policymakers and influencers (11 out of 11) responded that material selection needs to be improved by assessing the impact of material on the environment and people who are supposed to live with it for ages. Further, 10 out of 12 client representatives stated that the CI practitioners need to order the right (Sustainable Construction Group UK) material in the required quantities at the right time (without delay) to minimise waste.

As shown in Table 4.2, 33 out of 37 interview participants preferred to design out waste to avoid physical waste at the construction stage. In total, 12 out of 14 contractors mentioned that the designing out waste approach, saves virgin materials quantities and waste transportation costs. Further, 10 out of 11 policymakers and influencers mentioned that the designing out waste concept is new for NZ industry practitioners and requires attention mainly from clients, as the clients have a strong say in the design process.

In total, 32 out of 37 participants considered that the successful implementation of the Waste Minimisation Act influences C&D waste. A similar number of participants stated that Waste Minimisation Act is a comprehensive document that includes waste management hierarchy, product stewardship and waste levy to practise waste minimisation. Further, 9 out of 14 contractors mentioned that though the waste management hierarchy is a part of a discussion among contractors, its understanding and practice is limited.

Table 4.2 shows that 28 out of 37 interview respondents considered that the use of standardised and prefabricated building materials contributes to C&D waste minimisation. In total, 10 out of 11 policymakers and influencers identified standardisation and prefabrication as crucial waste minimisation techniques. One policymaker mentioned that use of standardised units reduces the quantities of off-cuts and the amount of construction waste (C-10). However, aesthetic look of the building is one of the reasons clients avoid standardise units that generate off-cuts and subsequently waste (A-07).

It can be seen from Table 4.2 that 28 out of 37 interview participants recommended Waste Management Plan to identify, quantify and manage C&D waste. In total, 10 out of 11 policymakers and influencers stated that if SWMP becomes part of compliance, then waste could be minimised significantly. They also argued that SWMP should be included in the building consent process in NZ. Further, 25 out of 37 interview participants confirmed that materials specification writing, influences C&D waste generation. In contrast, 12 out of 37 participants mentioned that the poor material selection process depreciates the action of specification writing and generates C&D waste.

In total, 20 out of 37 respondents expressed that C&D waste requires equal consideration among other SC indicators (e.g. energy, water). A contractor mentioned that construction projects have risks and risks associated with C&D waste that needs special attention from stakeholders (B-04). Further, 17 out of 37 argued that instead of equal consideration to C&D waste, the CI practitioners need to focus on the societal and environmental impact of C&D waste.

4.2.3 Construction

The qualitative interviews helped to identify factors influencing C&D waste during the construction and refurbishment stage. In total, the eight factors from the construction stage were identified. Further, three factors from the refurbishment stage were noted. Table 4.3 shows the factors that influence C&D waste during the construction and refurbishment stage.

Table 4.3: Factors influencing C&D waste during construction and refurbishment stage

Code	Factor	Number of responses by category			Total responses
		A	B	C	
Number of participants in each category		12	14	11	
Construction					
F17	Waste sorting and contamination	12	12	11	35
F18	Waste reporting	12	10	11	33
F19	Composition of waste	10	9	11	30
F20	Precise waste quantification	10	8	10	28
F21	Social values of waste	9	9	10	28
F22	Use of CivilShare	7	9	9	25
F23	On-site reuse	5	7	8	20
F24	Poor material storage and handling	5	6	9	20
Refurbishment					
F25	Environmental impact	10	9	11	30
F26	Availability of resources	9	10	9	28
F27	Condition of a house	7	10	8	25

As shown in Table 4.3, waste sorting received the highest number of responses (35 out of 37) and is considered the most influential factor in the construction stage. Conversely, poor material on-site reuse and poor material storage and handling factors received the lowest responses and were considered to have the least influence on C&D waste generation. Subsequently, the environmental impact of refurbished waste was considered the leading influencing factor in the refurbishment stage. Further, house conditions were noted as the least significant factor influencing refurbishment waste.

Waste sorting is a first step where value is created in the waste, and if site labours give attention to sorting, then waste handling services can play their role effectively (B-11). All client representatives and policymakers and influencers recommended waste separation at the source (on-site) to increase waste recovery through recycling and repurposing. Further, 12 out of 14 contractors mentioned that waste sorting helps practice on-site reuse and minimises waste.

Table 4.3 shows that waste reporting was considered the second most influencing factor in the construction stage. One contractor mentioned that the key feature of a waste report is the analysis of a different waste stream that helps contractors self-assess their work, their method of execution and waste generation pattern (B-11). In total, 33 out of 37 interview participants, expressed that waste reporting creates a sense of responsibility for C&D waste minimisation among CI practitioners. Further, 30 out of 37 participants mentioned that waste composition helps to identify feasible waste minimisation approaches and minimise waste. All policymakers and influencers mentioned that waste composition assists contractors to do better planning and decision making on waste management.

It can be seen from Table 4.3 that 28 out of 37 interview participants favoured precise waste quantification after considering its influence on C&D waste. One policy influencer mentioned that precise waste quantification is an indicator to determine material and cost wastage. These wastages signify unsustainability in the construction and demand for waste minimisation (C-10). Further, 10 out of 11 policymakers and influencers mentioned that waste quantification helps to identify priority waste streams and accordingly discuss waste minimisation techniques

In total, 28 out of 37 respondents stated that social values of waste, need consideration among other values, such as environmental and economic. The policymakers and influencers (10 out of 11) considered that societal benefits of waste minimisation, such as job creation and health and safety, enhance the social values of waste. Further, Table 4.3 shows that 28 out of 37 interview participants envisaged using an online resource-sharing platform such as CivilShare as important for C&D waste minimisation. A client representative mentioned that CivilShare allows civil contractors to buy, sell and swap the construction materials, machinery and labours (A-10). In addition, contractors (9 out of 14) mentioned that CivilShare helps reuse the over-ordered materials either through trade or donating to organisations such as Habitat for Humanity, Auckland City Mission and local churches. In addition, overordered materials are sent to Pacific islands to reuse (C-02).

As shown in Table 4.3, 20 out of 37 interview participants recommended the on-site reuse of waste. Interestingly, only 5 out of 12 client representatives responded that on-site reuse influences waste minimisation. In contrast, 7 out of 12 stated that reused

materials often don't qualify for the technical requirements and hence clients prefer virgin material.

The on-site material management includes material storage and handling activities (B-12). In total, 20 out of 37 interview participants mentioned that materials are damaged during storage and on-site transportation activities, and hence it has an influence on waste generation. One contractor mentioned that a scratch in a plasterboard sheet results in replacing the whole sheet. Similarly, dropping and breaking a glass panel contributes to material wastage (B-13). Further, policymakers and influencers (9 out of 11) give more consideration to material storage and handling than client representatives (5 out of 12) and contractors (6 out of 14). The client representatives (7 out of 12) and contractors (8 out of 14) claimed that Auckland CI practitioners execute efficient on-site material management and hence material handling has the least influence on waste generation.

The refurbishment of stage waste minimisation is a blank spot and has very little consideration compared to construction and demolition waste (C-07). Table 4.3 shows that 30 out of 37 interview participants, consider the environmental impact of refurbishment waste as the most crucial factor influencing waste. In addition, client representatives (10 out of 12) and contractors (9 out of 14) mentioned that materials recovered from the refurbishment process significantly reduce landfill contribution of refurbishment waste. Further, all policymakers and influencers expressed that if refurbishment waste is processed to reuse and/or recycle, it has a huge potential to create a secondary market in the Auckland CI.

Table 4.3 shows that 28 out of 37 participants considered the availability of the resources such as time, cost, labour and machinery, highly influences recovery from the refurbishment waste. Further, 9 out of 12 client representatives stated that optimising time and cost increases material recovery and reduces waste. In contrast, a lack of resources increases waste quantities and disposal cost. In total, 25 out of 37 participants responded that the house condition plays a vital role while extracting materials during the refurbishment process (Table 4.3). Further, 10 out of 14 contractors mentioned that houses built around mid-19th century were predicted to have asbestos as insulation. As per the current regulations, a special workforce is required to remove and dispose of asbestos. Therefore, the house condition is considered a crucial factor influencing refurbishment waste.

4.2.4 Demolition

The interview responses gave nine influential factors that contribute to C&D waste during the demolition stage. Table 4.4 lists these factors and the number of responses received by each factor.

Table 4.4: Factors influencing C&D waste during the demolition stage

Code	Factor	Number of responses by category			Total responses
		A	B	C	
Number of participants in each category		12	14	11	
F28	10R	12	14	11	37
F29	Waste levy	12	14	11	37
F30	Secondary market	11	14	11	36
F31	Recycling infrastructure facilities	12	10	10	32
F32	Waste cost	10	10	10	30
F33	Role of public and private institutes	10	12	8	30
F34	Resource recovery and margins	8	12	10	30
F35	Application of deconstruction	8	10	10	28
F36	Waste management and Resource Recovery plans	8	8	9	25

As shown in Table 4.4, all participants considered 10R thinking and waste levy as the most influential factors to waste generation. Further, waste management and resource recovery plans were considered the least influential factor in the demolition stage. The 10R represents Refuse, Rethink, Reduce, Reuse, Repair, Relocate, Remanufacture, Repurpose, Recycle and Recover. The interview responses of all participants indicated that the key to waste minimisation is how each R is practised in the industry. In addition, all participants mentioned that as a product of dollar-driven industry, a waste levy has a strong influence on C&D waste. All the policymakers and influencers credited waste levy for shifting CI's focus from throwing to minimising.

It can be seen from Table 4.4 that 36 out of 37 respondents consider the secondary market as an important part of the waste minimisation chain. The client representatives (11 out of 12) mentioned that the secondary market keeps resources in flow and

contributes to the circular economy. Further, all contractors stated that the secondary market creates a positive approach towards the recovered products and minimises waste.

In total, 32 out of 37 interview respondents mentioned that recycling facilities influence C&D waste. A client representative stated that the recycling infrastructure is growing in the Auckland region with support from both public and private organisations (A-06). Further, all client representatives expressed that recycling facilities provide more reach to improve the scale of a secondary market (Table 4.4). One client representative mentioned that good quality and affordable recycled materials drive the behavioural change in clients to practice circular economy (A-05).

Table 4.4 shows that 30 out of 37 interview participants consider waste cost as a key factor. The participants described waste costs differently based on their position in the CI. Contractors defined waste cost as the cost of establishing a waste minimisation division and the cost of hiring a waste handling service (B-03), while policy influencers (waste handling service representatives) define waste cost as the cost of sorting, disposal, and recycling (C-09). Most contractors (10 out of 14) preferred the appointment of a waste handling service, to manage their waste efficiently. Further, 10 out of 11 policymakers and influencers stated that sorting, disposal, and recycling costs are high and strongly influence waste minimisation.

The Auckland Council and the private sector is working together to improve the current status of waste minimisation (C-02). In total, 30 out of 37 participants stated that this collaboration can help to start new waste minimisation practices and scale up existing practices. The interview responses highlighted some considerations for public and private institutes: extended producers' responsibilities; community recycling centres; and building certification. Further, 10 out of 12 client representatives and 12 out of 14 contractors expressed that the promotion of aforementioned factors through public and private sector partnerships has a strong influence on waste generation.

In total, 30 out of 37 interview participants mentioned that the resource recovery and margin on second life products, influence waste minimisation (Table 4.4). Further, 10 out of 11 policymakers and influencers mentioned that recovery method, quality of recovered products and profit change clients' perspective on recovered products, which ultimately contributes to waste minimisation. Table 4.4 shows that 28 out of 37 participants preferred deconstruction instead of demolition. In total, 10 out of 14

contractors consider deconstruction an opportunity to earn profit and reduce the environmental impact of waste. Further, 10 out of 11 policymakers and influencers encourage industry practitioners to adopt the ‘design to disassemble’ approach. So, deconstruction will become part of the design stage, and waste could be minimised before construction.

It can be seen from Table 4.4 that 25 out of 37 participants considered the waste management and resource recovery plans as a crucial tool for waste minimisation. The Waste Management Plan includes waste streams and quantities. In contrast, the Resource Recovery plan focused on recoverable waste (A-10). Further, 9 out of 11 policymakers and influencers expressed that waste management and resource recovery plans, systematically identify waste streams and provide feasible solutions for waste minimisation.

4.3 Quantitative data analysis

The quantitative data was collected to validate the findings of the qualitative data. In other words, on-site observations were conducted to confirm the status of 36 C&D waste influencing factors identified in semi-structured interviews. The quantitative data was collected from nine sites. Three sites from each category, i.e. construction, refurbishment, and demolition, were chosen and labelled Alpha, Beta, and Gamma. Table 4.5 shows the findings of the on-site observations and validate the qualitative data findings

Table 4.5: Validation of qualitative data findings

Factor	Alpha 1	Alpha 2	Alpha 3	Beta 1	Beta 2	Beta 3	Gama 1	Gama 2	Gama 3
Poor contractual requirements	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Greenwashing and green claiming	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lack of early involvement of stakeholders	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lack of education and innovation	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Eco-labelling of building materials	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lack of industrial diversity thinking	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Conceptual waste minimisation plan	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Circular resources and circular economy	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Waste minimisation goals	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Poor material selection and overordering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Design out waste	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Use of WMA (2008)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Use of prefabrication and standardisation	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Waste management plan	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Factor	Alpha 1	Alpha 2	Alpha 3	Beta 1	Beta 2	Beta 3	Gama 1	Gama 2	Gama 3
Lack of detailed material specification writing	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unequal consideration to C&D waste	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
On-site sorting of waste and contamination	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Waste reporting and sense of responsibility	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Composition of waste	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Precise waste quantification	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Social values of waste	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Use of CivilShare	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
On-site reuse and recycling	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Poor material storage and handling	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Environmental impact	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Availability of resources	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Condition of a house	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10R	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Waste levy	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Secondary market	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Factor	Alpha 1	Alpha 2	Alpha 3	Beta 1	Beta 2	Beta 3	Gama 1	Gama 2	Gama 3
Recycling infrastructure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Cost of waste	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Role of public and private institutes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Resource recovery and margins on second life products	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Application of deconstruction	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Waste management and resource recovery plans	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Table 4.5 shows the validation of qualitative data findings. For instance, semi-structured interviews identified poor contractual requirements, greenwashing and lack of early involvement of stakeholders as waste influencing factors in the pre-design stage. Subsequently, the on-site observation noted that on all construction sites the aforementioned factors influenced waste generation. In contrast, factors such as poor material selection and overordering were identified influential via interviews; however, the on-site observations did not align with the qualitative findings as these factors were not seen influential on all construction sites.

The qualitative data findings noted on-site reuse and recycling as one of the most influential factors in construction and refurbishment stage. The on-site observations showed that this finding was valid for all refurbishment sites but only valid for 1 out of 3 construction sites. In the demolition stage, all the factors obtained through qualitative findings were observed to be influential on at least 1 out of 3 demolition sites.

The qualitative data divided factors into the stages, but some factors were validated to be influential in multiple stages. For instance, factors such as on-site sorting of waste and contamination was considered under the construction stage. However, it was observed across all nine sites. Further, use of WMA (2008) found to be an influencing factor on all sites. In addition, factors such as waste reporting, use of Civil Share and the waste levy was observed on most sites. The next sub-section provides detail about factors observed on each type of site.

4.3.1 Alpha

The construction process was observed on all three sites (Alpha 1, Alpha 2 and Alpha 3). Alpha 1 was a three-bedroom single-detached house located in the South of Auckland. Alpha 2 and Alpha 3 were the two bedrooms semi-detached houses located in the West of Auckland. All three houses had timber framing, metal roofing and plasterboard interior. The on-site observations were conducted for foundations, wall framing, internal wall lining, and house fit off stages. Apart from on-site observations, the researcher prepared handwritten notes and engaged with the project manager in informal discussions, to collect additional information on material storage, method of construction, use of machinery, and the number of bins.

Alpha 1 did not have a material management plan for storing and handling materials. Further, Alpha 2 and Alpha 3 had a material management plan which was useful in

avoiding double handling of materials. The timber frame method of construction was used on all three sites. In addition, all three sites used advanced timber cutting machines such as Table saw, Drop saw, and Radial arm saw. Further, Cordless drill and Saw stand were also used by the contractors. Alpha 1 had two bins, while Alpha 2 and 3 had two bins and one waste bag. Bins on Alpha 1 collected general waste and timber waste separately. While bins on Alpha 2 and Alpha 3 collected general waste, timber waste and plasterboard waste. The plasterboard waste was collected in a waste bag, and timber and general waste were collected separately in a standard 9m³ bin.

The researcher observed the on-site activities performed by labours and monitored the waste bins. Site labourers on all three sites were educated to practise waste sorting through toolbox meetings. It was noted through on-site observation that construction sites were significantly influenced by on-site sorting and waste reporting. For example, Alpha 1 sorted timber and general waste but did not collect plasterboard waste separately. As a result, the plasterboard was contaminated with other materials, and the contractor missed the plasterboard recycling opportunity.

Conversely, Alpha 2 and Alpha 3 collected plasterboard waste separately. In addition, timber was also collected in a separate bin. As a result, the contractors of Alpha 2 and Alpha 3 reuse, recycle and recover the timber and plasterboard waste with the help of waste handling services. The waste handling services from all three sites provided waste reports to contractors. The reports were generated monthly, in some cases fortnightly, as demanded by the contractors. The waste reports showed the size of the problem and encouraged contractors to pursue waste minimisation.

The on-site observations also confirmed that waste reporting on composition and quantification influences waste generation (Table 4.5). Timber, Metal and Plasterboard contributed more than half of the total waste on all three sites. With the help of waste composition and quantification data, the contractors analysed each waste stream separately and adopted specific waste minimisation approaches. For example, timber was reused, and plasterboard was sent for recycling. Further, the social benefits of waste and its promotion are remarked as a need for waste minimisation by site engineer. The project managers from all three sites educated the labourers on waste diversion's societal impacts and benefits. The researcher observed the change of attitude in labourers after the project manager educated them. The site labourers were more focused on reusing and sorting waste to gain the social benefits from waste.

4.3.2 Beta

Table 4.5 shows that three refurbishment sites, Beta1, Beta 2 and Beta 3 were observed to confirm the qualitative data findings. All three sites were single-detached houses located in Henderson, West Auckland. On Beta 1 researcher observed exterior cladding, weatherboard painting, extension and partition of rooms, electrical work, bathroom renovation and plumbing. Further, on Beta 2 and Beta 3, activities such as interior and exterior painting, roof tiling, kitchen renovation, structural work, insulation and window, plaster removal and replacement of window frames were observed.

All three sites were refurbished not to change the use of a building, i.e. to serve a similar purpose (residential to residential), though contractors practise optimised material consumption on all sites, on-site measurements varied, resulting in off-cuts. Materials obtained after the refurbishment from all sites included old timber, rotten floorboards and damaged pasteboard. Asbestos was found on Beta 1, and a special subcontractor was hired for asbestos removal and disposal. Further, Beta 2 and Beta 3 had no asbestos. No waste audits were performed on Beta 1 and Beta 2 to check the house's condition. On beta 3, the contractor conducted waste audits and listed out potential waste streams before the execution of work.

The on-site observations on Beta 1 confirmed that the environmental impact of materials obtained after refurbishment was not considered. The damaged and contaminated materials were sent to cleanfill without considering its reuse, recycle or recovery. Conversely, roof tiles obtained through refurbishment from Beta 2 and Beta 3 were reused. Further, the damaged pasteboard was sent to a recycling facility. Project managers from Beta 1 mentioned that clients trust more the virgin materials. Though refurbished materials are reusable, they are not being reused. Table 4.5 confirmed that the environmental impact of refurbishment waste influences waste generation. To change the current situation, the clients need education on the environmental impact of refurbished materials.

The on-site observations on all three sites noted that the availability of resources influence refurbishment waste (refer to Table 4.5). The project manager from Beta 3 mentioned that Auckland has limited recycling facilities to process mixed waste, and it is expensive to recycle waste than its disposal. Further, on Beta 1, it was observed that on-site sorting was not performed due to a lack of resources, which contaminated waste

(less than 5%). As a result, recycling was eliminated by the contractor. The lack of resources to sort and recycle waste noted as one of the important factors that influence refurbishment waste.

4.3.3 Gama

Three demolition sites, namely, Gama 1, Gama 2 and Gama 3, were observed to confirm factors influencing demolition waste (Table 4.5). All sites had three bedroom detached standalone houses with a single storey. On all three sites, the demolition contractors conducted waste audits. After the audits, Gama 1 was demolished, while Gama 2 and Gama 3 were partly demolished. The deconstruction technique was used on Gama 2 and Gama 3 to salvage the building material. The contractors from Gama 2 and Gama 3 obtained roof tiles, old timber, steel, and door and window frames. Gama 1 contractor recovered steel from the demolition debris. Further, no hazardous materials such as asbestos were found on all three sites.

It was observed on Gama 1 that lack of a waste management plan resulted in high waste generation (refer to Table 4.5). On the other hand, Gamma 2 and Gama 3 recover maximum benefits through reuse, recycle and recovery of salvaged materials. Both Gamma 2 and Gamma 3 had a waste management plan to execute soft stripping of building materials. The waste management plan included the composition and quantification of waste streams, the person responsible for waste minimisation, and feasible waste minimisation approaches.

The on-site observations noted that on Gamma 2 and Gamma 3, reuse, waste separation, recovery plan and actions, and deconstruction influence demolition waste. Old nail-free and chemical-free timber with no damage, was used for architectural and landscaping purposes. The reuse was possible because both sites had multiple bins to separate timber and general waste. Conversely, on Gamma 1, the contractor had a single bin to collect waste. It was noted that on Gamma 1, waste sorting and on-site reuse were not performed due to a lack of recovery plan and actions. The contractors on Gamma 2 and Gamma 3 have developed a resource recovery plan to get benefits. The plan helped the contractor to deconstruct and recover good quality materials, which were later reused, recycled and recovered to minimise the demolition waste.

The observation findings confirmed that the secondary market and recycling infrastructure also influence demolition waste (Table 4.5). For instance, steel obtained

from Gamma 2 and Gamma 3 was sent to a recycling facility due to local and international demand. However, old carpets from both sites end up in the bin due to a lack of secondary market and recycling infrastructure.

4.4 Factors influencing C&D waste in Auckland CI

The qualitative data analysis provided 36 factors that influence C&D waste. Subsequently, quantitative data confirmed the factors. The factors occur at different stages and cover the project's life cycle. Table 4. 6 lists the factors.

Table 4.6: Factors influencing C&D waste in the Auckland CI

Code	Factor	Code	Factor
F1	Poor contractual requirements	F19	Composition of waste
F2	Green washing and green claiming	F20	Precise waste quantification
F3	Early involvement of stakeholders	F21	Social values of waste
F4	Lack of education and innovation	F22	Use of CivilShare
F5	Eco-labelling of building materials	F23	On-site reuse and recycling
F6	Lack of industrial diversity thinking	F24	Poor material storage and handling
F7	Conceptual waste minimisation plan	F25	Environmental impact
F8	Circular economy	F26	Availability of resources
F9	Waste minimisation goals	F27	Condition of a house
F10	Material selection and overordering	F38	10R
F11	Design out waste	F29	Waste levy
F12	Use of WMA (2008)	F30	Secondary market
F13	Pre-fabrication and standardisation	F31	Recycling infrastructure
F14	Waste management plan	F32	Cost of waste
F15	specification writing	F33	Role of public-private institutes
F16	Unequal consideration to C&D waste	F34	Resource recovery and margins on second life products
F17	On-site sorting of waste and contamination	F35	Application of deconstruction
F18	Waste reporting and sense of responsibility	F36	Waste management and resource recovery plans

4.5 Challenges and opportunities in C&D waste minimisation

The semi-structured interviews and on-site observations noted 25 C&D waste minimisation challenges that need to be addressed. These challenges are categorised into four stages, i.e. pre-design, design, construction (and refurbishment) and demolition. Table 4.7 illustrates the challenges and opportunities in C&D waste minimisation for Auckland. It also shows the interview responses of client representatives (A), contractors (B), and policymakers and influencers (C).

Table 4.7: Challenges and opportunities in C&D waste minimisation in Auckland

Stage	Challenges	Number of responses by each category			Total response
		A	B	C	
Number of participants in each category		12	14	11	
Pre-design	Poor contractual requirements	12	14	11	37
	Greenwashing and green claiming	11	13	11	35
	Lack of early involvement of stakeholders	10	12	10	32
	Lack of education and innovation	10	12	9	31
Design	Lack of life cycle thinking	12	14	11	37
	Poor Waste minimisation goals	12	12	11	35
	Material selection and overordering	10	12	10	32
	Design out waste	9	10	11	30
	Use of Waste Minimisation Act 2008	11	9	10	30
	Use of pre-fabrication and standardisation	9	9	10	28
Construction	On-site sorting of waste and contamination	12	13	11	36
	Waste reporting and sense of responsibility	12	12	11	35
	Identification and quantification of waste	11	13	11	35
	Social values of waste	9	10	11	30
Refurbishment	Environmental impact	12	12	11	35
	Availability of resources	10	12	10	32
Demolition	10R	12	14	11	37
	Waste levy	12	14	11	37
	Secondary market	11	14	11	36
	Recycling infrastructure	10	14	11	35
	Cost of waste	9	11	10	30
	Role of public and private institutes	8	10	10	28

Stage	Challenges	Number of responses by each category			Total response
		A	B	C	
Number of participants in each category		12	14	11	
	Resource recovery and margins on second life products	7	9	9	25
	Application of deconstruction	7	7	10	24
	Waste Management and Resource Recovery Plans	7	7	10	24

As shown in Table 4.7, poor contractual requirements were noted to be the key C&D waste minimisation challenge in the pre-design stage. In contrast, lack of education and innovation was the least crucial challenge of pre-design stage. All interview participants mentioned that C&D waste minimisation is often not included in the contract documents. In addition, lack of early involvement of stakeholders (32 out of 37 participants) leads into selection of unsustainable materials (35 out of 37 participants).

In the design stage, lack of life cycle thinking/ circular economy was the key waste minimisation challenge. All participants stated that most, if not all, CI practitioners focused on end-of life waste management rather than minimising waste in the design stage. As a result, less attention is given to material selection (32 out of 37 participants). In total, 30 out 37 participants mentioned that provisions of WMA (2008) such as waste management hierarchy and product stewardship are yet to be practiced to their full capacity. Further, 28 out of 37 participants stated that lack of interest in using pre-fab and standardised building materials generates design waste.

It can be seen from Table 4.7 that on-site waste sorting received highest number of responses as the key challenge of construction stage. In total, 13 out of 14 contractors mentioned that waste sorting has not been seen as a recovery opportunity but an extra cost by contractors. Further, 35 out of 37 participants argued that poor standards of waste reporting don't urge a need for waste minimisation. In addition, lack of waste composition data often confuses contractors to select appropriate waste minimisation approach (35 out of 37 participants). In total, 30 out of 37 participants stated that contribution of C&D waste in landfills and cleanfills is seen as economic and environmental damage, neglecting the social impact of waste.

Table 4.7 shows that, refurbishment stage had two waste minimisation challenges. In total 35 out of 37 participants mentioned that contractors across Auckland CI often do not consider environmental impact of refurbished materials before disposing them at a landfill/cleanfill. Further, 32 out of 37 participants argued that limited actions of reuse and recycling of refurbished waste attract a smaller number of waste recyclers to process refurbish waste.

As shown in Table 4.7 the demolition stage had highest number of challenges. All participants described 10R thinking and the waste levy as the most important challenges of waste minimisation in the demolition stage. Further, 36 out of 37 participants stated that supply of recovered materials (reuse and/or recycle), surpasses the demand for recovered products as a result of limited secondary market. In total, 35 out of 37 participants stated that Auckland CI needs more recycling units. In addition, higher waste cost (e.g. collection, recycling) hinders waste minimisation through recycling (30 out of 37 participants). In contrast, 25 out of 37 participants argued that low margin on recycled products hinders waste minimisation.

Table 4.7 shows that 28 out of 37 participants considered the role of public and private institutes as one of the key challenges of demolition stage. Topics such as extended producers' responsibilities or product stewardship, community recycling centres and building certification requires promotion. Further, 24 out of 37 participants mentioned that deconstruction practices are essential yet limited in the Auckland CI. Similar number of participants argued that the lack of waste management and resource recovery plans impede deconstruction, in addition, overall demolition stage waste minimisation.

Some challenges, such as the implementation of the WMA (2008) and 10R, are applicable to all project stages. However, they are classified based on the interview responses and on-site observation. Similarly, challenges such as on-site sorting, waste reporting and social values of waste are also considered as challenges in refurbishment and demolition stage by CI practitioners. Chapter 5 discusses each waste minimisation challenge and its remedies in detail.

4.6 Chapter Summary

This chapter presented the findings of the qualitative and quantitative data collected for the research. The results of the semi-structured exploratory qualitative interviews with client representatives, contractors and policymakers and influencers helped to identify

the 36 factors that influence C&D waste. The factors helped to identify 25 C&D waste minimisation challenges for the Auckland CI.

The 36 factors occurred at different stages of project stages covering the life cycle. In the pre-design stage, contractual requirements, greenwashing of building materials, education and innovation and early involvement of stakeholders have a significant influence on waste. Further, design stage waste is influenced by circular economy thinking, waste minimisation goals, use of prefabrication and unequal consideration to C&D waste. The contractors deal with physical waste rather than design waste in the construction stage. The factors that influence the physical waste are waste sorting, composition and quantification of waste, use of online platforms for resource sharing and social values of waste.

The interview responses showed that refurbishment waste is also a topic of interest for Auckland CI practitioners. Factors such as house condition, availability of resources, and environmental impact of refurbished material play an important role in minimising refurbishment waste. Lastly, in the demolition stage, 10R thinking, waste management and resource recovery plans, recycling infrastructure, secondary market and margins on second life products, influence demolition waste. The interviewees' argued that Auckland CI practitioners need to focus on these 36 factors to minimise C&D waste over the life cycle.

The qualitative findings, i.e. factors influencing waste, are validated through a quantitative approach to lay the foundation for a waste minimisation framework for the Auckland CI. The quantitative findings confirmed the status of all identified factors that influence C&D waste. Furthermore, it was observed that consideration and application of these factors contributed to C&D waste minimisation. In addition, clear understanding and effective addressing of these factors could advocate SC through waste minimisation.

Chapter 5 Discussion

5.1 Introduction

This chapter presents a discussion on the research findings. The discussion offers a linkage to the research objectives and addresses the research questions. The chapter is divided into four parts. The first part discusses the challenges and opportunities in C&D waste minimisation in Auckland. The second part offers remedial measures for the challenges and opportunities. Subsequently, a waste minimisation framework is presented in the third part, while the fourth and final part summarises the discussion.

5.2 Challenges and opportunities in C&D waste minimisation in Auckland

This section discusses the waste minimisation challenges and opportunities for Auckland. The challenges are inspired by the 36 factors presented in the previous chapter. The challenges are divided into different stages of the project's life cycle.

5.2.1 Pre-design

The pre-design stage has four key challenges: poor contractual requirements; greenwashing and green claiming; lack of early involvement of stakeholders; and lack of education and innovation. It is important to understand each challenge to propose a remedial measure for them all.

i. Poor contractual requirements

Achieving waste minimisation goals through contractual agreements is not common worldwide (Hee et al., 2014). All interview participants mentioned that the role of waste minimisation in advocating SC, is often overlooked and ignored. Waste minimisation is not prioritised in contracts due to a lack of interest from clients and contractors (B-08). Waste minimisation often gets unequal consideration in contract documents and is not prioritised by stakeholders (Shooshtarian et al., 2020). Further, the contract documents lack in guiding waste tracking and management, rating tools, waste minimisation approaches and material selection (A-01). The literature findings discussed in sections 2.6.6.2 and 2.7.4.1 mentioned that contract documents are not oriented towards waste minimisation and hence exclude guidance on waste tracking, handling and minimisation.

The impact of poor contractual requirements, e.g. poor waste monitoring, was observed on 8 out of 9 sites (Table 4.5). One policy maker mentioned that there is no binding mechanism between clients and contractors that mandates the identification and quantification of waste at different project stages (C-02). Waste reporting is not considered as a priority in the contracts documents, but a client should demand waste monitoring, and the contractors should set up a waste assessment unit to review waste quantities and composition, after the completion of each stage (BRANZ, n.d.). The waste assessment develops a sense of awareness and encourages contractors to minimise waste (C-02).

In contrast, 7 out of 14 contractors argued that the contracts should include material specification and certification requirements instead of waste monitoring. The literature showed that the lack of material specification and negligence to certification in contract documents, is not common but seen to some extent depending on the scale of the project (Yuan, 2017). One contractor mentioned that materials such as Medium Density Fibreboard (MDF) coming from overseas are toxic to the environment but are still used because they are low-priced (B-08). A waste collector confirmed the contractor's finding and stated that the imported MDF is often of low quality and non-recyclable and creates environmental issues (C-09). The low quality MDF contains high levels of toxic formaldehyde that poses potential risk to the environment. In addition, MDF cannot be recycled safely in NZ (Junk Run, 2022). The contractor and the waste collector recommended including a new clause on the material specification in the contractual agreement.

The interview findings indicated that all participants favoured reuse, recycle and repurpose. The CI practitioners need to make these approaches a commonplace practice in the Auckland CI (BRANZ, 2014). The on-site observations noted that 3 out of 9 sites did not practice any of the above approaches through a contractual requirement. On all 3 sites the contracts' did not include anything about reusing, recycling and repurposing the waste. One contractor mentioned that willingness and policies around waste minimisation approaches play an important role in promoting waste minimisation (B-04). The Auckland CI have enough policies to promote waste minimisation. However, stakeholders' willingness to prioritise waste minimisation remains a concern (BRANZ, 2014).

ii. Greenwashing and green claiming

‘Greenwashing remains a concern, and its popularity is a bigger concern. In addition, the lack of rigorous material selection process results in the selection of (un)sustainable building materials’ (B-11).

Green materials are expensive and the Auckland CI have a cost-oriented perception (A-01). For instance, Econyl fabric made from 100% recyclable synthetic fibre costs \$20/metre, while nylon fabric costs \$11/metre (C-11). As a result, carpets made up of nylon have more demand in the NZ CI (C-11). Internationally, nylon carpets were found to be cheap, durable and stain resistant which makes them first choice. Nylon carpets accounted for nearly 65% of all carpets manufactured in the US (Sim & Prabhu, 2018).

It can be seen from Table 5.1 that 35 out of 37 participants confirmed that there is a lack of environmental consideration in the material selection process. Similar findings were identified in the literature review (section 2.6.7). Contractors neglect the long term benefits of green materials and select low-priced unsustainable materials (NZGBC, 2015). One contractor mentioned that in the Auckland CI, the battle is always between green versus cheap and contractors often select materials that appear green and cheap, but they are not green (B-04). The recycling facilities need to make cheap second life green products to attract clients and contractors (Auckland Council, 2019).

Designs provided by the architect also influence the material selection, (e.g. using a specific design and material to achieve the required strength) (A-07). Selection of a specific material to fulfil aesthetic or technical requirements without end-of-life assessment (biodegradable or recyclable) often leads to the selection of unsustainable materials (Esa et al., 2017). All policy makers and influencers expressed their concerns over the material selection process adopted by contractors.

A lack of a rigorous material selection process was observed on 6 out of 9 sites (Table 4.5). In particular, all three construction sites suffered from greenwashing and green claiming. A client representative suggested that contractors need to select eco-labelled materials (A-05). Contractors select eco-label materials depending on the demand from clients (Esa et al., 2017). In contrast, a contractor mentioned that cost constraints and demand influence the selection of (un)sustainable materials (B-04). The literature findings supported this argument. Though eco-label materials provide long term benefits to the contractors, their cost and client’s affordability influence the material selection process (Raouf & Al-Ghamdi, 2019)

iii. Lack of early involvement of stakeholders

‘...forecasting of future challenges and their transfer into opportunities is not happening at the moment. It is because people who deal with waste such as Site Manager and labourers and waste collectors and recyclers are not involved in the early project phase’ (C-03).

The interview responses and on-site observation confirmed that not all project stakeholders are involved early in the process. It can be seen from Table 5.1 that 32 out of 37 interviewees mentioned that the lack of early involvement of site personnel leads to high waste generation. This finding agrees with the literature that showed that the project stakeholders (clients, contractors and waste handling service) missed a holistic approach to see a project, as a result of late involvement which later becomes one of the key causes of waste generation (Ajayi & Oyedele, 2018). On 5 out of 9 sites, the lack of involvement of waste collectors and recyclers in the decision-making process was observed (Table 4.5). One client representative mentioned that project stakeholders' lack of early involvement results in a lack of knowledge and solutions to deal with waste (A-07). In other words, limited waste minimisation opportunities are identified and implemented. The early involvement of project stakeholders is seen as an affirmative action to discuss material selection, reuse, recycling and recovery options (Ajayi & Oyedele, 2018).

The construction process involved different trades, so each subcontractor has specific jobs and responsibilities. All construction sites had multiple sub-contractors. It was observed that only 2 out of 5 sub-contractors were involved early in the waste minimisation strategy. The sub-contractors don't participate early in the process (post-tender meetings) to discuss the projects' waste minimisation goals. The literature showed that sub-contractors did not practice waste minimisation unless encouraged by the main contractor (UNEP, 2015a).

One policymaker mentioned that site engineers and architects also need to be involved early in the process to discuss the design and its on-site implementation to reduce waste (C-06). However, lack of motivation and interest in waste minimisation hinders the discussion between site engineers and designers (Esa et al., 2017). Site engineers often find it difficult to work with architects' designs due to the difference between assumed site conditions and actual site conditions (C-03). The literature findings backed this argument. The architectural drawings are focused on aesthetic, while the nature of site decides the on-site construction practices. As a result, waste is generated through

material off-cuts (Islam et al., 2019). On 2 out of 3 construction sites produced large quantities of timber off-cuts due to a lack of discussion between the site engineer and architect.

iv. Lack of education and innovation

‘...industry is struggling to have a fresh perspective to see waste. The process from material to waste needs to be understood through education to stimulate innovation’ (A-04).

The success of waste minimisation is highly dependent on education about materials and innovative thinking to deal with surplus materials (section 2.8.2.1). Table 5.1 shows that 31 out of 37 interview participants considered the lack of education and innovation as a waste minimisation challenge for Auckland CI. The literature review endorsed similar findings. The CI practitioners underestimate the role of education and innovation for C&D waste minimisation (BRANZ, n.d.). Further, 9 out of 11 policy makers and influencers mentioned that material selection and waste handling are key areas to improve waste minimisation through education and innovation. The policy makers and influencers argument is supported by literature. Lack of education on what can be reused, recycled and recovered leads to selection of non-recoverable materials. In addition, poor understanding about waste handling e.g. sorting contaminates recoverable waste (Ghaffar et al., 2020).

A recycling facility manager (policy influencer) mentioned that the contractors are poorly educated on selecting sustainable materials. As a result, contractors often select low-priced materials which are non-recyclable (C-09). However, education is not a single factor for material selection, and it is accompanied with cost, availability, specification and demand (Calvo et al., 2014). On 5 out of 9 sites, the impact of lack of education and innovation was observed (Table 4.5). In particular, two out of three demolition sites produced non-recyclable waste such as low-quality MDF.

The lack of education results in a poor understanding of the problem, which ultimately hinders innovative thinking stage (Esa et al., 2017). 12 out of 14 contractors confirmed that Auckland CI needs innovative thinking around resource sharing and waste recycling. The literature findings were aligned with contractors' response because innovation has an influence on resource optimisation and waste collection and recycling (Henrotay et al., 2018).

One contractor mentioned that it is a contractor's responsibility to educate the site labourers, encourage innovation on-site, and ask subcontractors to practise waste minimisation approaches (B-03). However, due to lack of education, the contractors, subcontractors and site labourers don't consider C&D waste minimisation as a priority on the site. The literature on lack of education to site labourers showed that waste handling cost and lack of financial incentives are bigger concerns than education (Maués et al., 2020).

5.2.2 Design

The design stage has six key challenges: lack of life cycle thinking; poor waste minimisation goals; poor material selection and overordering; design out waste; use of WMA (2008); and standardisation and pre-fabrication. Each challenge is discussed in detail to broaden the understanding of C&D waste.

i. Lack of life cycle thinking

'There is no single player to blame for high waste generation. The whole life cycle is responsible. It starts with a poor choice of materials from a contractor, then lack of precise estimates of materials from a quantity surveyor, over-ordering of such materials by a site manager, poor execution process from workers and then lack of demand for recycled products from customers' (C-02).

Life cycle thinking closes the loop by promoting a circular economy (Ali et al. 2018). All 37 interview participants confirmed that life cycle thinking helps to minimise C&D waste and achieve a circular economy. The interview participants confirmation aligned with literature findings. The literature showed that the life-cycle-thinking or circular economy is required to have a comprehensive understanding of project stages, C&D waste generation and its impact and benefits of waste minimisation (EC, 2022). In addition, Table 4.5 shows that lack of life cycle thinking was identified as the most important waste minimisation challenge on all (9 out of 9) sites. However, Auckland CI practitioners have a poor understanding of the life cycle of a material. The literature review (section 2.8.2) showed that the building materials are selected without a thorough assessment on their environmental impact, reusability and recovery options.

A policy maker from MfE mentioned that the lack of life cycle thinking around materials is due to two reasons. Firstly, lack of policy to encourage life cycle thinking. The contractors consider the life cycle a wider national policy question. Therefore,

waste generation at each stage is not studied efficiently by them. The literature confirmed the MfE policymaker's viewpoint. Though public- private sector partnership provides procurement framework and recovery options, guidance for CI practitioners to promote life cycle thinking through stages is not available (Purchas & Ainsworth, 2019). Secondly, a life cycle study requires validation of benefits at each stage. Therefore, the contractors need to invest resources to analyse and select materials and recycle them to sell into the secondary market. The literature suggested that contractors need to select sustainable materials through rigorous process and should consider recycling and secondary market as a priority (Huang et al., 2018). The interview findings coincide with literature findings. Overall, it is difficult for contractors to do the commitments for life cycle thinking without policies and support (C-07). Another policy maker expressed that contractors' theoretical aspirations do not match their practical actions as they often consider life cycle thinking in the documentation but not on-site (C-10). The policymaker's comment was supported by literature because application of life cycle thinking in real life environment, is a concern for contractors due to lack of resources, less interest from clients and inadequate knowledge (Rosado et al., 2019).

ii. Poor waste minimisation goals

‘We build homes made of timber, and there is always timber waste. We have limited guidance on how much timber waste is acceptable and how much to divert’ (B-05).

Table 5.1 shows that 12 out of 14 contractors considered poor waste minimisation goals as a challenge for waste minimisation. The literature findings supported the contractors' argument. The findings showed that the aspirational waste minimisation targets (goals) set by CI practitioners, are low or non-practical (NZGBC, 2019). One contractor mentioned that waste minimisation goals encourage contractors to minimise waste at the source or recycling. However, construction contracts do not explicitly mention the goals, rather vaguely discussed possibilities of waste minimisation, while in some contracts, goals set for diversion are unachievable (B-06). The literature shows that contract documents mention about waste minimisation; however, waste minimisation targets and actions to achieve them are often not included in the contracts (Rose & Stegemann, 2018). The on-site observation noted that waste diversion goals were set for 7 out of 9 sites; however, no specific goals were set for reuse or recycling (Table 4.5). 3

out of 9 sites diverted more than 90% of the waste. The diverted waste included contaminated soil, timber and metal.

A policymaker argued that there is plenty of information available on C&D waste minimisation from REBRI and NZGBC to guide contractors to set achievable waste minimisation goals (C-02). The literature review findings supported the policymaker's argument. The REBRI templates and NZGBC waste minimisation goals are oriented towards the state-of the art of Auckland CI to help contractors to set achievable targets (BRANZ, n.d.).

Currently, setting up waste minimisation goals in the contract document is a voluntary action as there are no regulations (A-08). However, the industry practices show that voluntary actions are often neglected and not acted on by industry practitioners; hence legislation is required to set up waste minimisation goals in the contract document (A-03). The literature findings showed that C&D waste minimisation at source or by recycling needs to be promoted through contractual requirements and well informed regulations (Domingo & Luo, 2017). A contractor mentioned that it is important to have regulations for good design and performance. Contracts should have mandatory waste minimisation goals, and contractors must be obliged to achieve them (B-02).

‘...no one likes to be regulated when there is a scarcity of infrastructure. It is expensive and crazy for a contractor to send waste all over the country just to reach the waste minimisation goals’ (A-09).

The counter argument is setting waste diversion goals in the contractual agreement seems to be astonishing in theory, however in practice, it is difficult due to the lack of recycling facilities (B-04). One contractor recommended adaptation of European regulations such put a ban on recyclable materials to cleanfill or landfill. The researcher found mixed responses to the implementation of European regulations in Auckland, but most (30 out of 35) participants rejected the idea to ban recyclable materials from cleanfill or landfill. A recycling facility manager mentioned that it would be unfair for contractors and waste handling services to implement such regulations knowing the lack of recycling and recovery infrastructure (C-10). The literature findings showed that in the Auckland region, C&D waste recycling facilities to process mixed waste, are limited. In addition, the facilities still need to be improved. For other regions, it is difficult to achieve recycling goals due to a lack of facilities (Auckland Council, 2019). One contractor mentioned that it is important to understand that NZ has different

constraints such as population, connectivity and resources (B-12). Overall, setting up waste minimisation goals in a contract and at a wider industry level is a challenge for Auckland CI.

iii. Poor material selection and overordering

‘...both local and imported materials need to be put into a material purchasing framework so that contractors can choose the materials and minimise the waste. In particular, guidelines on buying insulation and double-glazed windows materials are required to make the material selection process easy for contractors’(B-08).

The lack of knowledge and understanding of the materials’ environmental impact beyond construction or demolition, result in poor material selection (Won & Cheng, 2017). Table 5.1 shows that 32 out of 37 interview responses considered poor material selection a challenge for Auckland CI. The literature findings described in section 2.8.2 also considered poor material selection as a crucial challenge for waste minimisation. One contractor mentioned that purchasing green materials is difficult for them due to a lack of material selection guidelines. The CI practitioners, especially contractors, are less aware about the guidance provided by Environmental Choice NZ on material selection (Roberts, 2019). Another contractor stated that their material selection process is often subject to social and government pressure (B-11). In contrast, a policymaker mentioned that responsibilities lead to poor material selection rather than social and government pressure (C-03). The literature findings showed that social and government pressure don’t have a significant impact on material selection (Kibert, 2016). Hence, it has become a problem of taking responsibility. To avoid the responsibilities, contractors settle for unsustainable materials (B-03). However, this is not the case all over Auckland. Some contractors select green materials and contribute to SC (A-03). The BRANZ material selection guidelines are used by contractors to select sustainable building materials (BRANZ, 2019b). However, the selected materials are often overordered to avoid project delays (A-07).

‘...for out of Auckland jobs, we order more at least 10-15 % of the total quantity of material as we have to travel, but in local jobs, we try to order less. However, I have not come across a single project which was not a victim of overordering’ (A-07).

Overordering is common in Auckland as contractors do not want to wait to procure more material if they run out (B-11). The literature showed that overordering is one of the crucial challenges. However, it has mixed views as it is seen as a decision taken to

avoid time and cost delays (UNEP, 2013). On 6 out of 9 sites, materials were overordered to avoid project delays (refer to Table 4.5). In particular, all construction sites overordered materials such as Timber and Metal. On all construction sites, the contractors overordered building materials: Timber by 30%; Metal by 35%; and Polystyrene by 20 %.

Overordering is seen as a commonplace practice in NZ performed by the contractors to avoid labour and machinery wastage (Roberts, 2019). In total, 10 out of 14 contractors confirmed this statement. However, 2 out of 14 had a different perspective. They mentioned that contractors overorder due to a lack of communication and coordination between them and quantity surveyors. For instance, the contractors think overordering is the quantity surveyors' fault as estimated quantities are more than required. In contrast, quantity surveyors argued that estimation is based on damage such as weather and transportation and hence materials need to be overordered (B-09; B10). Contractors consider overordering as a one of the key concerns as it increases project cost by 4% for a standard house (Shooshtarian et al., 2020).

iv. Design out waste

‘...waste diversion is in the spotlight, and designing out waste barely received attention from the stakeholders’. While it has to be other way round, eliminating waste in the design stage saves a lot of resources spent on waste management’ (A-01).

The design must be efficient and should have fewer revisions in drawings so that there would be less waste during construction (Osmani et al., 2008). As shown in Table 5.1, 30 out of 37 interview participants expressed the need for efficient design to minimise waste. All interview participants confirmed that designing out waste (DoW) is a new concept for the Auckland CI that has yet to be adopted thoroughly. The Aucklanders have shown interest in DoW as a result of MfE’s updated waste minimisation strategy. The MfE is planning to invest in re-designing of building materials to facilitate reuse of resources (Marshall, 2021).

A contractor stated that the off-cuts of building materials causes high waste generation due to less consideration given to designing out waste (B-01). One of the reasons is waste minimisation is seen as an activity to deal with a physical waste rather than design waste (Auckland Council, 2022). On 6 out of 9 sites, off-cuts of timber and plasterboard sheets were observed. Further, a policymaker added that lack of

collaboration between architect and site engineer at the design stage results in large quantities of off-cuts (C-02). The architects and site engineers often do not discuss each other's perspectives on material selection and site conditions (WRAP, 2011). In total, 10 out of 14 contractors expressed that they need guidance from territorial authorities to practice the DoW approach. The Auckland council-led projects such as Birkenhead War Memorial Park, attracted CI practitioners towards DoW (Auckland Council, 2021). Internationally, organisations such as EU provides guidance for contractors to implement DoW (EC, 2020).

v. Use of Waste Minimisation Act 2008

The Auckland CI lacks implementing WMA (2008) in its full competency. The Act is a legislative framework that advises industry practitioners to use waste hierarchy and product stewardship schemes. However, policymakers (territorial authorities) are encouraged to identify and quantify waste and set waste minimisation actions (Auckland Council, 2018b).

It can be seen from Table 5.1 that the use of the Act is a challenge for 30 out of 37 interview participants. In particular, implementing the waste management hierarchy is a key challenge for them (B-09). Though it has been claimed that waste management hierarchy is practised across Auckland, recovery dominates industry practices, followed by disposal (BRANZ, 2019a). The Auckland CI practitioners are exploring and enhancing their understanding about waste management hierarchy, except recovery and disposal (Roberts, 2019). On 6 out of 9 sites, contaminated soil was sent to the quarry and timber waste to the recovery station. A policymaker stated that recovery and disposal is widely practised as it is natural to find a cheaper way to deal with waste. Currently, disposal and recovery are the cheapest options available for contractors (C-04). In addition, landfill and cleanfill disposal is not considered a greater concern by contractors due to the low waste levy (C-02). Therefore, NZ government is increasing the waste levy. Also including C&D waste fill under it, to change CI practitioners throw away behaviour (MfE, 2020). In total, 9 out of 11 policymakers argued that contractors need to focus on top approaches (reduce, reuse and recycle) from the waste management hierarchy. Reduce and reuse are not widely practised in Auckland CI due to less client demand, while recycling has its limitation associated with high cost and limited secondary market (BRANZ, n.d.).

The other features of the Act, such as product stewardship, also needs industry attention (A-01). A policymaker mentioned that industry practitioners don't consider perhaps understanding their waste minimisation responsibilities. For instance, manufacturers fail to select sustainable materials; contractors avoid on-site waste segregation; and clients' lack of demand for eco-labelled products (C-02). Waste minimisation responsibilities are often distributed unequally due to the lack of knowledge and practice of product stewardship scheme (Auckland Council, 2019).

The contractors hire waste handling services and expect to get rid of the waste and avoid thinking about waste minimisation (A-07). The contractors need to share the waste responsibilities and participate in waste minimisation by analysing waste reports to improve the quantity survey (B-11). C&D waste minimisation responsibilities are not divided among all project stakeholders. In addition, contractors often appoint a third party to manage waste (Junk Run, 2022). The provision of the act about product stewardship scheme considers clients, contractors and waste handling services equally responsible for waste minimisation (A-04). Products such as polystyrene, plasterboard, metal, concrete and packaging waste need to be prioritised for the scheme (C-09). The aforementioned products have a significant contribution to C&D waste generation. For instance, concrete contributes up to 7% of total C&D waste generated each year (Auckland Council, 2019). On all construction sites (3 out of 3) product stewardship schemes were implemented for polystyrene and concrete waste.

vi. Standardisation and pre-fabrication

‘...its architect and the site engineer. The architect experiments with designs with non-standard material, while the site engineer validates the design on the site. This process results in large off-cuts as materials are manufactured with standard sizes. For instance, plasterboard sheets come in standard sizes, and non-standard designs generate lots of plasterboard off-cuts’ (B-13).

The aesthetic view of a building receives first preference when compared with construction with standardised units (Wu et al., 2019). As discussed in section 2.8.2, the application of standardised and pre-fabricated units has been a challenge for the CI. Table 5.1 shows that 28 out of 37 interview participants responded that standardisation and pre-fabrication is a challenge for the Auckland CI. A contractor mentioned that clients do not prefer the repeated construction of the same units (B-03). The lack of standardised design and inadequate design information, influence waste generation in the design stage (Kovac, 2018). In total, 9 out of 14 clients mentioned that architects are

inclined to customise designs or layouts to attract customers. Clients prefer non-standard designs to avoid repetition of units (Yuan, 2017). As a result, site engineers have to convert standard material sizes into design sizes and produce waste (B-03). The Auckland CI use standardised and prefabricated materials, but the extent is very small (B-13). Though prefabrication and standardisation is considered as an option to supply mass affordable homes, its potential to serve NZ CI is yet to be studied well (Brown, 2020).

On all construction sites, the contractors used pre-cut and pre-nail roof trusses (Table 4.5). However, the industry needs to extend the application of practices such as modular bathrooms and prefabricated window and wall panels (B-13). Subsequently, industry-wide promotion of such practices is required to minimise waste (C-03). The CI practitioners considered that prefab building components cannot serve individual clients needs due to standard dimensions (Brown, 2020). In contrast, prefab manufacturers are able to provide variety of sizes as per need and demand. It is important to change the CI practitioners perception on prefab components (Brown, 2020).

5.2.3 Construction

The construction stage has four crucial challenges for waste minimisation: on-site sorting of waste and contamination; waste reporting and sense of responsibility; identification and quantification of waste streams; and social values of waste. In addition, there are two key challenges in the refurbishment stage. These challenges are the environmental impact of waste and the availability of resources to perform refurbishment. All the challenges are discussed in detail to distinguish their status in Auckland CI.

i. On-site sorting of waste and contamination

‘The CI needs to see C&D waste differently than the current perception of seeing it as a non-profit waste. Waste is not diverted because site labourers don’t sort, and they don’t sort because they don’t care. When they learn the benefits of diverting, they will start sorting’ (A-09).

Construction projects fail to perform successful waste recovery (reuse/recycle) due to lack of waste sorting and high level of waste contamination (Menegaki & Damigos, 2018). Sorting at the site is one of the biggest concerns for contractors (B-04). Though on-site sorting is promoted through literature, its practical application is very low (B-05). One of the key causes is a lack of knowledge about sorting in the sub-contractors'

group, such as cavity and cladding fixer, internal wall liner, and roof installer (Chen & Lu, 2017).

As shown in Table 5.1, all policy makers and influencers stated that on-site sorting is a challenge for the Auckland CI. A recycling facility manager (policy influencer) mentioned that though Auckland has facilities to process mixed waste, contractors should prefer sorting on-site as the processing cost of mixed waste is higher than sorted waste. The recycling facilities have to sort the mixed waste through mechanical operations before processing it. As a result, sorting cost is added to the recovery cost (Chen & Lu, 2017). One policymaker mentioned that there are no facilities outside of Auckland to process the mixed C&D waste. Hence, waste sorting should be the priority of contractors outside the Auckland region. To assist in waste sorting, the NZ government is investing in recycling facilities to improve the status of C&D waste recycling across the country (Auckland Council, 2019).

In Auckland's inner city and multiple residential sections in the suburbs, the construction, refurbishment and demolition sites are congested and do not offer enough space for multiple bins. Therefore, different waste streams are collected in one bin (A-05). In contrast, major projects such as City Rail Link sort waste by using multiple bins (Auckland Council, 2019). On all sites, lack of space to sort waste was observed. On 2 out of 3 construction sites, timber waste was collected with plasterboard and metal waste. Further, all three demolition sites struggled to sort waste on-site. On 2 out of 3 demolition sites, off-site sorting was conducted by the waste handling services.

Waste contamination was observed on almost all sites (7 out of 9). A contractor mentioned that waste contamination occurs due to poor work skills. For instance, a labourer throws leftover paint on timber off-cuts (B-02). The lack of on-site education to labourers about waste sorting has become an important issue for contractors (Roberts, 2019). Another contractor mentioned that waste bins are not guarded all the time and often get contaminated with food, aluminium cans and coffee cups from outsiders (B-04).

As a result, resource recovery facilities received contaminated waste and were unable to deliver targeted recycling value (C-09). All interview participants agreed to promote on-site sorting to avoid contamination and minimise waste through reuse, recycle and recovery.

ii. Waste reporting and sense of responsibility

‘...actions drive outcomes. The lack of granular waste data is the reason for the lack of actions for wellbeing. The waste reporting should be used as an instrument to attract CI’s attention to take waste minimisation measures’ (A-08).

Auckland CI has very poor waste reporting with a lack of consistency on waste generation, waste recycled, waste diverted from landfills and sent to landfills (Auckland Council, 2019). It can be seen from Table 5.1 that 36 out of 37 interview participants consider waste reporting as one of the crucial challenges of the construction stage. The Auckland Council waste assessment report acknowledged that waste reporting is a challenge in NZ (Auckland Council, 2018b). A client representative mentioned that the lack of transparency in waste reporting results in a lack of sense of responsibility among all industry practitioners (A-01). On 7 out of 9 sites lack of responsibility in waste handling was observed. In particular, all refurbishment sites had poor waste handling and reporting.

Further, 6 out of 14 contractors claimed that the current waste reports are vague and difficult to interpret. In contrast, a recycling facility manager mentioned that waste reporting is entirely based on contractors’ behaviour. For instance, if contractors arrange multiple bins and perform on-site sorting, more granular data could be produced. However, this practice is not common in the Auckland CI as most, if not all, contractors have a single bin for all waste streams (Roberts, 2019). The literature findings showed that multiple bins give efficient reporting and also encourage contractors to minimise waste (Auckland Council, 2020). Sites with multiple bins and sorted waste with no contamination, have robust waste reports (Auckland Council, 2020).

All construction sites (3 of 3) had multiple bins to sort timber, plasterboard and general waste. Waste reporting helps contractors to perform self-analysis of their activities and produce a sense of responsibility (BRANZ, n.d.). All interview participants stated that waste reporting is not similar on all the projects in Auckland but support the fact that it needs improvement as it can bring awareness about waste minimisation .

iii. Identification and quantification of waste streams

‘...the composition of waste is missing, and it is a piece of information that often isn't available. So we don't know what goes in a bin at what stage, and hence we can't plan our interventions’ (A-03).

The waste assessment reports lack ability to identify and quantify all waste streams generated during the construction, refurbishment and demolition (section 2.8.2.3). Table 5.1 shows that 35 out of 37 interview responses confirmed that poor waste identification and quantification contribute to high waste generation. A contractor argued that data accountability on the composition of different waste streams is not excellent, considering current industry standards (B-02).

In total, 11 out of 12 client representatives mentioned that the composition of waste and contribution of different waste streams is poor across the Auckland CI. The site observations confirmed that on 7 out of 9 sites (Table 4.5), the stream-wise waste quantification for all waste streams was not studied, due to a lack of demand and awareness from contractors (BRANZ, n.d.). As a result, most waste streams are classified under ‘other mixed waste’, including Polystyrene, carpet & padding, and paper waste. Hence, specific waste minimisation approach cannot be applied to minimise the particular waste streams (section 2.8.2.3). The site engineer claimed that more waste would have been minimised during construction if they knew the composition and quantification of each waste stream.

A contractor stated that big claims are made on waste composition, but a little of that is in practice. In addition, there have been irregularities in precise waste quantification, such as not all waste streams are quantified (Auckland Council, 2019). Rather the focus is given to larger waste streams (quantity-wise) such as timber and plasterboard (A-03; A-04; A-06). Though timber and plasterboard quantification helps to divert more from landfill, zero waste aim cannot be completed without minimising all waste streams (Auckland Council, 2018a). On all construction sites (3 out of 3), timber, plasterboard and metal waste streams were focused. All interview responses showed that the Auckland CI needs a broad approach to see all waste streams, their extent, and remedial measures.

iv. Social values of waste

‘...throwaway culture is responsible for landfill and cleanfill waste. The societal harms of waste and the social benefits of waste minimisation are yet to be fully understood by industry. Consideration to social values of waste can improve both health and wealth’ (A-07).

The societal harm of landfilling hazardous waste such as asbestos, low VOC paint and treated timber is not part of the discussion among contractors and clients (C-02). The

hazardous waste causes short and/or long term health issues and hence requires attention from industry practitioners (Hossain et al., 2018). Table 5.1 shows that 9 out of 12 clients' representatives and 10 out of 14 contractors considered the health and wellbeing of society as an important factor. In addition, all policymakers and influencers confirmed that social values of waste need to be understood by the Auckland CI to achieve the social benefits of waste minimisation.

On 1 out of 3 construction sites, asbestos waste was found during foundation. The contractor hired a special team for asbestos removal and disposal. Further, on 2 out of 3 demolition sites, the site engineers educated labourers on waste sorting to achieve the social benefits of waste recycling

The territorial authorities, e.g. Auckland Council, have been advising the industry on the social responsibilities regarding waste and its management (Auckland Council, 2019). However, the social impact of waste on communities is often taken for granted by industry practitioners (A-06). In addition, the social benefit of waste management, such as job creation and good quality of life, are not promoted due to a lack of attention from contractors and clients (BRANZ, n.d.). In contrast, there is a lack of guidelines to promote waste minimisation and its social benefits (C-10). A mixed response was received on the promotion of social benefits through guidelines. In total, 20 participants supported the argument, while 17 participants mentioned that current regulations are encouraging CI practitioners and once waste minimisation is seen as a tool to improve quality of life, they will take social benefits into consideration.

v. Environmental impact

‘...client’s perception on the material extracted from refurbishment needs to change. The environmental impact of refurbishment waste is often underestimate by contractors’ (A-07).

Waste generated during construction, refurbishment and demolition have an adverse environmental impact (section 2.6.6.3). The interview responses (35 out of 37) showed that the environmental impact of refurbishment waste is a key challenge for the Auckland CI. The Environmental impact of refurbishment waste has been discussed among CI practitioners, however, the environmental impact of refurbishment waste doesn’t receive equal attention and is often neglected by them (Domingo, 2011).

As shown in Table 4.5, on all sites (9 out of 9) the labourers were not aware of the environmental impact of waste, such as land pollution and carbon emission. In particular, the waste from refurbishment sites was landfilled without assessing the environmental impact. Contractors' unwillingness and labourers' attitude to reuse/recycle refurbishment waste often neglects environmental impact of waste (Mihai, 2019).

A contractor stated that the waste from the refurbishment project is likely to be disposed of at landfill or cleanfill as there is a lack of demand for the products obtained from refurbishment process (B-08). Another contractor argued that no compliance or regulation around refurbishment waste, promotes reuse (B-12). In addition, clients don't prefer the reuse of refurbished materials and demand virgin materials (Ali et al., 2019). In contrast, a client representative mentioned that virgin materials are demanded as they have longer service life than refurbished materials (A-03). Therefore, reuse or recycling is not likely to happen on-site even though the waste is recoverable (Huang et al., 2018). A policymaker stated that, unlike construction waste, refurbishment waste is not the first choice of contractors to use on another refurbishment site (C-05). Further, due to the lack of secondary market, recovery of refurbishment waste is poor in Auckland (Shooshtarian et al., 2020).

vi. Availability of resources

‘...the quality and compliance is an important factor for contractors. However, the recycled products from refurbishment do not necessarily provide the same standards, and even when they do, clients don't want them on their property. Hence, refurbishment waste is processed poorly with limited resources’ (A-07).

Refurbishment is a process of replacing the end of life materials with virgin materials (Pombo et al., 2016). In Auckland CI, it is commonly accepted that refurbishment is done to put new materials into a house (A-07). The reusing or recycling of refurbishment waste is not a topic of interest for industry (Ali et al., 2019), and hence limited resources are being used to get benefits from the refurbishment of waste (B-05). As shown in Table 5.1, 32 out of 37 interview participants confirmed that the availability of resources such as time, cost and labour is a challenge to process the refurbishment waste. The CI practitioners avoid spending resources on refurbishment waste processing due to the lack of a secondary market Auckland (Calvo et al., 2014). On 7 out of 9 sites, resource scarcity to reuse waste was noted. Further, all

refurbishment sites (3 out of 3) had limited resources to practice on-site waste minimisation approaches.

A recycling facility manager mentioned that the materials obtained through refurbishment are heavily contaminated and require more resources to process (C-10). The waste composition is similar in refurbishment and construction, but the condition of the waste is different. For instance, the plasterboard received from a refurbishment site is more damaged than the plasterboard from a construction site (Junk Run, 2022). Another recycling facility manager stated that though the processing cost of refurbishment waste is similar to demolition waste, refurbishment waste often gives low-quality products with no or less demand. Further, a policy maker mentioned that the contractor's lack of time and labour investment (C-04) and clients' demand for virgin materials are the reason refurbishment waste is landfilled (Ali et al., 2019).

5.2.4 Demolition

The demolition stage has the largest number of challenges. In total, nine challenges were identified for Auckland CI. The challenges are 10R; waste levy; secondary market; recycling infrastructure; cost of waste; role of public and private institutes; resource recovery and margins on second life products; application of deconstruction; and waste management and resource recovery plan. All challenges are discussed in detail to recognise their importance and develop a remedial measure.

i. 10R

As shown in Table 5.1, all interview participants agreed on having multiple waste minimisation approaches through 10R application. A client representative mentioned that the Auckland CI need to take big steps to educate industry practitioners and develop infrastructure to practise 10R (A-01). Each R represents a unique way to achieve sustainable construction; however, each R has a challenge(s).

Refusing non-sustainable building materials is not an easy decision for contractors as sustainable building materials are expensive and less demanded by clients (B-04). A policymaker mentioned that the building material manufacturers have to do a lot of rethinking to produce sustainable materials at a lower cost. The non-sustainable building materials are cheap and are demanded by clients (Low et al., 2020). On 2 out of 3 construction sites and 1 out of 3 refurbishment sites, the contractors optimised their

resource consumption and practised a reduced approach. However, poor estimation and lack of education to site labourers were identified as the challenges.

The contractors on all construction sites reused timber off-cuts but did not reuse the plasterboard. A site manager mentioned that clients don't prefer reuse of plasterboard off-cuts hence we send them to recycling facilities (B-13). Plasterboard reuse practices are rare in the Auckland because Green Gorilla, a major waste recycler, introduced plasterboard recycling service (collection to secondary market) which contributed significantly to plasterboard waste minimisation (Green Gorilla, 2022).

During the interviews, a contractor mentioned that resource availability is a key challenge for material reuse (B-07). For instance, if the soil from a site needs to fill in the foundation, then the contractor has to appoint a geotechnical engineer for its reuse. The process requires a lot of time and cost. Hence, the contractor sends the soil to quarry filling or cleanfill instead of reusing it for foundation (B-07). In the Auckland region, it is common to use soil for quarry filling (Auckland Council, 2019).

In total, 30 out of 37 interview participants confirmed that repair and relocation of houses contribute to waste minimisation. A policy maker mentioned that clients' unwillingness, house conditions, and contractors' attitudes towards repair and relocation are the common challenges faced by the Auckland CI (C-06). The repair material is often sent to landfill or cleanfill due to lack of secondary market. However, material such as timber is reuse to divert landfill waste (Auckland Council, 2019). Though Auckland CI is practising relocation of houses to avoid waste, scaling up the relocation is a crucial challenge for industry practitioners (A-06).

A policymaker mentioned that Auckland has the infrastructure to remanufacture building materials from demolition waste (C-10). However, waste collection and profit on remanufactured materials require attention from clients and contractors (B-14). A recycling facility manager stated that their facility has the infrastructure to process old nylon carpets, but the return on investment is low, and hence old carpets are either reused or dumped in landfill but not remanufactured (C-11). The Auckland CI is in midst of expanding its secondary markets for end-of life carpets (Jacobsen Creative Surfaces, 2021).

The Auckland CI is repurposing plasterboard to make soil conditioners (section 4.2.1). On all sites, the plasterboard off cuts was repurposed. A client representative mentioned

that the plasterboards used to repurpose are often contaminated, and the gypsum extracted from them causes agriculture risks (A-01).

All interview participants confirmed that waste minimisation through recycling is the most practised approach in the Auckland CI. Further, all agreed on the fact that bad recycling is worse than no recycling. Hence, recycling challenges, such as on-site sorting and education for labourers, are important to address (A-06). A recycling facility manager mentioned that recycling monolithic waste such as concrete and steel is complex and challenging work for recyclers (C-10). The Auckland recycling industry suffers from issues such as waste collection, sorting and processing and low demand in the secondary market (Auckland Council, 2019).

A policymaker from MfE argued that the Auckland CI needs strong drivers to recover waste (C-04). For instance, waste streams such as cardboard and plastic are voluminous, but very little consideration is given to their recovery (C-02). Timber waste is the most common waste type recovered in NZ (section 5.2.4). Timber waste is used as a biofuel to convert waste into energy. One client representative mentioned that the Golden Bay cement kiln consumes a large amount of timber waste, but it is relevant to only Auckland. Other regions still struggled to recover timber waste (A-03). The interview responses of 37 participants showed that the Auckland CI is divided over opinion on using timber as a bio-fuel. In total, 15 out of 37 interview participants considered waste to energy as the easiest option to divert waste from landfills.

In contrast, 22 out of 37 interview participants stated that toxicants released into the air during waste to energy process, pollute the environment. The untreated timber needs to be recycled to make particleboard/fibreboard (UNEP, 2015b) and the treated timber should be treated by using methods such as wet oxidation to reuse or repurpose (Environment Canterbury, 2013). However, chemical treatments are expensive and timber is cheap. In addition, timber reduces greenhouse gas emission and NZ's dependence on imported fuel (Scion, 2022). One client represented mentioned that waste to energy transfers the problem from one industry to another (A-01). The Auckland CI requires motivation to find innovative solutions to tackle the recovery challenges (A-01).

ii. Waste levy

‘Waste levy in NZ is lower compared to provinces such as Melbourne, San Francisco, and London. The high tipping fees can change peoples’ behaviour and drive innovation to divert waste from landfill’ (A-10).

In NZ, the waste levy is considered far too low, and contractors often neglect waste cost. As a result, a lot of waste ends up in a landfill (C-06). In addition, not all the landfills are coming under the waste levy, and there is no levy on cleanfill at the moment, hence disposal at cleanfill is an easy option for industry practitioners (B-06). The NZ government has increased landfill waste levy. In addition, cleanfills will also be levied from 2023 (MfE, 2020).

It can be seen from Table 5.1 that all interview participants agreed that a low waste levy is a challenge for the Auckland CI. One policy influencer compared the NZ waste levy with Australian and UK waste levy and argued that the low waste levy in NZ is the reason industry practitioners are not willing to divert waste from landfill. The waste disposal has become the first choice for industry practitioners due to low waste levy (Auckland Council, 2019). On 8 out of 9 sites, the waste levy was observed as a waste minimisation challenge. In particular, on all demolition sites, site personnel were convinced that waste sorting is more expensive than waste disposal. The informal discussion with the site managers revealed that industry practitioners used waste levy as an excuse for not sorting and reusing the waste.

One client representative mentioned that the current waste levy fails to send a signal across the industry to divert the waste from landfills. Further, C&D waste landfills have fewer monitoring obligations and require less resources to get consent (MfE, 2020). In addition, currently, there is no waste levy on C&D waste landfills. As a result, disposal of C&D waste at C&D waste landfill is increasing in Auckland (A-01). One policymaker from MfE mentioned that the NZ government introduced a waste levy for C&D waste landfills with effect from 2023. The literature findings presented in section 2.10.2 mentioned that from 2023 C&D waste landfills will have \$20 landfill levy.

iii. Secondary market

‘...if a contractor uses recycled products to build a house and put 5 % premium on it, then they can attract the environmentalist, but every business wants all of their customer and not just environmentalists’ (B-05).

The waste minimisation in Auckland CI is improving, but still, some aspects need attention, and the secondary market is one of them (BRANZ, n.d.). Table 5.1 shows that all contractors and policymakers, and influencers are concerned yet confident about the secondary market in Auckland. One contractor mentioned that there are mixed feelings about recycled products among contractors, and a small percentage, (maybe 5-10%) of them, think about environmental benefits before economic benefits (B-05). Another contractor added that the secondary market is value and customer-driven. The lack of understanding about environmental benefits and higher cost of recycled products causes low customer attraction (Shooshtarian et al., 2020).

On all construction and demolition sites, it was observed that the secondary market depends on the waste types (Table 4.5). For instance, timber as a biofuel, soil and rubble for quarry filling and plasterboard for soil conditioner, has a huge secondary market. But, materials such as polystyrene and plastic packaging waste are recycled in NZ but have a limited secondary market in Auckland CI (Low et al., 2020) .

One contractor mentioned that if waste is brought back into the circular economy, it should have a value to create a secondary market. Further, client representatives (10 out of 11) expressed that recycled material needs to create significant commercial value and profit to endure in a secondary market. In the Auckland region there are more than a hundred waste management companies operating but less than 10 are in business of C&D waste recycling, due to the lack of value the recycled product creates in the secondary market (Auckland Council, 2019).

A recycling facility manager added that if waste handling services sees any profit in recycled or recovered materials, participation in C&D waste management will increase; ultimately expanding the secondary market (C-10). In contrast, few policymakers and influencers (5 out of 11) argued that the client demand is a prime cause of dormant secondary market rather than value. Overall, the secondary market is a challenge for the Auckland CI due to lack of value creation by secondary materials and a lack of demand from clients (Low et al., 2020).

iv. Recycling infrastructure

‘At our facility, we can recycle only three plastic waste types out of seven. The other four waste types can’t be recycled due to lack of infrastructure. A recycling facility should process all types of waste, but same time needs to create profit for the investor. Most importantly, a recycling facility required to see the whole picture instead of a small frame’ (C-11).

Globally, materials such as concrete, timber, glass, plastic, gypsum and scrap metals are reused and recycled (Kofoworola & Gheewala, 2009). In Europe, concrete waste accounted for 25 % of total C&D waste (900 million tonnes) and countries such as Denmark reuse/recycle 90% of the total concrete waste (Ottosen, 2022). In Canada, building rubble (including concrete, brick, tile and asphalt) contributes up to 52 % of the total C&D waste and a significant quantity of it is reused/recycled (UNEP, 2015b). Further, In Australia, building rubble represented 72% of C&D waste, of which, 66% of building rubble was recycled (Akhtar & Sarmah, 2018).

The average recycling rate in EU was 30-60%. In Australia and India, 50% of C&D waste was recycled, while US recycled 40%. China, the largest C&D waste contributor recycled 5% (UNEP, 2015b), while Japan recycled 90% of their C&D waste (Islam et al., 2019). In NZ, materials such as timber, plasterboard, carboard, plastic and metal are reused and recycled (BRANZ, 2019b). In total, 1.3 million tonnes (28%) of waste is recycled each year; C&D waste recycling rate is unknown (Parkar, 2022).

The Auckland region has more recycling plants to process C&D waste compared to other regions. However, the scale of infrastructure is small, and the plants are often overwhelmed with waste (C-09). C&D waste recycling industry In NZ, especially in Auckland, is in its early stage but growing rapidly (Auckland Council, 2019). All contractors, policymakers and influencers confirmed the lack of recycling infrastructure as a challenge for the Auckland CI (Table 5.1). A recycling facility manager mentioned that not all waste types are able to be recycled with Auckland’s current recycling infrastructure (C-11). The waste recyclers such as EXPOL don’t recycle all plastic types generated from C&D activities (EXPOL, 2021)

All demolition sites (3 out of 3) had waste such as nylon carpets and specific plastic types that were not recycled. A contractor stated that there has been a demand for incentivising the recycling infrastructure as the current output is shorter than the industry aspirations. However, most client representatives (10 out of 12) had a counter

argument that there is no point in incentivising recycling facilities when there is no secondary market for recycled products, although waste recyclers get financial incentives from the Auckland Council. In addition, the Council promotes the use of second life products to expand the Auckland's secondary market (Auckland Council, 2020b).

v. Cost of waste

‘...sustainable solutions need to be financially viable. If we use recycled products to build a house and sell it at a normal rate- how it can survive in the market?, every company needs to compete with its competitors. First comes the affordability, which includes the product's value, and then multiple factors and way down there is sustainability’ (B-05).

The waste cost influences waste minimisation and determines sustainability (section 2.6.6.4). It can be seen from Table 5.1 that 30 out of 37 interview participants considered waste cost as a challenge for waste minimisation. A policy maker stated that lack of attention by contractors to material cost, waste handling cost and recycling cost hinders waste minimisation (C-02). The CI's aspirations and practices both are tied to the waste cost. The contractors neglect the cost of materials in the bin and fail to consider recovery cost of waste (Low et al., 2020).

In addition, contractors avoid recycled products as they are expensive and don't offer required standards (B-04). A waste handling service representative countered the view and mentioned that waste collection, sorting and recycling are expensive stages of their work. As a result, recycled products are sold at higher prices (C-09). The Auckland CI needs affordable and sustainable recycled products in its secondary market to achieve waste minimisation targets (Auckland Council, 2019).

All interview respondents expressed the need for a balance between cost and quality. On 8 out of 9 sites, the waste cost was observed to be a challenge for waste minimisation. On all construction sites, materials such as contaminated soil, plasterboard and timber had expensive collection and recovery costs.

A recycling facility manager expressed that waste has not been seen as a value creation activity by clients and contractors (C-11). In contrast, a contractor responded that the waste disposal cost is lower than the recycling cost (B-02). The NZ government is providing financial assistance to recycling facilities and increasing waste levy to minimise waste disposal and maximise diversion (Parker, 2022). Overall, the interview

responses and on-site observation, showed that lower disposal cost and higher recycling cost, influences the industries' behaviour on waste minimisation.

vi. Role of public and private institutes

The Auckland CI is fragmented in nature and requires collaboration and communication between public and private institutes to achieve SC through waste minimisation (section 2.6.2). Table 5.1 shows that 28 out of 37 interview responses acknowledge public and private institutes' role as a challenge for the Auckland CI. The public-private partnership helps to equally share the waste minimisation responsibilities (Shooshtarian et al., 2020). A contractor added that subcontractors don't think about the efficient usage of materials or waste generation and are unwilling to share the waste minimisation responsibilities. Importantly, subcontractors don't carry liability for non-conventional materials such as tree stumps and soil and leave the site without acknowledging their impact (B-13).

On 2 out of 3 construction sites, the responsibility for polystyrene waste was shared equally among contractors, manufacturers and waste handling services. The site engineers mentioned that subcontractors did not participate in waste minimisation. It has been often claimed that subcontractors' role in waste collection, sorting and recovery, is not considered perhaps discussed during the design stage (Wu et al., 2019). A waste handling service representative mentioned that the responsibility of sharing is a relatively new concept across the CI and needs to be widespread (C-09). In Auckland, companies such as Expol and Winstone Wallboards collect waste as a part of their responsibility (EXPOL, 2022). Further, Expol processes the collected waste and sells the recycled products to the local and international markets (B-14).

One policymaker and influencer argued that the lack of public-private partnerships is the reason for limited community recycling centres in Auckland. A recycling facility manager supported the argument. The public-private partnership is able to create new community recycling centres and offer building materials such as timber, windows and glass at affordable prices (Auckland Council, 2019). The public-private partnership needs enhancement to improve recycling and achieve the zero-waste of Auckland's goal (C-02).

The poor public-private partnership activity is responsible for non-feasible building certification standards (A-03). A policy influencer mentioned that though different

building certification standards are available for industry practitioners, their connectivity with industry practices is not entirely satisfactory. For instance, the Environmental Choice NZ standards are unattainable, and the NZGBC standards are slightly above current industry performance (C-06). The practical achievements and theoretical aspirations in the building certification standards are different, which needs to be filled by creating a collaborative network in the industry (Low et al., 2020).

vii. Resource recovery and margins on second life products

‘If everybody is recovering everything, then why we are still extracting natural resources. Not all materials are given a second life. The current CI practices don’t have innovative approaches to manufacture second life products at an affordable budget’ (A-04).

The Auckland CI needs to recover all waste streams with profit to encourage a circular economy (BRANZ, 2019a). In total, 25 out of 37 interview participants confirmed that resource recovery and margin on recovered products, is a challenge for the Auckland CI (Table 5.1). A contractor suggested that the waste handling service suppliers need to check all possible and feasible options to recover different waste streams. It is often seen that CI practitioners, especially contractors and waste recyclers struggle to identify a recovery method e.g. repurposing to achieve resource recovery targets (NZGBC, 2016).

Table 5.1 shows that 9 out of 11 policymakers and influencers mentioned that Auckland CI needs feasible resource recovery opportunities, while 2 out of 11 argued that the CI needs to focus on existing practices to make affordable second life products (C-09; C12). For instance, Auckland has polystyrene recovery facilities; however, most of the recovered polystyrene is sent to Malaysia as it has a huge secondary market for second life products (C-09; C12). The Auckland region has a limited secondary market for recovered products. In addition, Polystyrene recovery is expensive and it is hard for businesses to earn profit due to lack of demand (EXPOL, 2022).

Another recovery facility manager mentioned that margins on a recovered product is one of the key concerns for their business (C-07). The returns on investment in C&D waste recovery are low. For instance, material such as glass and carpets are recoverable but give low profit (Auckland Council, 2019). As a result, most waste handling services choose to recover other wastes than C&D waste (C-07).

The interview responses showed that the client representatives and contractors were less interested in material recovery and margin on second life products. In total, 5 out of 12 client representatives and 5 out of 14 contractors argued that current waste recovery methods are poor and often give low-quality products. The quality of recovered material decides its demand in the secondary market (EXPOL, 2022). Further, a contractor stated that recovery facilities could earn a profit if the second life products are manufactured with acceptable building standards (B-01).

viii. Application of deconstruction

‘Some demolition contractors are practicing soft stripping (deconstruction) effectively, but the problem is value creation from the waste. It is like apples to bananas and not apples to apples. For instance, a new wood beam cost \$2 but to deconstruct the same wood beam, contractors spend \$30’ (B-06).

The Auckland CI does not have enough drivers to practice deconstruction (BRANZ, 2019a). Table 5.1 shows that 24 out of 37 interview participants acknowledge the need for deconstruction. The remaining participants (13 out of 37) did not consider deconstruction a challenge and favoured demolition. One of the key reasons is demolition requires less time, labour, cost, machinery and skills (Ajayi et al., 2017). A demolition contractor claimed that the deconstructed materials don’t give enough profit to fund their other projects, and they have to settle for less value on investment (B-03). However, literature offers a different viewpoint. The contractors often earn high monetary benefits with accurate planning and efficient resource recovery (Raghuwanshi, 2017).

Deconstruction is more understood among policymakers and influencers as 10 out of 11 participants encouraged CI practitioners to choose it over demolition. At a wider industry level, the knowledge and understanding about deconstruction benefits is not common among contractors and clients (Akanbi et al., 2019). On 2 out of 3 demolition sites, the contractors used the deconstruction approach. Materials such as timber, metal and plasterboard were reused and/or recycled. Further, on 2 out of 3 refurbishment sites, the deconstruction approach took door window frames, plasterboard, and timber.

The deconstructed materials is sold in NZ, some given to charities and the rest is sent to the Pacific islands (BRANZ, 2019b). A deconstruction contractor stated that the Auckland CI has a cost-based perception. In addition, the industry practitioners have not fully understood the societal benefits and positive environmental impact of

deconstruction (B-03). Further, the concept of circular economy through circular resources (using deconstruction), is yet to become a focal point for CI practitioners (Sanchez et al., 2019). As a result, deconstruction has remained a promising yet less practised approach in the Auckland CI (C-09).

ix. Waste Management and Resource Recovery plans

‘Potential waste streams and their management needs to be tabulated before demolishing or deconstructing a house. The absence of waste management and resource recovery plan gives no alternative than sending the waste to landfill’ (B-01).

The literature findings discussed in section 2.8.2 showed that CI lacks implementation of waste management and resource recovery plans. A policy maker from Auckland Council stated that the CI practitioners are yet to understand the benefits of waste management and resource recovery plans (C-09). In total, 24 out of 37 interview participants confirmed that implementation of waste management and resource recovery plans as one of the key challenges in demolition stage (Table 5.1); however, interestingly, only 7 out of 14 contractors considered it a challenge. A similar response (7 out of 12) was received from the client representative category. While 10 out of 11 policymakers and influencers mentioned that waste management and resource recovery plans should be implemented on all sites across Auckland to improve waste minimisation.

The contractors and clients are less interested to implement waste management and resource recovery plans for small projects. In contrast, major construction projects such as City Rail Link have waste management and resource recovery plans (Low et al., 2020). The residential projects lack such plans due to less demand by clients (B-12). The on-site observation showed that 2 out of 3 construction sites lacked implementing waste management plans due to a lack of acceptance by contractors (Table 4.5).

Further, the contractors did not have project-specific waste management and resource recovery plans on 1 out of 3 demolition sites. They did not conduct waste audits to list out all possible materials that could come out from demolition. As a result, the contractors lost the recovery benefits. The waste management and resource recovery plans help to understand the waste flow and develop waste minimisation remedies to recover more waste (BRANZ, 2019b).

Clients and contractors are still waiting to see successful waste minimisation case studies of waste management and resource recovery plans for residential construction (BRANZ, 2019b). Further, interviews with policymakers and influencers showed that acceptance of waste management and resource recovery plans by clients and contractors is a bigger challenge than knowledge of the plan.

5.3 Remedial measures: Advocating sustainable construction

The research findings showed that Auckland CI has an appetite for change. In addition, political and social interest in C&D waste minimisation has increased in Auckland CI. The semi-structured interviews and on-site observation found remedial measures for the waste minimisation challenges. The best possible waste minimisation approaches in Auckland CI are identified as the remedial measures. The next subsections present remedial measures for the waste minimisation challenges tabulated in Table 5.1.

5.3.1 Pre-design

Section 5.2.1 illustrated four key waste minimisation challenges of the pre-design stage. The semi-structured interviews and on-site observations development of remedial measures for those challenges. The remedial measure for each challenge is discussed in this section.

i. Poor contractual requirements

All interview participants affirmed the need for a waste minimisation clause in the contractual document. One policymaker mentioned that CI needs to use different instruments to promote waste minimisation through contracts. For instance, Kainga Ora Homes and Communities (previously Housing New Zealand), is currently adopting 6 Homestar for all new homes (C-02). The 6 Homestar tool encourages contractors to implement waste minimisation approaches. In addition, contractors are advised to select reusable and recyclable materials to divert maximum waste from landfill (Auckland Council, 2019). A policymaker mentioned that clients and contractors should discuss and set achievable waste minimisation targets in a contract document (C-04). Further, clients and contractors can consider the NZGBC waste targets and set new targets as per their resource availability (NZGBC, 2016). On all construction sites (3 out of 3), the contractors used the Homestar rating tool and set diversion goals for contaminated soil.

In total, 25 out of 37 interview participants expressed that waste tracking and monitoring should be a requirement in a contract. One client representative mentioned that the contracts should mention details of a responsible person(s) and their responsibilities regarding waste handling (A-01). However, contractors (10 out of 14) argued that the waste management plan already has this provision. However, implementing a waste management plan is not a priority and hence it needs to be included in the contract (B-03). The REBRI template of waste management Plan allows contractors to tabulate different waste streams, their quantities, set priority waste streams, select feasible waste minimisation approach and person responsible for waste minimisation. The 6 Homestar projects often uses the REBRI template and successfully minimises waste (BRANZ, 2014). On 2 out of 3 demolition sites, the contractors used the REBRI waste management plan to minimise demolition waste.

A policymaker from Hamilton City Council suggested that the clients should include the use of sustainable and recyclable materials as one of the contractual requirements (C-05). In particular, it should specifically mention the minimum recyclable content and acceptable environmental impact of materials (Shooshtarian et al., 2020). The construction contracts with 6 Homestar projects encourage contractors to select certified eco-label products to minimise waste (Auckland Council, 2019). All contractors confirmed that, at present, there is no such requirement practised in Auckland CI; however, they all supported the suggestion.

ii. Greenwashing and green claiming

‘...not every glitter is gold, and not every green is sustainable. The industry needs to avoid greenwashing at the pre-design stage to get material benefits in later stages (A-01).

A rigorous material selection process needs to be practised for green materials selection (section 2.6.6.1). One contractor mentioned that the material's social, economic, and environmental indicators should be assessed before ordering the materials (B-08). Another contractor added that the Auckland CI requires a new procurement framework to help contractors differentiate between sustainable and non-sustainable materials (B-03). Section 2.9.2 discussed the Australasian Procurement and Construction Council's framework and Auckland Council's Procurement strategy to help CI practitioners to select sustainable building materials. The literature findings are in contrast to the contractors' claim for a new procurement framework.

Almost all contractors (13 out of 14) expressed that workshops and conferences can create awareness about sustainable materials. They also added that awareness about eco-labelled materials is required for contractors and clients. The territorial authorities across NZ, include education and awareness programmes on material selection in their WMMP. The Auckland Design Manual (by the Auckland Council) inspires healthier building environment by guiding contractors on material selection and waste minimisation (Auckland Council, 2022).

The contractors performed a meticulous material selection process to avoid greenwashing on all construction sites. For instance, materials such as recyclable polyester (insulation material) were selected to avoid greenwashing. In addition, recyclable wooden pallets and paint containers were used to minimise waste.

A few interview respondents (7 out of 37) favoured having a regulation on the mandatory use of eco-labelled materials. In contrast, 20 out of 37 respondents argued that voluntary certification programmes are a solution to broaden the understanding of eco-labelled materials. Successful implementation of voluntary programmes subsequently contributes to future regulations, if required (A-03). As discussed in section 2.10.2 the Auckland Council, ECNZ and MfE have provided knowledge and education to the CI practitioners on environmental benefits of using eco-labelled materials and given a voluntary choice to use them to achieve SC.

iii. Lack of early involvement of stakeholders

The early involvement of stakeholders results in efficient decision making to minimise waste (Ajayi & Oyedele, 2018). In total, 32 out of 37 interview participants confirmed that the early involvement of site engineers, architects, and waste handling services during the pre-design stage, significantly contributes to waste minimisation. One contractor responded that initiatives such as Project Control Group (PCG) should be implemented to bring all project people on one platform to discuss potential remedial measures (B-13). The PCG ensure participation of all project stakeholders in the early planning phase to list out possible challenges and potential remedies. In addition, PCG helps sub-contractors and waste recyclers to shared their viewpoints on material selection (Australian Government, 2021) .

On all construction sites, the contractors created PCG to increase the participation of contractors, clients, sub-contractors, waste collectors and recyclers. As a result, a broad

perspective on design and material selection was obtained, before starting the construction. For instance, architects and site engineers participated early in the decision-making process and subsequently collaborated to select standard-sized materials while maintaining the aesthetic look of a house (B-02).

The majority of client representatives (9 out of 12) and policymakers and influencers (7 out of 11) suggested the promotion of Corporate Social Responsibility (CSR) to increase the early participation of building materials manufacturers, engineers, architects and waste collectors. CSR stimulates social and moral values of stakeholders and encourages them to achieve sustainability in construction (Mak et al., 2019).

One policymaker mentioned that CSR vitalises the social, environmental and economic responsibilities subjected to C&D waste minimisation and encourages everyone's early involvement in the process (C-07). As a result, the clients often demand the reuse of materials; designers and planners favour prefabricated building components, site engineers avoid over-ordering and demolition contractors prefer deconstruction (C-02). CSR induces drive in project stakeholders to achieve societal goals with ethical, economic and environmental responsibilities (Mak et al., 2019).

iv. Lack of education and innovation

‘...what if there is no place to take waste? A different perspective is required to see the waste and minimise it innovatively. The perspective cannot be developed without having knowledge about materials and their behaviour’ (A-04).

It is important to provide education on SC through waste minimisation (UNEP, 2015b). One contractor mentioned that their organisation has cross-functional SC groups to educate staff and clients about SC through waste minimisation (B-03). Worldwide literature shows that organisations that have SC groups/SC advisory teams promote innovation and examine the feasibility of prospective waste minimisation approaches (Section 2.6). Further, a policymaker added that education encourages contractors to find innovative remedies for waste minimisation challenges (C-10). For example, on 2 out of 3 construction sites, the site engineers innovatively minimised waste through process improvement and recycling. The site engineers drafted a material management plan to install multiple bins to sort waste and subsequently recycle it. Efficient on-site material management helps site labourers to avoid non-value adding activities such as unnecessary material handling. In addition, a good material management plan gives

more on-site space (Beldek et al., 2016). In a similar context, one policy influencer pointed out that process improvement and recycling can be used for other waste types such as carpets (C-11). Internationally, carpets are redesigned with biodegradable and recyclable fibres such as Aquafil. On the other hand, the carpets are recycled to manufacture new carpets (Jacobsen Creative Surfaces, 2021). The Auckland CI should investigate the feasibility of these practices for their successful implementation (B-14).

In total, 9 out of 11 policymakers and influencers recommended a third-party appointment to handle the waste. A contractor mentioned that the waste handling services (third party) often receives profit from material recovery. The literature findings supported the contractor's viewpoint. Waste handling services thrive on innovation to reduce their processing cost and increase their returns on investment (Kibert, 2016). On all sites (construction, refurbishment and demolition), the contractors appointed a third party to handle the waste. As a result, third party involvement successfully diverted materials such as timber, plasterboard, metal and packaging waste from landfill and cleanfill.

A policy influencer mentioned that public/private organisations could motivate industry practitioners by funding their studies (C-06). Auckland Council, MfE and Callaghan Innovation are currently funding research projects on different waste types, including but not limited to carpet, plastic and plasterboard (Auckland Council, 2019). Further, 31 out of 37 interview participants mentioned that community engagement programmes need to be conducted across Auckland to develop new waste minimisation approaches. The Auckland Council conducts educational events for communities to encourage waste minimisation practices (Auckland Council 2018b).

5.3.2 Design

This subsection presents the remedial measures for all the waste minimisation challenges that occur during the design stage of a project. The design stage has six waste minimisation challenges, as discussed in section 5.2.2. The remedial measures for each challenge were found through interviews and observation.

i. Lack of life cycle thinking

The Auckland CI needs a gentle push towards life cycle thinking to deliver better results and advocate sustainable construction (B-03). Most contractors (12 out of 14) believed that life cycle thinking is a client-driven action that needs more attention from clients. In

contrast, 10 out of 12 client representatives mentioned that contractors need to educate their staff to induce life cycle thinking from material selection to on-site reuse. The life cycle thinking could be promoted if clients' and contractors' focus on the environmental and social aspects of waste rather than the economic aspect (Low et al., 2020).

All interview participants suggested that industrial diversity thinking should be encouraged to boost life cycle thinking in the Auckland CI. The industrial diversity thinking unfolds new avenues for different waste types to be used as a resource for other industries (Raouf et al., 2019). A policy influencer stated that timber and plasterboard waste is often recovered to serve other industries such as agriculture (C-10). For instance, untreated timber is chipped and used for animal bedding and waste to energy, while plasterboard waste is used to make soil fertiliser (Auckland Council, 2019). On all sites (9 out of 9), the site engineers practised industrial diversity thinking and recovery of timber and plasterboard waste.

The life cycle thinking has to be a part of the contract document (C-02). Almost all policymakers and influencers (10 out of 11), argued that the client should encourage life cycle thinking through contractual agreements. The contractual agreement that requires construction projects to achieve 6 Homestar, recommends contractors conduct a life cycle thinking of materials before selecting them (BRANZ, 2014). All the building materials from floor coverings to steel roofing needs to be selected as per the specifications to reuse or recycle at the end-of life (BRANZ, 2014). One policy influencer mentioned that clients could ask all contractors to tender for the job with their waste minimisation approaches, based on the life cycle assessment of materials. The competition among contractors brings out innovative strategic options to minimise waste. Ultimately, this contributes to life cycle thinking (Domingo, 2011).

In total, 12 out of 14 contractors suggested that Auckland CI requires policy around life cycle assessment to promote life cycle thinking for each waste stream at a wider industry level. One contractor mentioned that materials such as crushed concrete is used for different construction works but often gives low returns as low-value products are manufactured due to a lack of life cycle thinking (B-09). Another contractor added that the life cycle assessment policy could help to manufacture high-value products from crushed concrete and encourage contractors to perform life cycling thinking (B-03). The Auckland CI has a significant demand for crushed concrete. The NZTA conducted life

cycle assessment on crushed concrete to prepare technical specification for their reuse (Rotorua District Council, n.d.).

ii. Poor Waste minimisation goals

‘...we need to shift the focus to upfront design, reuse and recycle of material. Inclusion of these factors in regulation can reinforce the waste minimisation goals (B-02), but regulation is not a single silver bullet that answers all the questions. The industry practitioners need to do things voluntarily as well’ (C-02).

The literature findings showed that NZGBC had set waste diversion goals (section 2.10.3). Almost all interview participants (35 out of 37) confirmed that NZGBC waste minimisation goals are considered widely; however, they are not followed by all industry practitioners. Most client representatives (9 out of 12) mentioned that a regulation should be enforced to achieve the NZGBC waste minimisation goals. In contrast, 10 out of 11 policymakers and influencers argued that a voluntary approach is required to promote waste minimisation goals. The voluntary agreements provide flexibility to contractors, change clients' attitudes and contractors' behaviour without putting a burden on achieving waste minimisation goals (Hee et al., 2014). One policymaker mentioned that voluntary agreements are focused on realistic goals rather than aspirational goals set in regulation (C-02). Further, a policy influencer added that voluntary agreements should also set goals for designing waste, using recycled material, and material reuse (C-06). Waste management is used as a broad term in contracts anticipating material reuse, design waste minimisation. In addition, the Building code provides technical requirement for materials regardless if it's a virgin material or recycled (Building Act, 2004). On 2 out of 3 construction sites, the contractor diverted 70 % of C&D waste, while 90% of C&D waste was diverted from 1 out of 3 sites. On all construction sites, the contractor had a voluntary agreement with clients.

The interview participants (35 out of 37) stated that the project compliance should have a mandatory/voluntary clause on waste minimisation goals. In addition, clients should include waste minimisation goals as one of the KPIs for contractors (B-09). Further, the contractors can also include on-site education to site workers, recovery rate, waste sorting at the site, reuse of material and use of recycled materials as KPIs' to encourage contractors to achieve waste minimisation goals (A-03). The NZGBC gives credits to the contractors who achieve the NZGBC waste minimisation goals. The credits act as a KPIs for contractors and help them to get a Homestar rating (NZGBC, 2015).

iii. Poor material selection and overordering

‘Overordering is like parking your money. It gives no benefits. It blocks your finance, and the material occupies a lot of space on site. Instead, contractors should do precise quantity estimation and order the material Just in Time’ (A-07).

The interview responses (32 out of 37) and on-site observation (6 out of 9 sites) showed that the contractors need a project-specific inventory management plan to select sustainable materials and order them in required quantities. The inventory management plan minimises material handling damages and avoid time and cost delays (Vinodh et al., 2011). One contractor mentioned that the material selection process should be improved by adopting a holistic approach to studying materials’ life cycle (B-12). As it helps contractors to reuse the material if possible, if not, recycle or repurpose to get maximum value from it (Won & Cheng, 2017). Another contractor added that building materials’ Environmental Product Declaration (EPD), should be considered during the material selection process (B-03). Moreover, a policymaker stated that EPD shows building materials’ characteristics that a contractor should observe before buying the material (C-04). Further, a site engineer from a construction site (Alpha 1) mentioned that they had procured EPD building materials, including plasterboard, paints and recycled plastic. The ECNZ have assessed environmental and social impact of different materials, including but not limited to metal, insulation material, concrete and paint and published eco-labels for to help contractors and clients to improve their material selection (ECNZ, 2022).

In total, 30 out of 37 interview participants recommended that the contractors should appoint a dedicated team to scrutinise materials and draft detailed material specifications. A dedicated design team develops a procurement framework and conducts a rigorous material selection process to avoid unsustainable materials (WasteMINZ, 2018).

One client representative mentioned that such teams could analyse weather and transportation damage before ordering the materials (A-06). In addition, the team should guide material purchase in Just In Time (A-03). In support of JIT procurement, one policymaker discussed its cost advantages, such as low transportation costs (C-01). Further, another policymaker encouraged contractors to adopt JIT procurement for efficient inventory control and management (C-03). However, the contractors’ interview responses showed that 12 out of 14 were not in favour of JIT procurement. One

contractor mentioned JIT procurement increases their reliability on suppliers, resulting in time delays (B-13). Another contractor mentioned that the delay situation gets worst for out of Auckland jobs as they have time pressure (deadline) (B-10). Successful application of JIT varies project to project as it involves collaborative efforts from top management, suppliers and design team (Polat et al., 2017). Overall, JIT procurement needs a lot of planning, and Auckland CI practitioners need to execute it with knowledge and experience.

iv. Design out waste

‘...when you are on-site, you are fighting a losing battle of the design. So it is important to identify and minimise waste in design and save time and money on handling construction stage waste’ (A-03).

The interview responses showed that all policymakers and influencers encourage contractors to design out waste through the establishment of a design and compliance team. One policy influencer mentioned that the teams’ objective should be to eliminate waste in design, before it becomes physical waste (C-04). Further, a client representative added that the design and compliance team should manage multiple tasks such as engaging with consultants to improve design efficiency, learning advanced software such as BIM and coordinating with suppliers and manufacturers to use pre-fabricated building materials (A-07). The design team often communicate with a client on their waste minimisation framework and strategies because their interaction determines success of waste management. In addition, the design team also helps site engineer to redesign on-site resource management to optimise the resource consumption (Park & Tucker, 2017). On all construction sites, the contractors had a design team; however, on-site observation showed that physical waste (construction stage) had more consideration than design stage waste.

One policy influencer argued that the Auckland CI needs intelligent clients who demand designing out waste to reach the zero-waste goal (C-10) and 9 out of 12 client representatives supported that reasoning. Most contractors (10 out of 14) supported the argument and mentioned that client demand is a pivotal driver of designing out waste. Clients have a strong say during the design stage, and contractors often prioritise their demands. In addition, the intelligent clients thrive to achieve value from waste and encourage contractors to adopt innovative waste minimisation approaches (Harris et al., 2021). In addition, 9 out of 11 client representatives mentioned that approaches such as

design for deconstruction, accurate design documents and efficient procurement should be used to minimise waste in the design stage. Interestingly, literature findings (section 2.9.3) also confirmed that these approaches are useful to minimise C&D waste in the design stage.

v. Use of Waste Minimisation Act 2008

‘What is low on the waste management hierarchy should not be practised, and high on the hierarchy should be incentivised. The Auckland Council and private sector really need a partnership to successfully implement WMA’ (B-02).

The Auckland CI needs to improve the current status of the waste management hierarchy, product stewardship and waste levy through a wide-ranging industry-council partnership (C-02). In total, 30 out of 37 interview participants believed that education on WMA could develop a long-term partnership between Auckland Council and the private sector. Auckland Council is educating contractors on WMA and supporting work schemes related to improving industry practices of the waste management hierarchy (Auckland Council, 2018b). In addition, the council also supports innovative approaches such as remanufacture and repurpose as an add-on to the waste management hierarchy (Auckland Council, 2019). Another policymaker from MfE, mentioned that government encourages businesses that collect waste through a take-back policy and practice product stewardship (C-07). On 6 out of 9 sites, the site engineers/demolition contractor successfully implemented the waste management hierarchy. Materials such as plasterboard and timber were reused and recycled. Further, the site engineers and polystyrene manufacturer partnered and implemented a product stewardship scheme on all construction sites.

The client representative category had a mixed response to the council's actions. In total, 5 out of 12 participants expressed uncertainty on the scale of the actions. While 7 out of 12 participants considered the actions as early positive steps toward WMA implementation. The majority of contractors (10 out of 14) considered the waste levy responsible for the poor implementation of WMA. The same majority of contractors consider the increase in waste levy as a remedy for the successful implantation of WMA. The low waste levy motivates contractors to skip top approaches of the waste management hierarchy. Therefore, NZ government increased the landfill levy (MfE, 2020).

vi. Standardisation and pre-fabrication

‘Poor material consumption is a symptom of waste generation. Pre-fabricated materials such as pre-nail roof trusses, modular kitchen and door and wall panels are a solution to waste minimisation’ (C-01).

Standardisation and pre-fabrication significantly contribute to waste minimisation (section 2.8.2). In total, 28 out of 37 interview respondents suggested that the Auckland CI should focus on using standardised and prefabricated building components, to minimise waste. One contractor mentioned that prefabricated materials such as roof trusses, bathroom ware, modular kitchen and door and wall panels are used by Auckland contractors to practice waste minimisation (B-13). In addition, standard size building components are also used for similar builds (B-10) which would reduce 85% of construction waste in the design stage (Olanrewaju & Ogunmakinde, 2020). Another contractor added that though the industry interest in standardised and prefabricated building materials has increased in the last few years, contractors' willingness, followed by client demand, needs industry attention (B-02). Contractors and clients often avoid prefab materials due to higher transportation cost and inflexibility to design changes during construction (Olanrewaju & Ogunmakinde, 2020).

The onsite observation showed that the contractors used prefabricated roof trusses on all construction sites. Further, on 1 out of 3 refurbishment sites, the contractor used a pre-fabricated modular kitchen.

A policy influencer mentioned that CI's orientation towards prefabricated building materials is not influenced by one factor rather a combination of multiple factors, such as site conditions, availability of materials in specific sizes, and productivity of off-site manufacturing plants as per industry demand (C-01). Further, 10 out of 11 policymakers and influencers suggested that contractual agreement is one of the remedies to promote prefabrication. The contractual agreement between client and contractor shows demand and willingness for standardisation and prefabrication (Harris et al., 2021). A client representative suggested using software applications such as BIM to understand actual site conditions and use a quantity survey that allows more use of standard-sized building components (A-03). In addition, BIM should be used to connect architects with site engineers to replace on-site components with pre-fabricated components (Moayeri, 2017). The on-site observation showed that no sites used BIM; however, site engineers from all construction sites showed interest to use BIM for future projects. In total, 20

out of 37 interview respondents mentioned that Auckland Council and MfE should provide technical and financial support for businesses willing to build new off-site manufacturing plants. Standardisation and prefabrication cannot be a commonplace practice in the Auckland CI without councils' support and industries' acceptance (C-09). Auckland Council's building consent authority helps prefab companies to develop a Product Technical Statement to get certification to meet the Building Code requirements (Auckland Council, 2022).

5.3.3 Construction

The construction stage has four key waste minimisation challenges. In addition, the refurbishment stage has two major challenges for Auckland CI. The remedial measures for each challenge are discovered through interviews and observation.

i. On-site sorting of waste and contamination

The NZGBC mandate three separate bins for on-site sorting of waste. However, contractors (12 out of 14) argued that due to lack of space, the goal of on-site sorting is often not accomplished. In total, 13 out of 14 contractors suggested that the site engineer needs to redraw the material management plan to create on-site space for multiple bins. The material management plan includes the material storage layout which is updated after completing each activity (e.g. wall framing, internal wall lining) to use maximum space on-site for multiple bins (Olanrewaju & Ogunmakinde, 2020). Further, a policy influencer suggested that contractors should manage waste bins based on project activities (C-08):

- Foundation activity: 1 hardfill waste bin and 1 general waste bin
- Framing activity: 1 timber waste bin and 1 general waste bin
- Internal Wall lining activity: 1 plasterboard waste bin and 1 general waste bin

Another policy influencer added that contractors could use smaller bins of 3m³ size instead of typical 9m³ bins in a limited space condition (C-08). Green Gorilla provides the 3m³ 'Gorilla Bags' with 1.25 tonne weight capacity to avoid lack of on-site space issues and practise waste sorting. In 2016, Green Gorilla recycled 4000 tonnes of plasterboard by collecting it separately (Green Gorilla, 2022).

The on-site observation showed that all 3 construction sites had two bins. On 2 out of 3 construction sites, the contractor used plasterboard bags to collect plasterboard

separately. Further, on 1 out of 3 refurbishment sites and 1 out of 3 demolition sites, the contractors had only 1 bin.

A client representative stated that site labourers need to be educated on waste sorting and contamination through workshops and meetings (A-05). Contractors can educate site labourers through training sessions and other modes of interaction such as tool-box meetings (35 out of 37 participants). Tool-box meetings are a common practice in the Auckland CI to discuss themes including but not limited to, construction processes, methodologies, material management, waste, hazard control and safety (SiteSafe, 2017).

A recycling facility manager mentioned that waste sorting generates a lot of profit (C-11) by saving the virgin materials cost (when reused and recycled) and by saving waste disposal cost (through diversion from landfill)(Low et al., 2020). Pallet wrap waste is one of the notable contributors to timber waste (Junk Run, 2022). Spending 15 min on sorting pallet wrap at the site can save hundreds of dollars at recycling facilities (C-10). Another recycling facility manager stated that contractors should be educated on processing time, cost, and profits for the general waste bin and the sorted waste bin (C-09). Sorted waste bins require less time and more recovery than general waste bins (Huang et al., 2018). One policy influencer claimed that more recovery happens, as the sorted bins are not contaminated (C-07).

The interview respondents (10 out of 14) from the contractors' category suggested that education regarding on-site sorting and contamination should be provided through an educational curriculum. For instance, waste minimisation through on-site sorting needs to be included in courses offered by Construct Safe and Site Safe (B-09). Site Safe's Environmental Site Management course developed in partnership with Auckland Council offers knowledge on on-site waste management to residential builders and sub-contractors (SiteSafe, 2022). Another contractor added that educational courses assist better understanding of on-site sorting and its benefits (B-10).

All policymakers and influencers pointed out the importance of waste sorting and urged contractors to identify sorting benefits for themselves and waste recyclers. Further, the contractors (11 out of 14) suggested educating industry practitioners through educational courses. Overall, on-site waste sorting is present in the discussions and practices in the Auckland CI.

ii. Waste reporting and sense of responsibility

‘The contractors need to establish a waste management unit to analyse the waste reports and identify activities with high waste generation. Such unit displays a sense of responsibility and help contractors to rewire the process’ (B-08).

Transparent waste reporting shows the real size of the problem and creates a sense of responsibility (UNEP, 2015b). In total, 35 out of 37 interview participants recommended transparent waste reporting through REBRI templates to encourage waste minimisation. One client representative mentioned that the contractors need to work with waste handling services to understand the C&D waste generation (A-06). A waste collector mentioned that they monitor waste closely and provide waste statistics on multiple waste streams (C-08). Waste handling services such as Junk Run provides detailed waste reports on all waste streams with their weight, volume and disposal information for contractors to claim for the waste diversion credits (Junk Run, 2022).

The contractors need to demand waste statistics from the waste collectors at the regular project intervals (B-02). One contractor stated that waste generation knowledge (stage by stage) could help contractors to review their processes and improve their waste minimisation practices (B-04). Waste reporting of each stage allows a contractor to identify priority waste streams and discuss and implement their remedial measures (Domingo, 2011). The on-site observation showed that on all sites, the contractors received the waste statistics for priority waste streams such as timber, plasterboard, hardfill and metal.

A contractor mentioned that at a wider industry level, precise waste reporting needs to be done by Auckland Council (B-11). Another contractor added that it is important to put the waste statistics in the public domain and share them among all industry practitioners to develop a sense of responsibility (B-06). The Auckland Council published their first Waste Assessment report in 2017 and stimulated CI practitioners thinking on C&D waste minimisation to achieve zero waste goal by 2040 (Auckland Council, 2017).

iii. Identification and quantification of waste streams

‘...knowing the composition of waste is similar to winning half of the battle of waste minimisation. Waste tracking should be a part of a daily progress report which tabulates material ordered, material consumed and material wasted’ (A-03).

The contractors should be aware of how much waste they are generating from a single house, perhaps from each stage of the house (A-07). All policymakers and influencers supported the act of daily recording of waste streams through photographic evidence. One contractor mentioned that the current industry practices should include real-time waste tracking (B-05). Advanced approaches such as remote sensing, image processing and eBins with BIM application can be used to track daily waste generation in real time (Shooshtarian et al., 2020). The on-site observation showed that only 3 out of 9 sites tracked the waste. In particular, 2 out of 3 construction sites and 1 out of 3 refurbishment sites tracked the waste and implemented waste minimisation approaches. For example, the plastic and cardboard packing from construction sites were quantified and recycled to minimise waste.

One demolition contractor mentioned that waste audits need to be conducted at regular project intervals to track waste efficiently (B-12). A client representative argued that waste tracking should be included as a mandatory clause in a contractual agreement to encourage waste minimisation (A-03). In total, 16 out of 37 interview participants supported the argument. However, 21 out of 37 participants considered that voluntary agreements should be sufficient to promote waste tracking and, ultimately, waste minimisation. Construction projects with 6 Homestar requirements includes development of a site-specific waste management plan. The plan helps contractors to identify and quantify different waste streams and decide their waste minimisation approach(es) (BRANZ, 2019b).

iv. Social values of waste

The contractors often do a quick throw away of waste and damage the environment without realising the social benefits that could be achieved from waste diversion (NZGBC, 2015). In total, 30 out of 37 interview participants mentioned that the social benefits of diverting waste, such as employment and positive environmental impact, needs to be advertised through workshops and conferences. Further, almost all policymakers and influencers (10 out of 11), preferred community engagement programmes to educate CI practitioners on the social values of waste. In addition, 10 out of 12 client representatives mentioned that contractors should arrange on-site training sessions for site labourers to promote social values of waste. The Auckland CI contractors educate site labourers through Toolbox meetings and training sessions (SiteSafe, 2017).

The majority of participants from client representatives (9 out of 12) and contractors (12 out of 14) category mentioned that visualisation of waste, its impact and the social benefits of waste minimisation should be promoted through Auckland Councils WMMP and Waste Assessment. Auckland Council's 2018 WMMP considered social benefits of waste minimisation such as public health and safety, community participation, jobs and sense of pride of Aucklanders and developed their Action Plan to minimise C&D waste. In addition, the Council set community engagement programmes as one of the key actions in their WMMP (Auckland Council, 2018a).

v. Environmental Impact

The environmental impact of refurbished materials is often neglected due to a lack of awareness of their reuse or recycling (A-02). All policymakers and influencers suggested that the Auckland CI should demand compliance on reusing and recycling the refurbishment waste. The refurbished waste could be reused by setting quality standards for refurbished materials (C-01). The NZTA and The aggregate Quarry Association has set standards for recycled crushed aggregates and similar initiatives are required for all building materials (Rotorua District Council, n.d.). Further, 12 out of 14 contractors proposed to include criteria relating to reuse of refurbishment materials, in contractual documents. The waste minimisation is often mentioned in the contracts and subcontracts, however clients don't see the reuse as an effective approach due to quality of material/contamination and demand from clients (Hardie et al., 2011).

All client representatives recommended to conduct educational events to change contractors' behaviour, clients' perception and labourers' attitude towards the refurbishment waste. As mentioned in section 2.10.2, the territorial authorities e.g. Auckland Council are setting waste minimisation learning units to educate CI practitioners and change their attitude towards waste minimisation. In total, 25 out of 37 interview respondents advocated that Auckland CI, especially Auckland Council, should support businesses that promote reuse and perform recycling of refurbishment waste. The Council provides financial help to resource sharing businesses such as CivilShare (Auckland Council, 2020b).

vi. Availability of resources

The refurbishment contractors need to invest more resources to process and recover refurbishment waste (C-08). A client representative mentioned that time and cost

required to obtain reusable materials from refurbishment waste, should be shared among clients and contractors (A-01). As a result, the burden and responsibilities of minimising refurbishment waste are shared (NZGBC, 2021). In total, 32 out of 37 interview participants agreed to share the collection and processing cost of refurbishment waste. Further, 10 out of 12 client representatives suggested creating a network of contractors, recyclers and clients, to increase the promotion of recycled materials obtained through refurbishment waste. The recycling network stimulates the demand of recycled products and increase waste diversion from landfills and cleanfills (Parker, 2022). In addition, 11 out of 14 contractors advocated that the territorial authorities should incentivise the recycling facilities that process refurbishment waste. The Auckland Council and MfE provides research grants for the feasibility of recycled products and also incentivises new entrants in C&D waste recycling industry (Auckland Council, 2019).

5.3.4 Demolition

The demolition stage has nine challenges, as discussed in section 5.2.4. The Auckland CI has been practising demolition waste minimisation for a decade. This sub-section presents different demolition waste minimisation approaches as remedial measures for the challenges faced.

i. 10R

The Auckland CI practitioners use different waste minimisation approaches but need to improve the approaches' scale (B-10). In total, 8 out of 12 client representatives advised contractors to focus on the refuse and rethink the approach. The contractors should refuse using non-recyclable building materials and rethink to make sustainable building materials (Hardie et al., 2011). One client representative suggested that the contractors should select carpets made from recyclable fibres such as Nylon or olefin (A-10). A policy influencer from Callaghan Innovation mentioned that their organisation supports the business that practises rethink approach (C-01). For example, Callaghan Innovation provides technical and financial support to a business that makes insulation products from hemp, a bio-based sustainable material (Callaghan Innovation, 2013).

The Auckland CI has a history of reusing building materials. In the past, big contractors used to store excess materials in backyards and reuse it for the next projects (A-07). Nowadays, contractors use online applications such as Civil Share, Trash and Treasure Facebook pages and Trademe to reuse building materials (Auckland Council, 2019). All

interview participants from the contractors' category recommended online applications for resource sharing. On all demolition sites, waste such as timber was reused. Further, on all construction sites, timber off-cuts and scaffolding were reused.

In total, 35 out of 37 interview respondents claimed that materials such as repurposed carpets and plasterboard have a secondary market. A recycling facility manager stated that the Auckland CI needs to invest in infrastructure for remanufacturing building materials (C-11). A case study from of the “Whole House Reuse’ project (Christchurch) showed that remanufactured products such as artwork from timber have potential to create a secondary market in the NZ (Zaman et al., 2018).

A recycling facility manager stated that the Auckland CI should create a network of remanufacturing and recycling facilities to promote waste minimisation (C-09). Further, one contractor expressed the need to set engineering standards for low-value products made from timber, concrete, glass, plastic and plasterboard waste (B-11). Material quality standards drives demand for second life products and expand the secondary market (Zaman et al., 2018).

Another contractor mentioned that repurposing requires innovative thinking, and recycling requires incentives and support (B-03). Almost all policymakers and influencers (10 out of 11) encouraged the commercialisation of innovative waste minimisation ideas. The Callaghan Innovation is currently supporting businesses to commercialise the ideas such as using plastic waste in concrete, plastic waste to make bricks and aggregates (C-01).

All interview participants expressed that Auckland CI practitioners should aim to give second and third liveso waste materials by using 10R (Refuse, Rethink, Reduce, Reuse, Repair, Relocate, Remanufacture, Repurpose, Recycle and Recover) thinking. Some of the current practices of 10R are (Auckland Council, 2018b, 2019):

- Reuse of concrete, timber, plastic, polystyrene, ceiling tiles;
- Extraction of lime from gypsum board to use as a fertiliser for agriculture industry;
- Crushed concrete to fill base for the road;
- Use of plastic bottle waste to make road;
- Plastic waste to replace (at some extent) sand and concrete and;
- Manufacturing of bio-based plastic façade.

All participants considered 10R thinking as an effective waste minimisation solution, but it is only possible if CI practitioners use green materials to increase material recovery through different approaches (C-10). In addition, the CI need more Research & Development to check the feasibility of different waste minimisation approaches at the local level (Callaghan Innovation, 2013).

ii. Waste levy

‘... cautiously optimistic that an increase in waste levy will divert more waste from landfills. Back in the past, when the levy was raised, some people thought it would negatively impact. For a peak of 3 months, illegal dumping was high but then became normal’ (C-07).

The NZ government is increasing the waste levy, which is expected to be a positive step towards waste minimisation (MfE, 2022). One contractor mentioned that the increase in levy would bring behavioural changes among contractors to divert more waste from landfill (B-08). With the increased levy, all interview participants expressed the need for compliance and monitoring to avoid the illegal dumping of C&D waste. The majority of interview respondents (32 out of 37) supported the governments’ decision on the C&D waste landfill levy. One policy influencer stated that introducing a waste levy to C&D waste fields would help CI practitioners practice waste minimisation (C-03). In addition, a higher C&D waste levy can help contractors to see the opportunity and value in waste (MfE, 2022). Further, a policymaker from MfE mentioned that the increased levy could fund more waste minimisation initiatives (C-07). The increase in levy comes with an assumption of reduction in waste (C-02) and assurance on supporting innovative businesses that promote circular economy (MfE, 2020).

iii. Secondary market

‘It is easy to identify opportunities but hard to find viable opportunities. The secondary market is a product of a chain reaction. The waste collector collects the waste, the recycler makes second life products, the distributors promote the products from their shelves, the client sees the product's benefits and asks the contractor to procure the products’ (B-08).

The Auckland CI has the potential to scale up the secondary market in Auckland (Auckland Council, 2019). One contractor mentioned that it is possible to expand Auckland’s secondary market if recycled building materials qualify with industry requirements and generate profit for the recycler (B-09). All interview participants acknowledge the increasing demand for second life products made from timber, steel

and plasterboard. In particular, crushed concrete has the largest secondary market in Auckland (Rotorua District Council, n.d.). A recycling facility manager argued that the secondary market depends on recycling, and the recycling depends on demand from the clients (C-11). The distributors should promote the recycled materials through conferences or community engagement events (B-04). On all construction sites, the contractors used recycled cardboard and plastic for material packaging.

The majority of client representatives (9 out of 12) suggested that the CI practitioners need to focus on the design life of materials. It is important to conduct materials' life cycle assessment to make feasible second life products (Shooshtarian et al., 2020). A client representative added that clients prefer to buy second life material if they have been offered a choice (A-07). The Auckland Council support businesses that recycle, innovate, educate clients and are committed to diverting the waste (Auckland Council, 2019).

iv. Recycling infrastructure

‘Timber, steel and cardboard are low hanging fruit and easy to divert from landfill considering the current recycling infrastructure. However, we need to invest more in the recycling infrastructure to maximise recovery. In addition, new recycling facilities should be incentivised at least to cover their first year's operation cost' (B-03).

The success of different waste minimisation regulations, laws and Acts depends on the availability of the recycling infrastructure (UNEP, 2015b). In total, 8 out of 11 policymakers and influencers suggested that the performance of existing recycling infrastructure should be assessed to understand the demand for new infrastructure. Further, the public-private partnership should encourage general (organic) waste recyclers to start recycling C&D waste (Auckland Council, 2019). One recycling facility manager mentioned that the waste recyclers should see waste as a commodity (C-11). In addition, profit on recycled products could increase the investment in recycling infrastructure (UNEP, 2015b).

Most contractors (10 out of 14) suggested that MfE and Auckland Council should use waste levy from landfill to incentivise existing recycling facilities. In 2020, NZ government invested NZD 124 million in recycling infrastructure to reduce waste. Green Gorilla, one of the C&D waste recyclers, received NZD 3.1 million for the expansion of their innovative waste recycling facility (Beehive.govt.nz, 2020). One

contractor mentioned that the waste levy from C&D waste could fund new recycling/remanufacturing facilities (B-03). Another contractor added Auckland Council should provide technical support to new businesses to build new recycling infrastructure (B-06).

v. Waste cost

‘The human tendency is to go for an affordable option, but clients buy a recycled product if they can afford them. It is a bit cynical, but big construction companies care for money. Creating value out waste with equal quality and the equal cost is a challenge and opportunity’(C-04).

The Auckland CI needs a viable business model to create affordable and sustainable recycled materials (Callaghan Innovation, 2013). One contractor mentioned that a recycling business survives if it produces sustainable building materials at reasonable prices (B-11). In total, 10 out of 11 policymakers and influencers recommended the Product Stewardship Scheme to share waste minimisation responsibilities and make low-cost sustainable materials. The Product Stewardship Scheme is useful to improve the efficiency and effectiveness of waste management (Low et al., 2020). A policy influencer stated that material, waste handling, and recycling costs should be shared among manufacturers, contractors, and waste recyclers (C-03). The on-site observation showed that the Product Stewardship Scheme was used for polystyrene waste on all construction sites. Almost all interview participants (35 out of 37) showed positive intent to include other building materials under the scheme.

vi. Role of public and private institutes

‘Equal pain needs to be experienced by everyone, including contractor and manufacturer. Contactors should sort the waste, and the manufacturer should remanufacture it. The equal pain gives equal responsibilities’ (C-04).

The interview responses from all participants provided three key themes that required public and private institutions’ attention. The themes were: extended producers’ responsibilities or Product Stewardship Scheme; Community recycling centres; and Building certification standards. In total, 35 out of 37 interview participants encourage CI practitioners to implement a take-back policy. In developing countries, such as in Africa, local NGOs, partner with private recycling companies to share resources and divide waste responsibilities. It helps them to implement take-back policy and create resale value for materials such as bricks, stones and concrete slabs (UNEP, 2019).

The material supplier (manufacturer) should establish a return depot to provide drop-off facilities for end of life materials (B-02). For instance, the Brazilian CI practitioners have established voluntary collection points for glass, plastic and paper across the country to improve waste collection and recycling (UNEP, 2018b).

Companies such as EXPOL had collection bins across Auckland to collect Polystyrene waste (EXPOL, 2021). Similar initiatives were taken for other waste streams such as old carpets (Jacobsen Creative Surfaces), plasterboard (Green Gorilla), bathroom ware and timber (Waste Management Ltd) (BRANZ, 2019b). The Auckland CI practitioners needs to improve the scale of take-back policy (35 out of 37 participants). The take-back policy for different waste streams needs to be promoted through voluntary schemes (Envirocon NZ, 2022) .

The Auckland region has five community recycling centres and requires more to process different waste streams (Auckland Council, 2019). In total 30 out of 37 interview participants recommended an incentive policy to build new community recycling centres. In South Africa, local government organisations provide financial support to private sector to build recycling centres (Aboginije et al., 2020). The Auckland Council financially supports C&D waste minimisation research projects and recycling businesses through their Waste Minimisation Fund (Auckland Council, 2019). In addition, NZ government provided NZD 1.1 million to Waste Revolution (a collaborative initiative between Junk Run and Kiwi Recycling) to create resource recovery centre in the Auckland (Parkar, 2022). The public-private institutions' partnership should also fetch CI practitioners' attention towards recycled materials (B-10).

All client representatives expressed the need for building certification standards to promote waste minimisation. In total, 31 out of 37 interview participants recommended that the public and private entities should conduct surveys to ask participants (contractors) about their experience with building certification standards and publish the findings to encourage other contractors (C-06). The literature findings in section 2.6.5 showed that building certification guidelines are often based on industry practitioners' experiences. The on-site observation showed that the contractors received the 6 Homestar certificate for all construction sites. The NZGBC encourages CI practitioners to adopt the rating system for their newbuilds. In addition, Kainga Ora collaborates with NZGBC, Scion and BRANZ to adopt 6 Homestar rating on their social housing

projects. Further, Kainga Ora is working on its pilot 9 Homestar project in Auckland (Kainga Ora, 2022).

vii. Resource recovery and margins on second life products

The Auckland CI needs to create a resource recovery hub with a variety of facilities for commercial business (Auckland Council, 2019). The interview respondents (32 out of 37) recommended industry and council partnership promotional events to create a recovery hub. Internationally, partnership of local governing organisations and private sector have created awareness about secondary market but still needs more promotion to achieve zero waste goal (Ali et al., 2019). Promotional events helps to advocate material recovery, promote recoverable materials and increase consumer awareness about second life products (Palmerston North City Council, 2019). Timber and plasterboard off-cuts were recovered to minimise waste on all construction sites.

A recycling facility manager mentioned that the margins on recovered products depending on the quality of products and industry demand (C-11). In total, 30 out of 37 interview participants were in favour of specifications or certification for recovered products. One client representative mentioned that the public and private sectors could create material recovery guidelines to increase the profit margin for recovering facilities (A-03). For instance, native timber has high recovery value, but it gives low profit if used as a bio-fuel instead of repurposing (A-01). Further, if fire retardant timber is repurposed, it gives low profit, as the use of timber has limitations (A-07). Therefore, the guidelines will help recovery facilities to choose the correct recovery method and earn profits through industry demand (Palmerston North City Council, 2019).

viii. Application of deconstruction

‘...deconstruction is like common sense. Instead of welding two plates, it is easy to screw and unscrew them and later use them as and when required. Deconstruction needs skillset and action plan’ (C-04).

The Auckland CI practitioners reuse, recycle and repurpose the materials obtained through deconstruction (BRANZ, n.d.). All interview participants claimed that deconstruction elevates social, economic and environmental standards. A case study of 6 multi story residential units from Florida, USA showed that deconstruction reduced disposal cost by 41% per house. In addition, cost of deconstruction with salvage value was 37% lower than demolition cost (Guy & McLendon, 2000). In NZ, deconstruction holds the potential to become the cornerstone of the secondary market (Auckland

Council, 2019). In total, 35 out of 37 participants expressed the need for deconstruction promotion through community engagement events. The Auckland Council reuses the second life construction materials on council-led projects to promote deconstruction and set up an example for CI practitioners (Auckland Council, 2019).

Further, 30 out of 37 respondents suggested that training courses for contractors should be conducted to develop their skillset. In addition, the current training courses need to include resource planning to improve waste recovery (SiteSafe, 2022). The on-site observations showed that from 2 out of 3 demolition sites, the contractors recovered roof tiles, old timber and steel through deconstruction.

ix. Waste Management and Resource Recovery plans

Waste Management and Resource Recovery plans should be implemented for waste minimisation (BRANZ, n.d.). In total, 35 out of 37 interview participants suggested that the REBRI templates need to be included in contracts. Further, 29 out of 37 interview participants recommended that the resource consent process should include Waste Management and Resource Recovery plans. The on-site observation showed that all construction sites and 2 out of 3 demolition sites had Waste Management and Resource Recovery plans. Further, none of the refurbishment sites had Waste Management and Resource Recovery plans. Due to the lack of demand for refurbished waste, contractors often neglect the Waste Management and Resource Recovery Plans. Hence, it is important to change contractors, and clients, perceptions about refurbished waste (BRANZ, 2014).

All contractors responded that the Auckland Council and MfE need to conduct workshops to develop project-specific Waste Management and Resource Recovery plans. The literature findings in section 2.10.2 showed that all city councils, including the Auckland Council, set resource recovery as one of the key goals and is taking actions to promote it. In total, 9 out of 14 contractors and 8 out of 12 client representatives suggested seeking international practices to promote the plan. One client representative mentioned that the UK government had published Site Waste Management Plan Regulations to help contractors prepare a Waste Management Plan (A-01). Similar regulations need to be adopted in the Auckland CI (A-01). However, in 2013, the UK government repealed the regulations to reduce regulatory burdens on businesses (DEFRA, 2013). Therefore, the majority of participants (32 out of 37) argued that the Auckland Council needs to conduct a feasibility study on the application

of such regulations in Auckland and subsequently introduce its local version for the Auckland CI practitioners.

5.4 Waste minimisation framework

The waste minimisation challenges and their remedial measures are combined to develop a waste minimisation framework. The interview responses and on-site observation identified the state-of-the-art of waste minimisation challenges. Subsequently, the challenges were classified into five stages (pre-design, design, construction, refurbishment and demolition). Remedial measure(s) for each challenge were discussed during semi-structured interviews and observed during site visits. Figures 5.1 and 5.2 show the connection of each challenge to their remedial measures and proposed waste minimisation framework for Auckland CI.

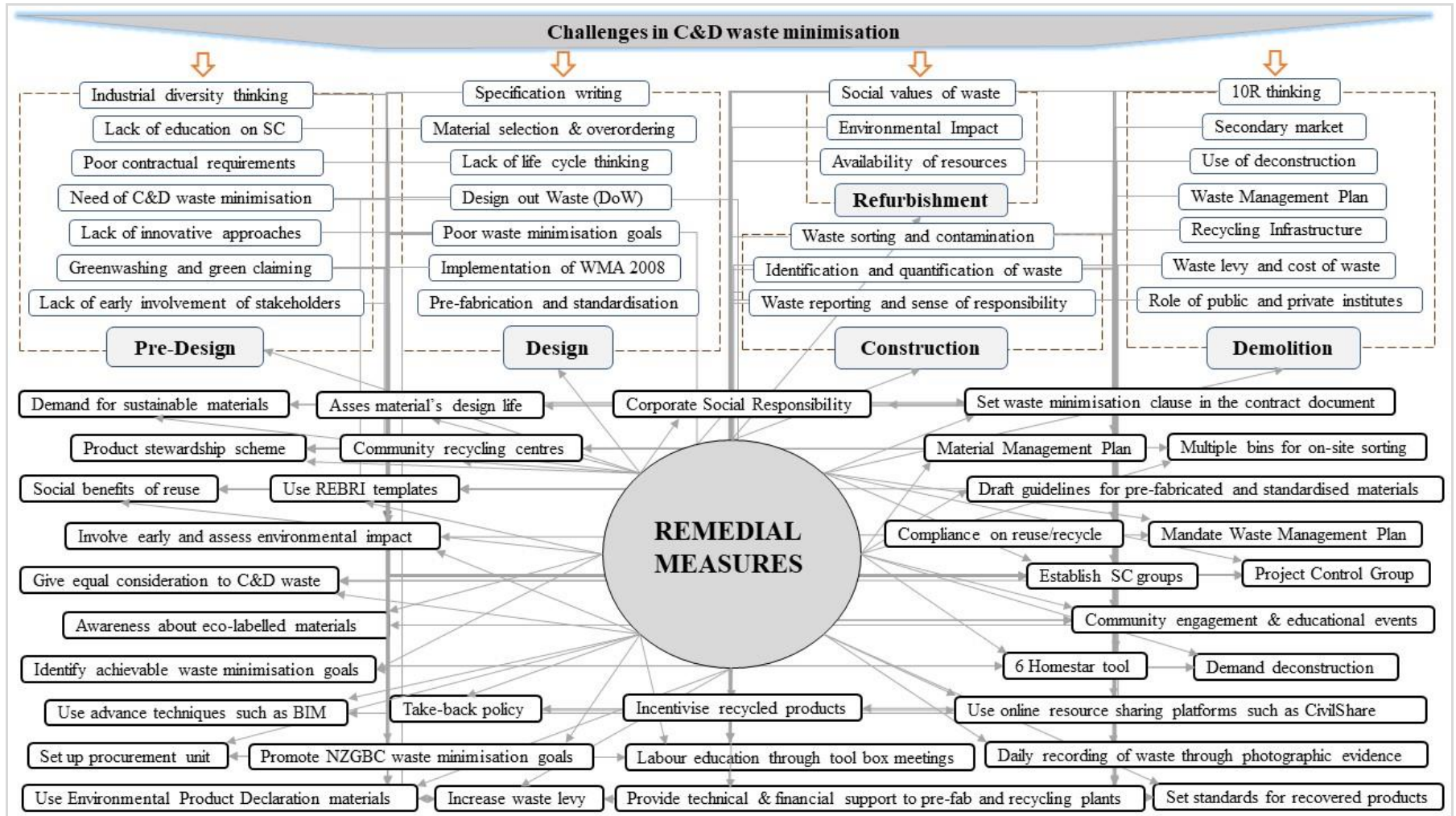


Figure 5.1: Waste Minimisation Framework

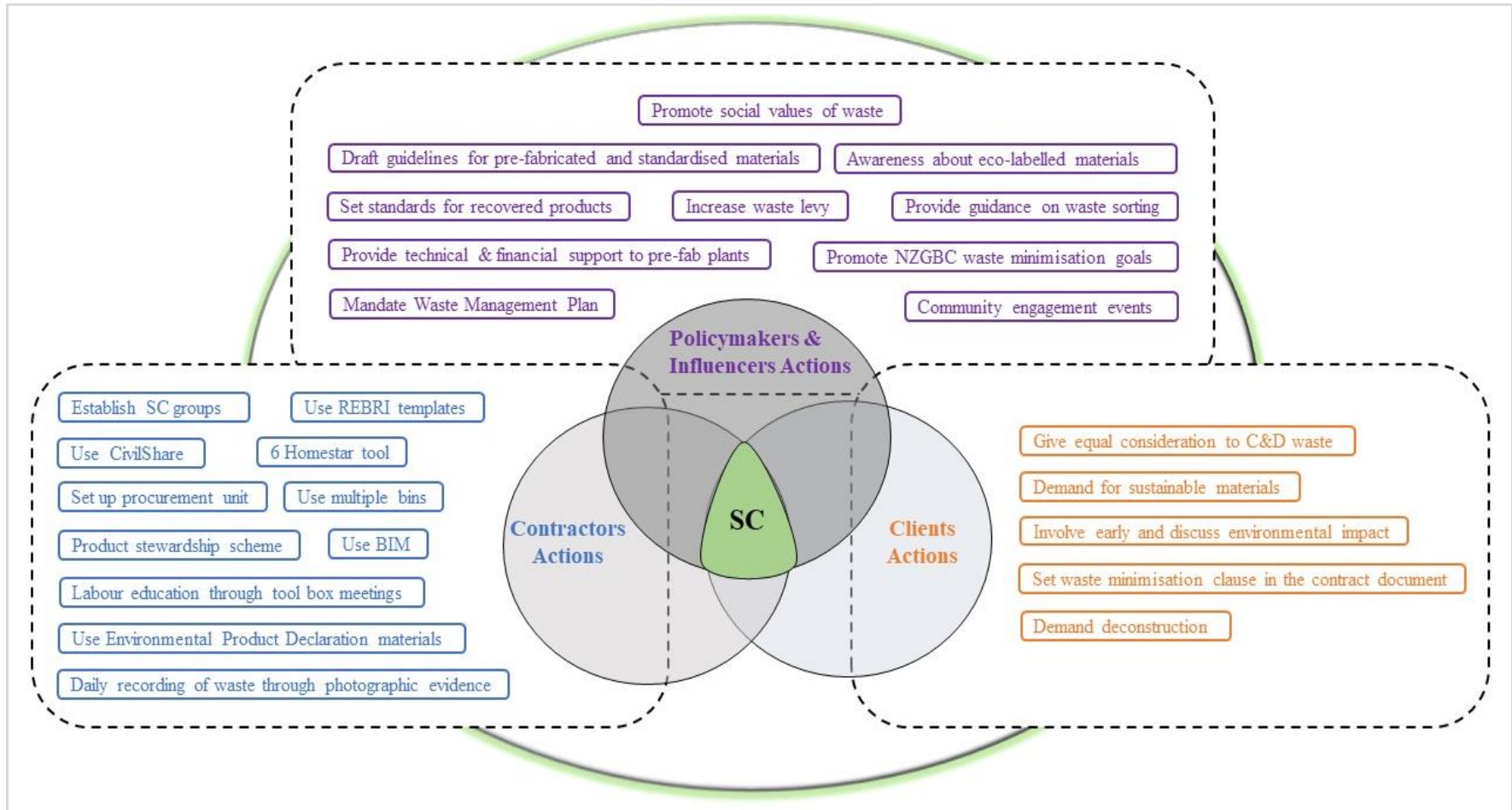


Figure 5.2: Waste Minimisation Framework

Figure 5.1 shows that the circle of REMEDIAL MEASURES sent five arrows to five stages (pre-design, design, construction, refurbishment and demolition). Subsequently, an arrow goes from each challenge to its remedy. Multiple arrows are sent from a challenge if it has more than one remedy. Further, each remedy is connected to the circle of REMEDIAL MEASURES.

It can be seen from Figure 5.1 that each challenge has one or more than one remedy. For instance, the lack of industrial diversity thinking should be addressed through the demand for sustainable materials, the establishment of SC groups and community engagement workshops. Further, poor material selection and overordering challenges need to be eliminated by setting up a procurement unit, selecting eco-labelled materials, using BIM, and assessing materials' design life. Similarly, some remedies were used to address multiple challenges. For example, product stewardship schemes stimulate 10R thinking, reduce waste costs, and expand the secondary market. In addition, REBRI templates help contractors to develop waste management plan, resource management, waste audits and resource recovery plan.

Figure 5.2 shows actions required from client representatives, contractors and policymakers and influencers. One group's actions should be acknowledged by the other two groups for their successful implementation. For instance, if policymakers decided to fund community recycling centres and recovery facilities, the client representatives need to demand sustainable materials, and contractors need to perform on-site sorting. Further, if contractors sort waste on-site, policymakers need to set technical standards for reuse and recycle products. Clients' representatives should allow the use of recycled products on their property. In other words, action from one party should be supported by the other two parties to achieve SC through waste minimisation.

5.5 Chapter summary

This chapter presented the challenges and opportunities in C&D waste minimisation in Auckland CI. Subsequently, remedial measures for each challenge identified through semi-structured interviews and on-site observations, were discussed. Further, the chapter proposed a waste minimisation framework and discussed actions required from clients representatives, contractors and policymakers and influencers to minimise C&D waste in Auckland.

Waste minimisation challenges were noted throughout the life cycle, i.e. pre-design, design, construction (and refurbishment) and demolition. Four key challenges in the pre-design stage (poor contractual requirements; greenwashing and green claiming; lack of early involvement of stakeholders; and lack of education and innovation), were discussed to understand their impact on waste minimisation. During the design stage, the most crucial challenges for Auckland CI were lack of life cycle thinking, poor waste minimisation goals, material selection and over-ordering; DoW; Implementation of WMA (2008), and pre-fabricated and standardised materials.

Further, the construction and refurbishment stages had four and two challenges, respectively. The construction stage challenges were lack of on-site sorting, poor waste reporting, poor identification and quantification of waste. In addition, a lack of importance for social values of waste contributed to higher construction waste. During refurbishing buildings, poor consideration of the environmental impact of refurbished materials and lack of resources to recover reusable and recyclable materials hinders waste minimisation. The interview responses and on-site observations showed that the demolition stage had the highest (nine) number of waste minimisation challenges. The challenges were: the absence of 10R thinking, low waste levy, limited secondary market, lack of recycling infrastructure, high waste cost, poor public-private partnership, low profits on recovered materials, less demand for deconstruction and lack of waste management and resource recovery plans.

The discussion on each waste minimisation challenge highlighted the need for C&D waste minimisation. The data collected during semi-structured interviews and on-site observation, offered remedial measures for each challenge. For pre-design stage challenges, the key remedies are increasing client demand for sustainable materials, using eco-labelled materials by contractors, introducing a mandatory or voluntary waste minimisation clause in contract document, and establishing a project control group (PCG). Subsequently, the design stage challenges need to be addressed by using advanced technologies such as BIM; setting up procurement unit and SC group; introduced guidelines for pre-fabricated and standardised materials use, and conducting educational events to promote WMA (2008). Further, waste minimisation challenges that occurred during the construction and refurbishment stage should be solved by using REBRI templates for waste reporting, daily recording of waste, use of CivilShare, equal consideration to C&D waste, mandatory waste management and material management plan and implementation of the product stewardship scheme. Remedial measures for

demolition stage challenges are: establishing new community recycling centres, increasing waste levy, setting technical standards for recovered products, demand for deconstruction, implementing a take-back policy, assessing the design life of materials, incentivise recycled materials, providing financial support to recycling facilities, and practice extended producers' responsibilities.

C&D waste minimisation challenges and their remedies obtained through semi-structured interviews and on-site observation, matched with the literature findings. For instance, literature review and semi-structured interviews both identified industrial diversity thinking in the pre-design as a crucial challenge for C&D waste minimisation in NZ. Further, in the demolition stage, application of deconstruction to minimise C&D waste was noted as a remedy in literature and interview responses. In addition, on-site observations witnessed the need for industrial diversity thinking to process the deconstructed materials.

The compilation of waste minimisation challenges and their remedial measures proposed a waste minimisation framework for the Auckland CI. In addition, the framework shows actions required from clients' representatives, contractors and policymakers and influencers to achieve SC through waste minimisation.

Chapter 6 Conclusions and Recommendations

6.1 Introduction

This chapter outlines conclusions and recommendations of this research informed by the research findings. The first section reviews the research aim and objectives and discusses methods used to accomplish those objectives. Subsequently, key contributions of this research to existing literature and industry practices of C&D waste minimisation, is discussed. The chapter then offers recommendations to construction industry practitioners, policymakers and future researchers to advocate SC through C&D waste minimisation. Finally, the chapter provides the thesis concluding remarks.

6.2 Review of Research Aim and Objectives

The aim of this research was to propose a C&D waste minimisation framework considering the life cycle of residential building projects, to advocate sustainable construction. With this aim in mind, four objectives were formulated. The objectives embraced a research design of a mixed-methods approach to identify factors influencing C&D waste, C&D waste minimisation approaches and challenges in C&D waste minimisation and their remedial measures. This research used the literature review, semi-structured interviews and on-site observations to achieve the objectives of the study. The subsequent sections discuss how each research objective was fulfilled.

6.2.1 Objective One

To investigate C&D waste generation over the life cycle of building projects

The objective was achieved through three approaches, literature review, semi-structured interviews and on-site observations. The literature review identified different project stages in the life cycle of building projects. Internationally and in NZ, the project stages are categorised as pre-design, design, construction, refurbishment, and demolition. Through the review of literature, this research conducted in-depth analysis of each stage to understand how waste was generated during each stage and over the life cycle of the building projects.

Similarly, semi-structured interviews identified different stages of projects. Subsequently, on-site observations were conducted for different stages of project (construction, refurbishment and demolition) to investigate waste generation. The on-site observations

were not possible for pre-design and design stage. The research question set to achieve this objective was:

How is C&D waste generated throughout the lifecycle of building projects?

This research question examined the decisions taken during each stage and their consequences in the form of waste. The literature review, semi-structured interviews and on-site observations showed that different reasons contribute to waste generation over the life cycle of the project. The reasons were broadly classified under social, economic and environmental categories.

The major causes of waste generation in pre-design and design stage were found from the literature review and semi-structured interviews, while the causes of waste generation in construction, refurbishment and demolition stages were found through the same processes. In the pre-design, C&D waste minimisation is not demanded from clients. Subsequently, in the design stage very little consideration is given to C&D waste minimisation. As a result, construction, refurbishment and demolition stages, generate large quantities of C&D waste. The review of literature, analysis of semi-structured interviews and on-site observations fulfilled the first objective.

6.2.2 Objective Two

To analyse factors influencing C&D waste generation to find its causes and the challenges of waste minimisation

This objective was one of the crucial objectives of this research as it identified origins of C&D waste and opportunities in C&D waste minimisation. A literature review was conducted with keywords such as factors influencing C&D waste, causes of C&D waste, C&D waste minimisation and challenges and opportunities in C&D waste minimisation. Subsequently, semi-structured interviews were conducted. The interviews included questions such as:

1. What are the factors that influence C&D waste during each project stage?
2. What are the causes of C&D waste? and
3. What are the challenges and opportunities in C&D waste minimisation for each project stage?

The literature review and analysis of interviews revealed factors contributing to C&D waste, causes of C&D waste and challenges in C&D waste minimisation. Further, on-

site observations validated the findings of the literature review and interview discussions.

In the pre-design stage, the major factors that influence C&D waste, are lack of contractual requirements, green washing and green claiming of building materials, early involvement of stakeholders, education and innovation, eco-labelling of building materials, industrial diversity thinking and conceptual waste minimisation plan. Further, the design stage is often influenced by circular resources thinking, waste minimisation goals, material selection and overordering, designing out waste, use of WMA (2008), standardisation and prefabrication, waste management plan, specification writing and equal consideration to C&D waste.

During the construction stage, factors considered, include such as waste sorting and contamination, waste reporting, composition of waste, precise waste quantification, social values of waste, use of CivilShare, on-site reuse and recycling and poor material storage and handling influence the quantities of C&D waste. Further, C&D waste at a refurbishment stage, is influenced by environmental impact of refurbished material, availability of resources to process refurbishment waste and condition of a house. In the demolition stage major factors that influence waste are: 10R thinking, waste levy, secondary market, recycling infrastructure facilities, cost of waste, role of public and private institutes, resource recovery and margins, application of deconstruction and waste management plan. Each factor that influences C&D waste needs to be addressed before they become a C&D waste minimisation challenge.

The literature review, semi-structured interviews and on-site observations identified 25 challenges of C&D waste minimisation in Auckland. The challenges were inspired from the factors. Similar to factors influencing C&D waste, the challenges in C&D waste minimisation also occurred at each stage of the project. For example, cited here are: poor contractual requirements in the pre-design stage, lack of life cycle thinking in the design stage, on-site sorting and contamination in the construction stage, environmental impact of waste in the refurbishment stage and lack of deconstruction in the demolition stage.

6.2.3 Objective Three

To understand C&D waste minimisation approaches used in Auckland CI.

This objective was achieved through literature review, semi-structured interviews and on-site observations. A research question was set to accomplish this objective:

What are the available techniques for C&D waste minimisation?

The literature review identified different waste minimisation approaches internationally and in NZ, while the interviews and on-site observation, provided understanding of waste minimisation approaches practice in NZ, especially in Auckland CI. The C&D waste minimisation approaches are broadly classified into three categories: waste hierarchy, guidelines and regulations on waste minimisation and waste minimisation tools.

In Auckland CI, reuse and recycle dominate the waste minimisation practices, recommended in waste hierarchy. Materials such as timber is often reused on-site, while plasterboard is recycled to minimise demolition waste. The reuse and recycle practices are getting attention from industry practices and requires promotion to make it a commonplace practice in Auckland CI. Table 6.1 shows the waste minimisation approaches used for different materials

Table 6.1: Waste minimisation approaches

Material	Approach
Timber	Reuse, Recycle and Recovery
Metal	Recycle
Plasterboard	Recycle and Recovery
Carpet	Recovery
Polyester	Recovery
Polystyrene	Recycle
Cardboard	Recycle

The MfE and territorial authorities have published guidelines and regulations on C&D waste minimisation for CI practitioners. The building act 2004 encourages optimising consumption of resources through sustainability clause. The waste minimisation Act promotes product stewardship and regulate waste disposal through waste levy. In

addition, the Auckland Council publishes waste minimisation plans and sets objectives and goals of waste minimisation. The organisations such as ECNZ, REBRI and WasteMINZ encourage industry practitioners to minimise C&D waste. The ECNZ published specifications to practice environmentally preferable C&D waste services to achieve environmental benefits. The REBRI provides guidance to contractors through different waste minimisation guides such as building products guide; resource recovery guide and; design and planning guide. The WasteMINZ published technical guidelines on disposal of waste. Further, initiatives such as zero waste, also contribute to C&D waste minimisation.

The Auckland CI practitioners use different C&D waste minimisation tools such as REBRI templates. In addition, tools such as Lean Construction, BIM and supply chain management are used for C&D waste minimisation. However, the extent of these tools in practice is limited and needs improvement. Subsequently, deconstruction is viewed as the most common tool for waste minimisation. Further, prefabrication and standardisation has also used to design out waste.

6.2.4 Objective Four

To propose a better waste minimisation approach

This was the final and most important objective of this study. The objective aimed to develop a waste minimisation framework to form the findings of this thesis. The study established following research question to achieve this objective.

How can a Waste Minimisation Framework aid C&D waste minimisation to advocate sustainable construction?

The literature review, semi-structured interviews and on-site observations were used to develop a waste minimisation framework. The framework included causes of waste, challenges in waste minimisation and remedial measures. It also included actions to be taken by clients, contractors and policymakers and influencers at each stage of the project. The actions from one category requires support from other two to efficiently minimise the waste. In other words, success of actions is interdependent among all three categories. For example, in pre-design stage to address the challenge of contractual requirements, the client needs to demand sustainable materials; the contractor should perform rigorous material selection process and the policymakers are required to set use of sustainable materials as a priority in the contract document. These actions are

remedial measures for the challenge of poor contractual requirements. Similarly, remedial measures for all waste minimisation challenges are shown in the waste minimisation framework.

6.3 Contribution to knowledge

C&D waste minimisation aim to achieve sustainable construction and provides social, environmental and economic benefits to New Zealanders. Achieving SC through C&D waste minimisation has become a priority for construction industry practitioners. This thesis has contributed to C&D waste minimisation knowledge body for industry practitioners and academic scholars. The distinguishing theoretical and practical contributions of this thesis are:

Theory:

- The research investigated the factors that influence C&D waste. In total, 36 factors were identified that contribute to C&D waste throughout the life cycle of a project i.e. pre-design, design, construction, refurbishment and demolition stages. The previous studies have limitations of identifying factors for a specific project stage (s) and not for project life cycle. Factors from each stage were explored in-depth to find out challenges of C&D waste minimisation for the Auckland CI.
- The study highlighted 25 challenges in waste minimisation for Auckland construction industry. These challenges were one of the main contributions of this study to the existing body of knowledge on challenges in C&D waste minimisation.
- The study established state of the art of C&D waste minimisation in the Auckland CI and showed the dire need for waste minimisation. This study has explored C&D waste minimisation through a life cycle approach to minimise waste in each stage.

Practice:

- This research has provided knowledge on importance of C&D waste minimisation to achieve sustainable construction in the NZ construction industry. The previous studies lacked provision of empirical data on the C&D waste minimisation for residential construction through a life cycle approach.

- This research identified different perceptions on C&D waste minimisation of different construction industry personnel including clients, contractors and policy influencers and makers. The spectrum of perception from construction industry personnel introduced remedial measures of C&D waste minimisation.
- The study offered a C&D waste minimisation framework for residential building projects. The framework is built on viable waste minimisation practices in and around Auckland. The framework aid to achieve SC through C&D waste minimisation.

6.4 Recommendations

This section lists out recommendations for construction industry practitioners, policymakers and future researchers. The recommendations are in the form of opportunities that emerged from the findings and the discussion sections of this research. The next sub-sections discussed specific recommendations for each category.

6.4.1 Construction Industry Practitioners

The current C&D waste minimisation practices in the Auckland CI requires improvement. This study has identified some of the improvements and labelled them as recommendations for CI practitioners. The CI practitioners, it is suggested, should consider the following recommendations to achieve SC through C&D waste minimisation.

- This study recommends the early involvement of stakeholders through initiative such as Project Control Group (PCG). The CI practitioners needs to participate in the process through as early as possible in pre-design stage. The early involvement helps to set achievable waste minimisation goals through preventive actions. For instance, conceptual waste minimisation plan during the pre-design stage minimises significant amount of waste and prove and effective instrument to achieve the waste minimisation goals;
- The CI practitioners needs to think about circular economy through circular resources. To achieve circular economy, special attention has be given to eco-labelled materials to avoid greenwashing. Further, a rigorous process has to be carried out by contractors while selecting building materials;
- The Auckland CI practitioners needs to utilise salient features of WMA (2008). The product stewardship on building materials would establish the Corporate

Social Responsibilities of everyone involved the process of construction i.e. from manufacturing to disposal. The current practices of Polystyrene collection through a take back policy is a good example of CSR.

- This research recommends CI practitioners adopt a broader perception to deal with waste. For example, 10R thinking, the 10R represents Refuse, Rethink, Reduce, Reuse, Relocate, Remanufacture, Repurpose, Recycle and Recover. The traditional waste minimisation approaches promoted through waste hierarchy needs to be updated with new approaches derived from wider observations;
- This study recommends CI practitioners, especially contractors use online resource sharing platforms such as CivilShare, Trademe and Trash and Treasure Facebook pages. The current waste minimisation practices showed that reuse approach contributes a significant share in minimising the waste. The Auckland CI practitioners are recommended to practice resource sharing through CivilShare to enhance the current reuse practices. CivilShare allows smooth transaction of materials between buyers and sellers and provides maximum benefits to CI practitioners with minimum efforts;
- The Auckland CI practitioners, especially contractors, are recommended to choose deconstruction over demolition. Further, resource recovery plan is advocated before performing the deconstruction. Such plan helps to minimise waste through on-site reuse and recycling. In addition, resource recovery plan encourages waste minimisation through off-site recycling. Overall, the resource recovery plan is recommended for its remarkable contribution to waste minimisation.

6.4.2 Policymakers

The policymakers from Auckland CI could improve the existing C&D waste minimisation practices through introduction of mandatory and/or voluntary policies. The improvement in the policies would initiate better on-site results. The policymakers should consider the following recommendations to improve C&D waste minimisation.

- This study noted that poor contractual requirements has been one of the prime factors of waste generation. The Auckland CI needs a policy to set out waste minimisation as a priority in a contract document. Further, a contract needs to encourage contractors to achieve 6 Homestar rating. Overall, the contract

document needs to give equal consideration to C&D waste among other parameters of sustainable construction;

- The current scale of pre-fabrication and standardisation needs extension. The Auckland CI requires to draft policies to encourage use of prefabricated and standardised materials. This could be done by taking inspiration from international policies. For example, the Chinese government mandated that 30% (by building floor area) of the nation's annual new construction required to be prefabricated by 2025;
- This research noted that the Site Waste Management Plan has a noteworthy contribution in minimising C&D waste. The Waste Management Plan encourages waste sorting and provides precise waste quantification of each waste stream, which helps to find out viable remedial measures. The policymakers require to introduce a policy such as mandatory Waste Management Plan similar to the Hamilton City Council to improve the waste minimisation in the Auckland CI. The case study of Hamilton region needs to be considered to prepare similar policy for the Auckland region with achievable aspirations;
- This research aims to inspire C&D waste minimisation at a project level and at a wider industry level. At a wider industry level, the Auckland CI needs a policy to endorse social values of waste. The sharing of the social benefits of waste helps to create a sense of responsibility among all stakeholders. Further, it will improve the waste reporting across the Auckland region. The precise estimates of waste generation guide the Auckland Council to set achievable waste minimisation goals;
- The Auckland CI has a limited secondary market for recycled products; however, it holds a huge potential to become an unrestrained secondary market. To increase the size of secondary market. the policymakers should help recyclers make sustainable products at affordable prices. For instance, providing incentive to the recycler and contractors to promote recycled products. Such initiatives can be funded by increasing the current waste levy.

6.4.3 Future Research

This thesis has established foundation for Auckland CI to achieve sustainable construction through C&D waste minimisation throughout project life cycle. The future investigation in the subject matter could be useful for academic researcher and industry

practitioners to add information to the current findings. This study gives pathways to explore following areas to append new knowledge to this research.

- This study identified the need for education and innovation in C&D waste minimisation practices. The on-site education to site workers and contractors could inspire innovative solutions to minimise waste. Further, the current innovative solutions need scientific investigations to assess their environmental impact. For example, Plasterboards are recycled to produce soil fertiliser, Auckland CI requires future studies to make it a commonplace practice;
- This research found out remedial measures to minimise C&D waste throughout project life cycle. However, the Auckland CI have limited understanding about waste minimisation in the pre-design and design stage. As a result, the current waste minimisation practices are focused on later stages of project life cycle i.e. construction, refurbishment and demolition. Future researcher could explore the waste minimisation in the pre-design and design stage through specific case studies. For instance, designing out waste through application of BIM in the Auckland CI;
- Future studies on availability and profitability of new recycling infrastructure needs to be done to improve the waste minimisation. For example, Auckland CI requires to set up recycling infrastructure for carpet recycling. A detailed inquiry on environmental and financial analysis on recycled products could help to explore the feasibility of local secondary market.
- This study noted that success of waste minimisation depends on public and private partnership. Further studies have to be carried out to understand the responsibilities of both sectors and improve the state-of-the-art of waste minimisation. For instance, public sector provides incentives for the recovery and the private sector recovers the waste. Future studies could provide insights on funding requires to recover waste and profits on recovered products.
- The findings of this thesis are limited to residential sector in the Auckland CI. Future investigations through detailed case studies could assess relevance of current findings to non-residential sector.

6.5 Limitations of this research

This research adopted best-suited approaches, methods, and techniques to collect and analyse data. However, it is impossible to get the exact degree of accuracy and hence this section acknowledges the limitations of the research.

This research has five main limitations. First, the study focused on minimising C&D waste in residential construction and hence application of waste minimisation framework to non-residential construction may produce different outcomes. Secondly, the data collection and validation of findings were limited to the Auckland region (pilot study, interviews, on-site observation). During some of the interviews, the researcher asked probe questions based on interviewees' response and witnessed bias for their category (client representative, contractor and policymakers and influencer). Further, a large sample size for data collection and validation may have produced different results. However, considering the timeframe of PhD study and available resources, the sample size was restricted. However, the restricted samples provided a sense of data saturation and reliable findings.

Thirdly, this research adopted the mixed-methods approach through a sequential procedure, i.e., qualitative approach findings were validated through a quantitative approach. It has been noted that one approach often has an impact on the other approach in sequence. The waste minimisation framework was developed on interview responses, and hence interviewees' truthfulness needs to acknowledge as a limitation. Further, during the on-site validation of the framework in a few instances, the researcher witness behavioural change among site workers. Overall, it was challenging to free the research from methodological effects during the sequential procedure. However, combination of data collection techniques provided credible data to produce generalise findings.

Fourthly, the literature on C&D waste minimisation has published arguments on the importance of machinery and labour waste minimisation. For instance, an efficient machine improves productivity through waste minimisation. In addition, systematic labour allocation reduces idle time for labourers and significantly minimises C&D waste. However, this research focused on material waste due to its social, environmental and economic impacts on society. Fifth and last, the research findings are most relevant to Auckland CI, and generalisability of the findings allow their application all over the NZ. However, outside NZ, the interpretation of findings may have a different outcome.

6.6 Concluding statements

The aim of this study was to achieve SC through C&D waste minimisation in residential building projects. This research investigated the problem of C&D waste from its origin to the current state in New Zealand CI. The literature review offered a knowledge gap which showed that CI had a limited understanding of life cycle approach to minimise C&D waste. A mixed method approach with a pragmatic philosophical stance was adopted, which made this thesis an exploratory inquiry. The methods adopted for data collection gave a broad spectrum of information from clients, contractors, policymakers and influencer. Further, analysis of the information generated findings of this research.

The research findings are based on 37 in-depth semi-structured interviews and on-site observation of nine sites (construction, refurbishment and demolition). The interviews and on-site observations provided list of factors that influences C&D waste. Further, the research found several challenges attached to C&D waste minimisation and provided remedial measures for each challenge.

This research has provided a better understanding of C&D waste minimisation and its contribution to SC. This thesis is assumed to have a positive impact not only at project level, but at industry level. To conclude this thesis, it is hoped that findings of this study will improve C&D waste minimisation practices across the Auckland CI, and possibly in the New Zealand CI.

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Appendices

Appendix A: AUT Ethics Committee Letter



Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

4 September 2020

Jeff Seadon
Faculty of Health and Environmental Sciences

Dear Jeff

Ethics Application: **19/418 Minimising construction and demolition waste in residential building projects to advocate sustainable construction**

We advise you that the Auckland University of Technology Ethics Committee (AUTEC) has **approved** the qualitative data collection stage of your ethics application at its meeting of 31 August 2020.

This approval is for three years, expiring 31 August 2023.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the [Auckland University of Technology Code of Conduct for Research](#) and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through <http://www.aut.ac.nz/research/researchethics>

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: rohit.gade@aut.ac.nz; Mani Poshdar

Appendix B: Observation Protocol

Observation protocol.

Name of the primary researcher.

Rohit Jindas Gade

Date observation protocol Sheet Produced:

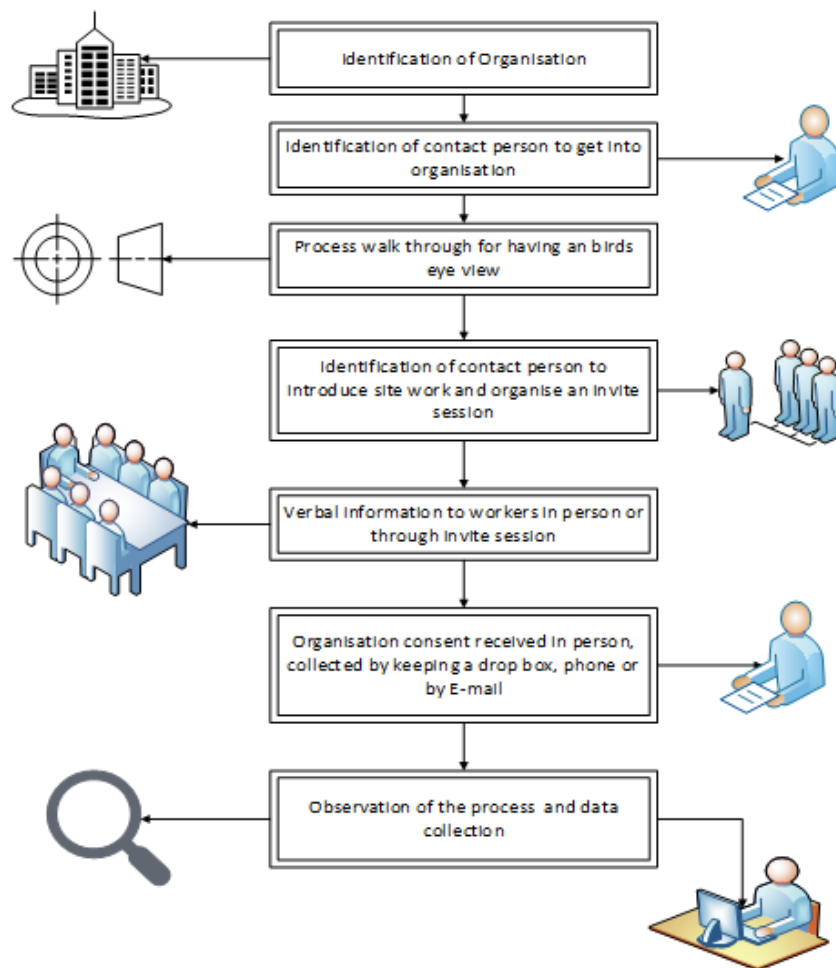
09 August 2020

Project Title

Minimising Construction and Demolition waste in Residential Building Projects to advocate Sustainable Construction

Observation Protocol.

The process flow is given below



- ***How will people be recruited?***
As per the process flow.
- ***How will people be informed about the observation?***
- The site workers will be initially informed verbally by the contact person through the invite session and then in person. The workers will be informed about observation one week prior to researchers site visit.
- Then the organisation consent is received in person, collected by keeping a drop box, phone or by E-mail.
- ***How will people consent to the observation?***
The observation does not recruit and observe personal particulars of any participant. The observation focus on the construction process. The site workers will be informed about the research and recruited after receiving the consent from organisation.
- ***What will be observed and what data will be collected?***
The daily routine activity performed by site workers in a process will be observed and data will be noted by the primary researcher.

Data collection would include, but not limited to several steps in the activity, input to the activity, output to the activity, the time is taken for the activity, interruptions in the activity and number of tools used to perform the activity. In addition, the frequent issues, constraints, interruptions, and difficulties in the activity would be collected.

The observation collect data answering the research questions but same time do not collect any commercially sensitive data. In addition, observation would not collect any identifiable information about the site workers and only observe the process. The organisation can review the collected data.
- ***How will the data be collected?***
The process will be observed and then noted manually with pen and paper. The process do not include, any digital recording such as images, video or any other identifiable information.

Observation may include but not limited to
 - Observation of the business process.
 - Observation of people doing the activity in the process.
 - Observation of machines.
 During observation; the construction process, its issues, and their issue in relation to the process, the wastes generated, and suggestions to improve will be noted.
- ***How any deception involved will be managed?***
There would be no deception during the research work. The site worker will be aware of observation.
- ***The data collection instrument***
The recording will be through notes on a plain A4 paper.
- ***What does the researcher do during observation?***

Introducing self.

- Wait till the worker notices and attends to you.
- Greet them and introduce myself
- Thank them for being a part of the study

Explaining the observation of activity.

- Inform the worker that you are starting the observation process.
- Inform the worker if he or she is uncomfortable at any time during the observation he can withdraw from the process.
- Request them to advice on the safe place to stand and observe.

Observing the process.

- Observe the process for three cycles.

Noting the observation.

- Note the activity observed in an A4 sheet.
- Note the questions, if any

Concluding the observation.

- Thank the worker for letting me observe.
- Check with the worker for any clarification and note down.
- Thank the worker for their cooperation.

What will be the outcomes of the observation?

- Present a report to the organisation on issues, challenges, and improvements identified in the process.
- The report would contain a waste minimisation framework including life cycle of building projects. The report would not include a comparison between employees, statements, or data, which may have them at risk. In addition, the report would not contain any identifiable information of workers or commercially sensitive data of organisation.
- Present an appreciation letter mentioning good practices and cooperation rendered along with a copy of organisation report presented to the participant

Note: The aim is to conduct direct observation in COVID-19 alert level 1. In addition, the researcher (Rohit) will follow Health and Safety and COVID-19 related guidelines advised by site manager.



AUCKLAND UNIVERSITY OF TECHNOLOGY ETHICS COMMITTEE (AUTEC)

Guide for drafting a Researcher Safety Protocol

DEFINITION & PURPOSE:

This is a guide to drafting a Researcher Safety Protocol and needs to be adapted for each research project.

Researchers need to assure their own safety as well as that of their participants and research assistants. The main purpose of a researcher safety protocol is to assess the level and likelihood of risk and to provide appropriate arrangements to minimise and manage those risks.

Situations in which researcher safety is likely to be at risk may include times when:

- ❖ *researchers are visiting the homes of others;*
- ❖ *researchers are undertaking sensitive research in a manner that puts them at personal risk;*
- ❖ *researchers are undertaking research in hazardous conditions;*
- ❖ *researchers are undertaking their research in a social or cultural setting with which they have minimal familiarity;*
- ❖ *researchers are involving people who pose a higher risk than would normally be the case (e.g. people with a known propensity for violence);*
- ❖ *the study impinges on the vested interests of powerful persons;*
- ❖ *the study is subject to the exercise of coercion or domination (e.g. where the research is about social conflict or where participants may face political threat, discrimination or stigma);*
- ❖ *there is an increased exposure to everyday risks (e.g. accidents, illness).*

Researchers may find it useful to read this research about levels of violence towards researchers in the field ([QUALITI \(INCRM\) COMMISSIONED INQUIRY INTO THE RISK TO WELL-BEING OF RESEARCHERS IN QUALITATIVE RESEARCH](#) by Bloor, M., Fincham, B., and Sampson, H.)

The following questions may be used to help write a protocol that is relevant to the context of the research.

Project title and brief description:

Title: Minimising Construction & Demolition waste in Residential Building Projects to advocate Sustainable Construction

The Construction Industry accounted for 6% of global GDP and it was the fifth-largest sector in New Zealand. The contribution and growth of sector impact on the extraction of natural resources and poor control over the consumption of resources created waste. In 2018, Construction and Demolition (C&D) waste was the largest waste stream in Auckland which made the construction sector less sustainable.

The practice in New Zealand to optimise the consumption of resources begun in the early 1990s and waste minimisation approaches were added in later years to promote Sustainable Construction (SC) through C&D waste minimisation. However, the knowledge gap in practice still exists in understanding and implementing the waste minimisation approaches such as governing guidelines, regulations, and tools. It has been argued that SC could be promoted through C&D waste minimisation by assessing the factors influencing C&D waste and by practicing their remedial measures.

The proposed research aims to minimising C&D waste by conducting up to nine case studies in New Zealand, covering C&D building projects. This study will adopt a qualitative approach to collect the data considering the life cycle of the project. The preliminary data collection followed by multiple case studies covering causes of waste, factors influencing waste, and waste minimisation approaches would be analysed and validated. This study focuses on C&D waste and its impact on the environment and proposes a waste minimisation framework covering the life cycle of the project.

Applicant

Name: Jeff Seadon

Faculty: Built Environment, Design and Creative Technologies.

Email: jeff.seadon@aut.ac.nz

Primary Researcher

Name: Rohit Jindas Gade

Student ID Number: 1399220

Faculty: Built Environment, Design and Creative Technologies

Email: rohit.gade@aut.ac.nz

Where is the research being undertaken?

What [current travel warnings](#) are in effect in the area in which the research will take place?

The participants of this research are client representatives, contractors, and project engineers in the construction industry. Based on public data, conference, and network of physical sites Auckland region is selected for conducting the research work. It is the largest labour market for construction and construction related occupations in NZ and hence the research will be undertaken in the Auckland region. Currently there are no travel warnings related to research.

At whose property will the research be undertaken?

The interview and direct observation will be under taken in the head office (on-site observation) of each participant located in Auckland.

Who is likely to be present at the research location?

The client representative, contractor, and project engineer will be present at the head office with the research.

What access permissions are needed to undertake the research at the chosen location?

No access permission is needed at the head offices.

What maps and guides has the researcher consulted to ensure familiarity with the locations?

Google map will be aiding the researcher in finding and traveling to the locations.

What reliable local public transport is available?

The Auckland head offices will be accessed via Uber or Ola for transport purposes. In an instance the head office is further away a rental car will be used.

Which reputable taxi firms are easy to access?

No taxi firms will be used as Uber and Ola are very much accessible.

Where is it safe to use private cars and leave them in the area?

Judging by the visual maps provided by Google Maps, all locations have parking area if the car hire was to be used.

What local rendezvous or contact points are available for researchers?

The head offices are located near cafes and restaurants which won't be used by the researcher.

How close to your research location are hotels or safe accommodation?

As the research is based in Auckland, there is no need for accommodation.

Who will be collecting the data and interacting with participants?

Who will be accompanying the researcher?

The researcher will travel alone.

How will the safety of any dependent children accompanying the researcher be assured?

Not Applicable.

How will the safety of any translators, interpreters, intermediaries or transcribers be assured?

Not Applicable.

How familiar is the researcher with the social or cultural context of the research ?

What level of familiarity does the researcher have with the social context of the participants and the research?

At this point because the identity of participants are still unknown, the research has no inkling of the social context of the participants except that there are the clients, contactors, and project engineers of reputable organisations.

What level of familiarity does the researcher have with the cultural context of the participants and the research?

At this point because the identity of participants are still unknown, the research has no inkling of the cultural context of the participants.

What consultation has taken place?

The researcher has attended the AUT workshop entitled Interviewing Skills for Qualitative Research as well as past experiences of Interviewing respondents at a Master and Bachelor level course requirements. Besides the researcher have no other consultations.

What language support is needed?

English Language is used to communicate to participants. No language support is needed at this stage.

What local tensions are there?

The content of the interview and direct observation is based on business practices and environmental plans. No local or cultural tensions will be present at the interview and direct observation.

How strongly active are any cultural, religious or racial divisions?

This research has no mention of any form of cultural, religious or racial divisions to be discussed or asked.

What do local sources, such as the police or local leaders, say about risks in the research area?

There is no police or public warnings stated in Auckland besides the basic safety measures taken by the researcher on a daily basis.

Which local 'community leaders' have been spoken with to explain the research and gain their endorsement?

The supervisors of this research will be made fully aware of the locations the researcher will travel to and fully endorse the data collection period for the completion of the research.

How safe are the activities in which the researcher is taking part?

Does the research involve sports or activities that may be hazardous in nature?

This research does not focus on collecting data related to activities that are hazardous to nature. However, such circumstances may arrive as observation will take place on-site, for example, removal of asbestos. In such cases researcher will follow the site guidelines and guidelines provided by WorksafeNZ.

What safety protocols are in place?

The researcher will follow Hazard board instruction before starting the observation. Further, the researcher is aware of risk hence he will use all personal protective equipment while doing the observation. In addition, the researcher will follow WorksafeNZ and NZ government guidelines related to working on-site. The occupational health and safety guidelines will also be practiced during the on-site observation.

Will sufficient qualified personnel be in attendance to supervise the activity or respond swiftly to any emergency?

The researcher will do all observation by following on-site safety guidelines and in case of any emergency the researcher will contact the site manager.

What level of access to support is available?

Who will be available to provide assistance should it be required?

In case of an emergency the site manager will be notified.

How will the researcher ensure that those providing support will be aware of any need that arises?

The researcher will notify the supervisors and close family members of the interview and direct observation locations.

What will those providing support do if it is needed?

They will all contact the head office of the organisation and emergency services such as fire or police department, if required, and revealed the location the site (and researcher). At this point no such emergency can be predicted.

What emergency plans are in place? Who can help?

What training or support is needed and how will it be accessed?

No training is required of the researcher and supervisors. In case of emergency the police will be notified.

What University policies are relevant to your project? Have you read and understood them?

Yes, the project doesn't undermine any policies of the university.

How have significant local actors, such as statutory and community organisations been contacted?

No such organisations are needed to be contacted at this stage.

Who has been in touch with potential participants and what advice have they given?

No communication has been made with potential participants until the ethics has been approved.

Who else is aware of the researcher's itinerary and research schedule?

The supervisors and close family and friends of the researcher are aware of the schedule of the researcher.

How will the researcher keep key support people informed of what is happening?

The researcher will keep key support people (supervisors and family and friends) informed via texts and emails.

How will key support people react if the agreed contact protocols are not followed?

In case of emergency and immediate help the site manager will get involved. In case of non-emergency situations, the researcher will be contacted just for confirmation of physical and mental wellbeing.

Don't forget to update your safety protocol regularly:

Date for next review

Appendix D: Interview Protocol for Semi-Structured Interviews

Interview Protocol for Semi-Structured Interviews

Rohit Jindas Gade

Rohit.gade@aut.ac.nz

+64-2041181718

Prior to interview

- Identifying interviewee and essential background information about them
- Design a set of interview questions tailored to the interviewee
- Arrange date and time of the interview, explain research aim, objectives and questions
- Sending interview questions ahead of interview along with information sheet and consent form to provide research background to the interviewee
- Request permission for taping the interview
- Inform interviewee that research findings will be provided to them
- Check tape recorder, spare batteries, and tapes.

During the interview

- Providing background information on the project in short
- Make the interviewee comfortable by asking introductory questions
- Check tape recorder and conduct voice test
- Take notes of important points and lead interviewee towards next question
- Maintain the flow of discussion and cover all the interview questions

After the interview

- Write up contextual interview notes.
- Identify action points from audio recordings and then transcribe the tapes
- Write a letter of appreciation to the interviewee and ask for confirmation of promised contact (if any)
- Enter factual content information from the interview into database
- Analyse interview data to perform further research step

Note: The aim is to conduct interviews in COVID-19 alert level 1. In addition, the researcher (Rohit) will follow Health and Safety and COVID-19 related guidelines advised by Ministry of Health.

Appendix E: Participant Information Sheet – Interview



Participant Information Sheet-Interview

Information Sheet for the participating employees of the organisation.

Date Information Sheet Produced

09 August 2020

Project Title

Minimising Construction and Demolition waste in Residential Building Projects to advocate Sustainable Construction.

An Invitation

Kia Ora,

I am Mr. Rohit Jindas Gade, currently a PhD candidate at Auckland University of Technology in the Built Environment Department. As part of my PhD candidature, I am undertaking research entitled "Minimising Construction and Demolition waste in Residential Building Projects to advocate Sustainable Construction".

I would like to invite you to participate in my research project. Your participation is voluntary.

What is the purpose of this research?

The proposed study is aimed at developing a Construction and Demolition (C&D) waste minimisation framework to advocate an overall sustainable built environment. Through this research work, the researcher, Rohit Jindas Gade, will gain knowledge of practices in waste minimisation approaches in the construction industry, a PhD degree, and academic publications. Through the findings of this research, the interview participants will get an understanding of a waste minimisation framework considering the life cycle of the project; to promote sustainable construction. The study will be based on interviewee's daily activities in dealing with Construction & Demolition waste which needs improvement. There are no other conflicts or constraints with your participation. The information gathered by me through the interview will be kept confidential, and the findings of this research will be used for academic publications and presentations.

How was I identified and why am I being invited to participate in this research?

The selection process of your participation is based on your organisation being part of the market of the Construction Industry in Auckland either as a client, contractor or engineering services. You have been identified as best suitable for this research based on your corporate position in the organisation who has executive decisions in adopting a new construction and demolition waste minimisation approach.

How do I agree to participate in this research?

After reading this information sheet, if you would like to participate in this research, then please sign the consent form provided. The consent form and data will be confidential and viewed by the researcher only. Your participation in this research is voluntary (it is your choice), and you are able to withdraw from the study at any time.

What will happen in this research?

This stage of research adopts face to face semi-structured interview approach of inquiry. The researcher will ask open-ended questions to understand how construction and demolition waste is generated during the life cycle of building, what are the factors that influence this waste, and how can we minimise this waste. You are expected to share your experience and knowledge. The interview would be recorded if you consent. The timing of the interview should last from 30 to 60 minutes.

The interviews will be recorded (with your consent) and transcribed to analyse the findings of the research. The interviews will take place at the your office or near public spaces. You will receive a copy of the interview summary after the interview if they wish. The researcher (Rohit Jindas gade) is aware of AUT code of conduct and obliged to maintain participants privacy; hence no identifying remarks will be made on an interview during the findings of the research. The researcher will provide research findings to all participants showing a waste minimisation framework. The findings of the research will be provided to you by the end of 2021.

the findings will include;

- List of most influencing factors of construction and demolition waste;
- Life cycle approach analysis considering such factors;
- The remedial measure to address the factors and;
- Good practices to minimise overall waste to promote the sustainable built environment

The findings would not contain any comparison between other participants or data, which would identify or affect the interview participant. Further, the study will help the researcher in his PhD Journey, and the results will be included in his thesis. In addition, the interview data will also be used for academic publication without revealing any details of the participant's identity. The complete thesis will be made available in AUT Library on its completion (by the end of 2021), and the results of this study will be electronically sent to the participants if the participants wish to have them.

What are the discomforts and risks?

We don't expect that you will be expose to any discomfort or risk. However, if you feel any discomforts or risk, you can announce your concerns to researcher. The research design does not force any participant to be a part of the research. You reserved all rights to withdraw your participation in case of discomfort or risk. The researcher is obliged to protect participants from discomforts and risk.

What are the benefits?

The following are the likely benefits.

You: You will not have any direct benefits from the interview. However, the findings of the research will help to understand different waste minimisation practices, their challenges, and opportunities.

Researcher: Knowledge of practices of waste minimisation approaches, PhD degree, and academic publications.

Wider community: Sustainable built environment.

How will my privacy be protected?

The interview will be transcribed and processed with other interview participants to understand the common themes and concerns of the organisations in the industry. Any relevance to your identity will not be indicated in the research except a simple categorisation

as a client representative, contractor, and project engineer working in the Auckland construction industry. The consent form with your details will be stored in a secured file cabinet in the property of the Auckland University of Technology in the Built Environment Department (WS 316C, City Campus; primary supervisor's office).

What are the costs of participating in this research?

No monetary costs are associated with the interview. Participating in this research requires the participant's time. The interview will be conducted at participants office or nearby public spaces that are most convenient for the participants. The interview will be approximately 30-60 minutes.

What opportunity do I have to consider this invitation?

Accepting to participate in this research is contacting the interviewee via rohit.gade@aut.ac.nz. From the time this information sheet is provided to you until the acceptance of the invitation within 1 month.

Will I receive feedback on the results of this research?

The interview summary will be provided to participants after the interview. The findings of this research will be emailed to participants (if they wish) once it is finalised by the end of 2021.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the primary supervisor, *Dr Jeff Seadon*, jeff.seadon@aut.ac.nz, +64 921999 ext.6789.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEK, ethics@aut.ac.nz, 921 9999 ext. 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Name: Rohit Jindas Gade Email: rohit.gade@aut.ac.nz Phone: +64 2041181718.

Project Supervisor Contact Details:

Primary Supervisor: Dr Jeff Seadon, Email: jeff.seadon@aut.ac.nz Phone: +64 921 999 ext. 6789.

Secondary Supervisor. Mani Poshdar,Email: mani.poshdar@aut.ac.nz Phone: + 64 921 9999 ext. 8956.

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEK Reference number *type the reference number*.

Appendix F: Participant Information Sheet – Direct On-Site Observation



Participant Information Sheet-Direct on-site Observation

Information Sheet for the direct on-site observation participants of the organisation.

Date Information Sheet Produced

09 August 2020

Project Title

Minimising Construction and Demolition waste in Residential Building Projects to advocate Sustainable Construction.

An Invitation

Kia Ora,

I am Mr. Rohit Jindas Gade, currently a Ph.D. candidate at Auckland University of Technology in the Built Environment Department. As part of my Ph.D. candidature, I am undertaking research entitled “Minimising Construction and Demolition waste in Residential Building Projects to advocate Sustainable Construction”.

I would like to invite you to participate in my research project. Your participation is voluntary.

What is the purpose of this research?

The proposed study is aimed at developing a Construction and Demolition (C&D) waste minimisation framework to advocate an overall sustainable built environment. Through this research work, the researcher, namely, Rohit Jindas Gade, will gain knowledge of practices in waste minimisation approaches in the construction industry, a PhD degree, and academic publications. Through the findings of this research, the observation participants (construction site workers) will get an understanding of a waste minimisation framework considering the life cycle of the project; to promote sustainable construction. The study will be based on construction site workers daily activities in dealing with Construction & Demolition waste which needs improvement. There are no other conflicts or constraints with your participation. The information gathered by me through the direct on-site observation will be kept confidential, and the findings of this research will be used for academic publications and presentations.

How was I identified, and why am I being invited to participate in this research?

The contractor (your employer) with whom you are employed hold an industry profile who deals with Construction & Demolition waste. The selection process of your participation is based on your position in the Auckland Construction Industry as a construction site worker.

How do I agree to participate in this research?

After reading this information sheet, if you would like to participate in this research, then please sign the consent form provided by me. The consent form and data will be confidential and viewed by the researcher only. Your participation in this research is voluntary (it is your choice), and you are able to withdraw from the study at any time.

What will happen in this research?

This research adopts an on-site direct observation approach of inquiry. The researcher will observe construction site workers like you. While you performed your daily on-site activities. You are not required to interact with the researcher, and the researcher will observe the process. In addition, no interview will be conducted with you; rather, the researcher will observe you while you perform your work. The researcher will observe you for a maximum of 60 minutes. The researcher will not record any identifiable information (picture or video) related to you and only record the process outcomes (with your consent). In addition, no commercially sensitive information regarding organisation will be recorded and published in the findings of the research.

This research may include incidental participation during on-site observation. In such a case, all construction site workers will be given information about direct on-site observation before researchers visit. The researcher will only observe consenting participants and write notes. No other construction site worker will be observed, and no remark will be made on their activities. However, in addition to consenting participants, other construction workers can see researchers notes made during the observation. No participant will be observed without organisational and individual consent. The researcher (Rohit Jindas gade) is aware of AUT code of conduct and obliged to maintain your privacy; hence no identifying remarks will be during the findings of the research. The researcher will provide research findings to all participants showing a waste minimisation framework. The findings of the research will be provided to you by the end of 2021.

the findings will include;

- List of most influencing factors of construction and demolition waste;
- Life cycle approach analysis considering such factors;
- The remedial measure to address the factors and;
- Good practices to minimise overall waste to promote the sustainable built environment

The findings would not contain any comparison between site workers or data, which would identify or affect the you. Further, the study will help the researcher in his PhD Journey, and the results will be included in his thesis. In addition, the observation findings will also be used for academic publication without revealing any details of your identity. The complete thesis will be made available in AUT Library on its completion (by the end of 2021), and the results of this study will be electronically sent to you if consent to have them.

What are the discomforts and risks?

We don't expect that you will be expose to any discomfort or risk. However, if you feel any discomforts or risk, you can announce your concerns to researcher. The research design does not force any participant to be a part of the research. You reserved all rights to withdraw your participation in case of discomfort or risk. The researcher is obliged to protect participants from discomforts and risk.

What are the benefits?

The following are the likely benefits.

You: You will not have any direct benefits from the interview. However, the findings of the research will help you to understand different waste minimisation practices, their challenges, and opportunities.

Researcher: Knowledge of practices of waste minimisation approaches, PhD degree, and academic publications.

Wider community: Sustainable built environment.

How will my privacy be protected?

The researcher will observe the process and make notes after getting your consent. The observation will be transcribed and processed with other participants to understand the common themes and concerns related to Construction & Demolition waste. Any relevance to your identity will not be indicated in the research. The consent form with your details will be stored in a secured file cabinet in the property of the Auckland University of Technology in the Built Environment Department (WS 316C, City Campus; primary supervisor's office).

What are the costs of participating in this research?

No monetary costs are associated with direct observation. Participating in this research require you to do your daily on-site activities. The observation will take place on-site for a maximum of 60 minutes.

What opportunity do I have to consider this invitation?

Accepting to participate in this research is contacting the researcher via rohit.gade@aut.ac.nz. From the time this information sheet is provided to you until the acceptance of the invitation within 1 month.

Will I receive feedback on the results of this research?

The observation summary will be provided to you after the observation. The findings of this research will be emailed to all consent participants once it is finalised by the end of 2021.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the primary supervisor, Dr. Jeff Seadon, jeff.seadon@aut.ac.nz, +64 921999 ext.6789.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEK, ethics@aut.ac.nz, 921 9999 ext. 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Name: Rohit Jindas Gade Email: rohit.gade@aut.ac.nz Phone: +64 2041181718.

Project Supervisor Contact Details:

Primary Supervisor: Dr Jeff Seadon , Email: jeff.seadon@aut.ac.nz Phone: +64 921 999 ext. 6789.

Secondary Supervisor. Mani Poshdar, Email: mani.poshdar@aut.ac.nz Phone: + 64 921 9999 ext. 8956.

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEK Reference number *type the reference number*.

Appendix G: Consent Form – Participant (Interview)



Consent Form – Participant (Interview)

Project title: Minimising Construction and Demolition waste in Residential Building projects to advocate Sustainable Construction

Project Supervisor: Dr. Jeff Seadon

Researcher: Rohit Jindas Gade

- I have read and understood the information provided about this research project in the Information Sheet dated 09 August 2020.
- I have had an opportunity to ask questions and to have them answered.
- I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, the removal of my data may not be possible.
- I agree to take part in this research.
- I wish to receive a summary of the research findings (please tick one): Yes No
- I understand that I may be identified in the report to the employer.
- I understand that I may be observed doing the activity in my workplace.

Participant's signature :

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Participant's name:

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Participant's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 27 July 2020 AUTEK Reference number 19/418

Note: The Participant should retain a copy of this form.

Appendix H: Consent Form – Participant (Observation)



Consent Form – Participant (Observation)

Project title: Minimising Construction and Demolition waste in Residential Building projects to advocate Sustainable Construction

Project Supervisor: Dr. Jeff Seadon

Researcher: Rohit Jindas Gade

- I have read and understood the information provided about this research project in the Information Sheet dated 09 August 2020.
- I have had an opportunity to ask questions and to have them answered.
- I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, the removal of my data may not be possible.
- I agree to take part in this research.
- I wish to receive a summary of the research findings (please tick one): Yes No
- I understand that I may be identified in the report to the employer.
- I understand that I may be observed doing the activity in my workplace.

Participant's signature:

.....

Participant's name:

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Participant's Contact Details (if appropriate):

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.....

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEK Reference number type the AUTEK reference number

Note: The Participant should retain a copy of this form.